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Prevention of Boar Taint in Pig Production: The 19th Symposium of the Nordic Committee for Veterinary Scientific Cooperation

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**ORAL PRESENTATIONS**

S1 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, 2, 3, 4, 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 andrien-3β 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 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, 14, 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]. 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 than 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...
Figure 1 (abstract S1)

Factors affecting skatole and androstenone in entire male pigs.

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 CYP2E1 expression [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 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, androst enol 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 welfareist’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.

**References**

Table 1 (abstract S1) Some alternatives to surgical castration

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Reference</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>To use methods for the screening of taint on-line</td>
<td>Colorimetric measurement of skatole equivalent</td>
<td>Mortensen &amp; Sørensen [34]</td>
<td>Simple and rapid</td>
<td>Does not discriminate between skatole and indole. Does not measure androstene none levels</td>
<td>Nowadays, used in Denmark to sort out tainted carcasses</td>
</tr>
<tr>
<td></td>
<td>Colorimetric measurement of 16-androstenes</td>
<td>Squires [35]</td>
<td>Simple and rapid</td>
<td>Does not measure skatole levels. Never been validated at slaughterhouse settings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electronic nose</td>
<td>Annor-Frempong et al [36]</td>
<td>Sensitivity and good correlation with records from human sensory panels</td>
<td>Does not discriminate between skatole and androstenone. Never been validated at slaughterhouse settings</td>
<td></td>
</tr>
<tr>
<td>Immunocastration</td>
<td>Active immunization against gonadotropin-releasing hormone at the end of the fattening period</td>
<td>Bonneau et al [31] Dunshewa et al [32] and other</td>
<td>Reduced boar taint, aggression behavior and mountings</td>
<td>Some variability between studies. Not all pigs responded to immunocastration</td>
<td>Consumer reaction on the meat should be studied!</td>
</tr>
<tr>
<td>Feeding diets rich in indigestible carbohydrates</td>
<td>E.g. inulin; raw potato starch; sugar beet pulp (short feeding period)</td>
<td>Jensen et al [20]; Zamaratskaia et al [23]; Rideout et al [38];</td>
<td>Reduced skatole levels. No adverse effects on growth performance or animal health.</td>
<td>Does not reduce androstenone levels.</td>
<td></td>
</tr>
<tr>
<td>Genetic selection</td>
<td>Against androstenone only</td>
<td>Willeke &amp; Pirchner [29]; Seller et al [30]</td>
<td>Reduced androstenone levels</td>
<td>Reduced growth performance and delayed puberty in female pigs</td>
<td></td>
</tr>
<tr>
<td>Gender selection</td>
<td>Elimination of male type sperm cell</td>
<td>Johnson [39]</td>
<td>Production of female-only herds</td>
<td>Expensive. Possibility of sperm losses and cell damages during selection</td>
<td>Not commercially available</td>
</tr>
</tbody>
</table>


S2

Piglet castration and EU animal welfare legislation

Rex Horgan


Introduction- EU animal welfare policies: Since the 1970’s a growing body of rules concerning animal welfare and
protection has evolved in the European Union (EU). The importance of this issue is manifested by the European Community (EC) Treaty’s Protocol on Protection and Welfare of Animals which recognises animals as sentient beings and requires that in formulating and implementing the Community’s agriculture, transport, internal market and research policies, the Community and the Member States shall pay full regard to the welfare requirements of animals.

Council Directive 98/58/EC [1] concerning the protection of animals kept for farming purposes requires that the owners or keepers of animals take all reasonable steps to ensure the welfare of animals under their care and to ensure that those animals are not caused any unnecessary pain, suffering or injury. However on the issue of mutilations this Directive was relatively silent, stating that pending the adoption of specific provisions relevant national provisions shall apply in accordance with the general rules of the Treaty.

**Council of Europe and EU policies:** Exceptionally, however, concerning piglet castration Directive 98/58/EC [1] acknowledged that specific rules were already in place and the afore-mentioned provision was cited “without prejudice to Directive 91/630/EEC”. Council Directive 91/630/EEC [2] lays down minimum standards for the protection of pigs and it stated that, if practised, the castration of male pigs aged over four weeks may be carried out only under anaesthetic by a veterinarian or a person qualified in accordance with national legislation. This provision was in addition to a Council of Europe Recommendation concerning pigs dating from 1986 [3] (subsequently revised in 2004 [4]) and elaborated within the framework of the Council of Europe Standing Committee of the European Convention for the Protection of Animals kept for farming purposes. This Council of Europe Recommendation provided that procedures such as the castration of male pigs should be avoided where possible and shall be carried out by a veterinary surgeon or a skilled operator. It also specified that the castration of male pigs over eight weeks of age shall be performed under anaesthesia by a veterinary surgeon or any other person qualified in accordance with domestic legislation. Council Directive 91/630/EEC [2] was amended by Commission Directive 2001/93/EC [5] which introduced, subject to certain exceptions, a general prohibition on all procedures intended as an intervention carried out for other than therapeutic or diagnostic purposes and resulting in damage to or the loss of a sensitive part of the body or the alteration of bone structure. One of the exceptions specifically provided for was the “castration of male pigs by other means than tearing of tissues” and it was stated that such procedures shall only be carried out by a veterinarian or a person trained or experienced in performing the applied techniques with appropriate means and under hygienic conditions. Deviating quite clearly from the Council of Europe Recommendation it stated that “if castration...is practised after seventh day of life, it shall only be performed under anaesthetic and additional prolonged analgesia by a veterinarian”.

Council Directive 2001/88/EC [6] also provided an amendment to Council Directive 91/630/EEC [2] requiring the Commission to submit to the Council a report on this issue, drawn up on the basis of an opinion from the Scientific Committee on Animal Health and Welfare. This report would take into account socio-economic and sanitary consequences, environmental effects, different climatic conditions and the development of techniques and systems of pig production and meat processing which would be likely to reduce the need to resort to surgical castration. It was also stated that “if need be, the report shall be accompanied by appropriate legislative proposals on the effects of different space allowances and floor types applicable to the welfare of weaners and rearing pigs”.

More recent developments have included a revised Recommendation concerning pigs which the Council of Europe has elaborated, adopted by the Standing Committee on 2 December 2004 and which entered into force on 2 June 2005 [3]. This provides that the mutilation of pigs shall be generally prohibited and that measures shall be taken to avoid the need for such procedures in particular by changing inappropriate environmental factors or management systems by enriching the environment, or selecting appropriate breeds and strains of pigs. The Recommendation states that “exception to this general prohibition may be made by the competent authority only in respect of the following mutilations: castration of male pigs under 7 days without tearing of tissue. Castration of pigs over 7 days of age shall be performed under anaesthesia and prolonged analgesia and in accordance with national legislation the procedures shall be carried out by a veterinary surgeon or by a skilled operator and in accordance with national legislation”.

Taking Switzerland as an example of additional legislative provisions on this issue the Swiss Federal Act on Animal Protection of March 9, 1978 (State as per July 1, 1995) and Swiss Animal Protection Ordinance of May 27, 1981 (State as per November 1, 1998) [7] provide that “persons with suitable experience are authorised to carry out the following operations without anaesthesia: castration of male pigs up to fourteen days of age”. Therefore it is clear that in terms of legislative provisions and official guidance on the issue of piglet castration the picture is certainly evolving and will demand further actions.

**The European Food Safety Authority report and opinion:** In light of its obligation under Council Directive 2001/88/EC [6] to “submit to the Council a report, drawn up on the basis of an opinion from the Scientific Committee on Animal Health and Welfare (SCAHAW)” the European Commission sent on 6 August 2003 a request to the European Food Safety Authority (EFSA) – see note, to issue a scientific opinion on the welfare aspects of the castration of piglets. This EFSA report and opinion on piglet castration was adopted in July 2004 [8], and its findings included that:

- “Approximately 80% (100 million) of the male piglets are castrated in the 25 EU Member States each year, however information on the castration of piglets from some countries is sparse.”
- “While it appears that low numbers of female pigs are castrated there is also a lack of information concerning the extent of, and techniques associated with castration of female pigs.”

There is significant variation in the extent of the practice of piglet castration across the EU, with countries such as Ireland and the United Kingdom slaughtering pigs at a lower liveweight and not practising piglet castration. This trend also applies to a considerable extent in Spain and Portugal. However it seems that in a majority of EU Member States male pigs are systematically castrated. Although the practice of the castration of female pigs is not specifically foreseen in EU legislation EFSA reported that female pigs of certain breeds were castrated in localised regions of the EU, either to avoid management problems due to oestrus behaviour, to avoid pregnant females at slaughter or to improve growth performance.
On numerous points the EFSA report and opinion concluded that more data and research were required, for example:

- "There is a lack of quantitative information regarding the methods and procedures that are used for castrating the male and female pigs. There are no clear data demonstrating that pain perception related to surgical castration is lower in pigs younger than 7 days of age than in older ones.
- There is no information concerning the interaction between castration and other painful husbandry practices.
- There is no validated protocol for use of long-lasting analgesics which could be applied in commercial herds for reducing mid and long-term pain due to castration."

EFSA also reported that "some producers may carry out castration of piglets later than the first week of life, most often without any anaesthesia/analgesia" and questioned the feasibility and practicality of castrating male pigs by means other than tearing of the tissues. It was highlighted that the pain inflicted on piglets when castrated at various ages is scarce and the influence of the age at castration upon the immune system was unclear. The stress of handling the animals and actually administering anaesthetics/analgesics was also highlighted. EFSA also highlighted the costs of approving and licensing veterinary drugs such as analgesics which may be very important for animal welfare but where the economic returns may not justify the licensing approval costs.

On boar taint current Community legislation (Directive 64/433/EEC [9]) provides that male carcases over 80 kg may be allowed for human consumption provided that they bear a special mark and undergo treatment (i.e. processing) before entering the food chain. To this end Member States can recognise a test method and establish their acceptability criteria to ensure that carcases with pronounced boar taint will be detected. However at present there is no harmonised method for detecting boar taint, but the United Kingdom has established the 'boiling test' for this purpose. In the absence of a harmonised method, there is evidence that 'on-line' detection methods of pronounced boar taint may vary among Member States. Concerning the issue of boar taint some of the EFSA conclusions were also quite stark:

- "There is no standardised chemical and sensory method for measurement of chemical compounds contributing to boar taint.
- The sensory description of boar taint is not clear.
- Official criteria for inspectors to accept/reject limits for boar taint on slaughter lines are not established unequivocally.
- Carcass accept/reject criteria are not fully established with respect to consumer accept/reject limits especially in the different EU countries".

Various non-surgical methods of castration were reviewed, including the local destruction of testicular tissue by chemical compounds (e.g. formaldehyde, acids and salts), down-regulation of the hypothalamic-pituitary-gonadal axis by the administration of exogenous hormones, or immuno-castration. However these methods have not been systematically evaluated in terms of consumer acceptability, animal welfare and product quality implications.

With regard to alternative methods of castration EFSA concluded that:

- "Later surgical castration is very effective in reducing boar taint but is not practical.
- Local destruction of testicular tissue by chemicals, with the methods currently available, should not be used because of possible pain to the animal and continuing risk of boar taint.
- Exogenous hormones are effective in inhibiting sexual development. Very little is known on their efficiency for reducing boar taint.

- Immunocastration has been proven to be very effective in inhibiting sexual development and reducing boar taint. However a number of uncertainties are listed...
- No recommendation on the use of sexing of sperm and its insemination methods can be made at present."

The EFSA report and opinion highlight to a large degree the necessity for future research on the extent of piglet castration and how it is performed, age-related pain perception mechanisms, the effects of castration on the immune system, the advantages and disadvantages of local anaesthesia, alternative methods of castration, the control of boar taint in meat etc.

**Trying to fill the knowledge gaps:** Faced with such scientific uncertainties or lack of knowledge it is incumbent upon the European Commission to seek to address such issues before proposing further legislative amendments or guidance. Already in December 2002 within the 6th Framework Research Programme the Commission had launched a call for applications for future research in this area with an indicative budget of 500,000 € foreseen. The specific task “Welfare implications of surgical castration in pigs” was published in a call on 17 December 2002 which had an overall indicative budget of 149.1 Million €. The indicative budget of area 1.4 “New and more environment friendly production methods to improve animal health and welfare including research on animal diseases such as foot and mouth disease, swine fever and development of marker vaccines” was 7 Million € and this area had 7 tasks, with task 6 addressing welfare implications of surgical castration in pigs. The stated objectives were to develop techniques and systems of pig production and meat processing which would be likely to reduce the need for surgical castration. An indicative budget of 0.5 Million € was foreseen for this task but only one project application was submitted for this task and upon evaluation it did not meet the thresholds for approval.

Nevertheless further research avenues are being actively investigated by the Commission, to address in particular knowledge gaps identified in the EFSA opinion and report. A prospective Community-funded research project plans to consider issues such as marker- or gene-assisted selective breeding as an alternative to the castration of pigs in order to reduce boar taint. Projects are also planned on improving the quality of pork and pork products for the consumer as well as a more specific call for the collection of data on the issue of piglet castration. Relevant issues will include a review of current practices concerning the castration of male and female piglets in the EU and possible means of reducing the poor welfare implications of castration by improving castration methods, using techniques other than surgical castration and/or alternative management practices to reduce the risk of boar taint in meat.

**Ongoing political interest and attention:** Meanwhile at the Agriculture and Fisheries EU Council of Ministers Meeting of 21–22 December 2004 [10] Member States welcomed EFSA’s work in presenting comprehensive reports of the most recent research findings in this area. EU Commissioner for Health and Consumer Protection Markos Kyprianou highlighted that existing EU legislation obliged farmers to avoid any unnecessary animal suffering and that a new call for research would be issued on this specific topic of piglet castration before the Commission further reports to the Council. The Council Presidency noted this announcement and the need for new detailed studies concerning alternative methods of castration of piglets.
Future perspectives: For many years there has been debate on the issue of mutilations performed on farm animals and the associated animal welfare implications. This is one of the main reasons why current EU animal welfare legislation highlights that piglet castration is an issue to be re-visited in the near future. However any future policy proposals need to be underpinned by a sound scientific basis and an assessment of the possible implications of any changes in existing legislative provisions. It is clear that consumer preferences and market trends also have a role to play here. For these reasons the European Commission is currently intent on promoting research and collecting further data on this issue so that its future report to Council will be as well-informed and soundly-based as possible, taking account also of initiatives by such international organisations as the Council of Europe. It is clear that a balance needs to be found between modern intensive farming practices, any associated animal health and welfare considerations and allowing animals to express their natural behavioural needs, while responding to consumers’ clear demands and preferences.

Note: The SCAHAW held its final plenary meeting on 24–25 April 2003. Responsibility for the provision of scientific advice in this field has now been transferred to the Panel on Animal Health and Welfare of the European Food Safety Authority (EFSA).

References

S3 Animal Welfare Aspects of Preventing Boar Taint
Mette Giersing, Jan Ladewig and Bjørn Forkman
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Introduction: Since boar taint is connected to testicular hormones and sexual maturity, surgical castration has for centuries been the method employed to prevent taint in meat from male pigs, as well as to obtain more docile pigs. However, since the castration is performed without anaesthesia, it is painful for the pig and therefore poses a serious welfare problem. With growing focus on animal welfare in animal production, surgical castration without anaesthesia and some form of analgesia is now increasingly regarded as unacceptable.

The options, singly or combined, are: - castrating the pigs by methods that do not entail suffering, either surgically or non-surgically - raising entire male pigs by methods that limit the development of boar taint
- selecting pigs with low levels of taint
- producing only female pigs for consumption.

This presentation focuses on the animal welfare concerns of these different ways of preventing or reducing boar taint.

The welfare aspects of castration have recently been reviewed by a working group under European Food Safety Authority [1], by Bonneau & Prunier [2] and by Prunier et al.[3]. We wish to acknowledge the many involved authors, as these reviews provide a significant basis and the references for this presentation – supplemented by references that have since come to light.

Surgical castration: Surgical castration without anaesthesia is painful, as shown by the acute physiological responses (increased Hypothalamic-Pituitary-Adrenal-responses and protein c-fos expression in spinal neurons), as well as by vocalisation and behaviour during and immediately after the operation. The frequency and duration of high-frequency calls points towards the extraction of the testes and the severing of the spermatic cords as being the most painful in the procedure. Behavioural changes include disturbed massaging/suckling, activity, play and behavioural synchronisation. Some behavioural changes may persist for more than 24 hours after the operation, e.g. tail-wagging and rump-scratching, behaviours that may be related to wound-healing. It appears that the assumption, that pigs under the age of 7 days experience castration as less painful
than older pigs, is not substantiated. The incomplete neural development of young animals may render them more, rather than less, sensitive to painful stimuli. The effect of surgical castration on immune response varies with the type of challenge, with the age at castration, and is modified by the use of anaesthesia [4]. The different results are, however, open to interpretation in terms of pig welfare. Reports that castration compromises the health of the pigs in that the prevalence of pneumonia and other diseases was higher in castrates compared to gilts, and castrates compared to boars and gilts, are not confirmed by a review of data from Danish abattoirs. Here the opposite was found with regard to Mycoplasma hyopneumoniae infection, with boars having the highest risk, females the lowest and castrates intermediate [5]. Possible long-term effects on disease susceptibility need further investigation – with regard to effects of the castration procedure as well as the absence of male steroids. Local anaesthesia (commonly lidocaine plus adrenalin in a pH-buffered vehicle) effectively reduces the pain and stress symptoms of castration - most effectively when injected both into the testes and in the funicular area of the scrotum [1]. This happens in spite of the additional handling involved, as the response to intratesticular injection is much lower than to castration without anaesthesia. Prunier [6] recently confirmed the effect of anaesthesia, but found no further effect of pre-emptive analgesia with flunixin. General anaesthesia of piglets, both injection and inhalation, has been regarded as unrealistic (time, cost and forced veterinary assistance) under practical conditions. It has moreover been associated with high piglet mortality as well as risks in the postoperative period of sedation. Although CO₂ inhalation has been regarded as too averse to pigs, new research indicates that CO₂ anaesthesia, in the right gas proportions and with the right equipment, may be effective and practicable at farm level [7]. The whole procedure is very fast: 15 seconds to unconsciousness, 1–2 minutes to total anaesthesia, 15 seconds for castration and 30–40 seconds for full recovery. Anaesthetic as well as analgesic properties of the procedure are under further investigation, as is the significance of the pig’s initial aversion responses to the gas in relation to welfare. However, more recent results concerning anaesthesia of piglets prior to castration are discussed in another paper of this volume. Non-surgical castration: Methods of non-surgical castration include immunocastration, by which male pigs are actively immunised against GnRH, thus inhibiting testicular development. Currently this method is used in Australia and New Zealand. When effective, the behaviour, production and boar taint level of the immunocastrates are similar to surgically castrated pigs. The procedure must be repeated twice to be effective, which means twice capture, restraint and injection of relatively large pigs because, in order to retain the production advantages of entire males, the pigs are immunocastrated as late as possible (14 and 18 weeks of age). Stress or trauma from capture, restraint and injection could probably be minimised by correct handling procedures. Lesions in the hypothalamus, the target site of the vaccine, were initially reported, but a subsequent report by the same group of scientists concludes that immunisation against GnRH does not induce either morphological or pathological abnormalities in the brain [8]. The welfare consequences of this vaccination still need further investigation. Another method of non-surgical castration is local destruction of testicular tissue by chemical compounds such as formaldehyde, acetic acid, or salt from silver or zinc. No thorough welfare evaluation has been made. Swelling of the testes or scrotum has been observed which indicates inflammation and, although not proven, is likely to cause pain. The use of exogenous steroid hormones or steroid agonists, to down-regulate the HPG axis, is not a method which would be acceptable to EU-consumers. Raising entire male pigs: Producing entire males for meat consumption calls for particular management procedures to minimise boar taint and to promote pig welfare. The one main boar taint substance, skatole, can to a large extent be controlled by feeding and by keeping the pigs clean. The latter may lead to extensive use of slatted floors, which is not conducive to pig welfare. An alternative, and more welfare friendly approach, is to control the climatic environment and provide pigs with possibilities for thermoregulation, e.g. showers, instead of leaving them to wallow in their own excreta. To reduce skatole development it is moreover recommended that feed be withheld from entire males from 26 hours before slaughter. This may be a welfare problem, as modern pigs have large appetites, but the harm to the welfare this might cause has not been investigated. The remainder of this section is devoted to effects of – and on – androstenone. Entire males are more aggressive than females and castrates – this applies also to play fighting behaviour in young pigs. Both aggression/fighting and sexual behaviour/mounting which takes place in groups with male pigs, compromise animal welfare as well as meat and carcass quality through skin damage and leg injuries. Recently, agonistic behaviour at feeding and sexual (mounting) behaviour was found to be significantly higher in entire male groups and mixed male and female groups compared to females alone [9]. In earlier studies [1] it has been shown that boars in mixed sex groups had higher fat androstenone levels and were more sexually mature than those in single sex groups when slaughtered at over 100 kg live weight. Dominance and aggression are related to increased levels of androstenone, with dominant animals having the highest levels. High level of androstenone in a group has an enhancing effect on androstenone levels of that group. Salmon [10] found the highest level of aggression, sexual (mounting) behaviour and the highest testes weight in a male-only environment, compared to rooms with both male and female groups, which could confirm that strong boar pheromone odour has a stimulating effect on other boars. This is perhaps not surprising, considering that boars in nature live in bachelor groups when reaching sexual maturity. Aggressive behaviour as well as sexual behaviour has been shown to be associated with increases in testosterone and androstenone levels in plasma, whereas corresponding increases in fat levels have only been measured after HCG challenge. Mixing unacquainted pigs will always lead to aggression/fighting until a new dominance order has been established. Mixing entire males will therefore not only be stressful and injurious, but increase the risk of higher androstenone levels. ‘Birth to slaughter’ systems, where litters of pigs are kept together from birth to slaughter, including transport and pre-slaughter lairage, not only minimises skin damage (fighting), but also reduces the level of androstenone in entire males [11]. Whether litter rearing and minimal mixing influences the development of
sexual maturity and mounting behaviour is not yet clear. It is likely that mixing of strangers and establishment of new hierarchies will provoke testicular activity and accelerate the initiation of puberty, whereas the initiation of puberty may be inhibited in stable sibling groups.

Because of increased aggressiveness and activity levels, it is likely that rearing environments and handling facilities for entire males should contain more resources (space, facilities, including devices for thermoregulatory behaviour) than normally provided for castrates in order to minimise competition and aggression. If adequate facilities are not given, effects of behaviour on skin and leg injuries, as well as the general stress level, may be increased if pigs cannot escape or avoid harassment from particularly active males. Effects of these factors on boar taint are not documented. High levels of received aggression or levels of cortisol have not been associated with either skatole or androstenone levels.

Genetic selection: It is not known whether selecting or breeding animals for low skatole and androstenone production or for high skatole and androstenone metabolism has any consequences for animal welfare, but this seems unlikely.

Sperm sorting: The current technique for sperm sorting in pigs, in order to produce only female pigs for meat consumption, necessitates intrauterine insemination of the sows, which could increase the risk of discomfort, injury and pain and thus compromise the welfare of the sows. This may change with the development of new techniques.

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S4 The consumers’ view/reaction
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Introduction: The purpose of this paper is to present and discuss some of the issues and problems that should be taken into consideration when working with consumer reactions to boar taint. It is generally accepted that boar taint is an unpleasant odour or flavour mainly caused by the two compounds skatole and androstenone. Boar taint may occur when heating meat from some – but not all – non-castrated (entire) male pigs. Castrates and gilts may also, in some rare cases, contain high levels of skatole, and therefore exhibit boar-like taint.

Discussion: Many consumers do not know the term “boar taint” when asked directly. But if you ask: “Would you like your pork to smell of boar?” the answer will most probably be “No!” Farmers, their families and others with direct or indirect connections to pig production are of course consumers with a special knowledge regarding boar taint. They know that male pigs may be castrated and that entire male pigs may exhibit boar taint. The consumer views on and reactions to boar taint will therefore differ between urban and rural areas.

Describing consumer reactions to pork from entire male pigs is complicated because they depend on many factors and because they are not very easy to measure. As indicated above, consumers do not all react in the same way. Consumers in different countries react differently as demonstrated in the EU Boar Taint project [1], where for example the proportion of dissatisfied British consumers did not depend very much on the level of skatole and androstenone. A tentative explanation could be that British consumers are used to pork from entire male pigs, or that the consumers most sensitive to boar taint have stopped eating pork all together. Consumers within a country also have different sensitivity to skatole and androstenone – some being very sensitive and others being completely anosmic to androstenone [2]. The frequency of very sensitive persons seems to be larger among women than among men – at least regarding androstenone [2].
There seems to be a stronger correlation between skatole/androstenone and negative reactions to odour than to flavour, and for most countries, the correlation is stronger for skatole than for androstenone [1]. The former may account for consumers saying that the boar taint problem is larger when cooking than when eating.

When performing consumer surveys on boar taint, you usually select pigs with different levels of the malodorous compounds (for example low, medium and high levels) in order to test the variation in consumer reactions to the different levels. But when simulating the expected reactions of a given consumer population, you need to take into account the distribution of skatole and androstenone in the pig population. In most cases (countries) the distributions of skatole and androstenone are very skew, with many pigs at low levels, and very few pigs at high levels of the compounds [3]. The distributions may of course be changed by different actions within the pig production (feeding, management, slaughter weight etc.) or by sorting out pigs with high levels. This will affect for example the expected frequency of negative reactions within a given consumer population [4].

After describing the consumer reactions to boar taint, for example by calculating the expected frequency of negative reactions to pork from entire males, you may want to decide if this frequency is acceptable or not. It may of course be a matter of politics, but it also depends on what you compare with. You can compare with the alternative production method – castrates, or you can compare with the “consumers alternative” in the supermarket – pork from female pigs.

Furthermore, the frequency of negative reactions in a given survey depends on the choice of product and how the meat is cooked and presented to the consumers. If part of the problem is believed to be in connection with cooking the meat, this should be included in the survey. If the meat is kept warm for a longer period of time, or even reheated, some of the skatole and androstenone will evaporate leaving the meat more acceptable.

On the other hand the consumers may experience warmed-over-flavour (WOF) that in most cases will reduce the liking of the meat. The WOF effect may not be the same for entire male pigs over-flavour (WOF) that in most cases will reduce the liking of the meat. The WOF effect may not be the same for entire male pigs as for female pigs because of differences in fatty acid composition. It is important to understand that the consumers “liking” is a sum of many factors that we may or may not have control over.

**Conclusion:** In general, consumers react negatively to high levels of skatole and androstenone in pork, but there are variations. Some individuals are very sensitive and others do not care at all. The frequency of negative consumer reactions to pork from entire male pigs depends on the consumer population, the distribution of skatole and androstenone in the pig population and of course, on the composition of pork products available on the marked.

**References**


**S5**

**Boar taint related compounds: Androstenone/skatole/other substances**

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**Introduction:** Two substances are the main contributors to boar taint in pork from entire male pigs i.e. the steroid androstenone (5α-androst-16-ene-3-one) [1] and skatole (3-methyl-indole) [2, 3]. The relative contribution of these substances to boar taint varies in different studies. Other substances may also contribute to a minor degree and a range of substances with an off-odour/off-flavour has been identified in boar fat. Among these indole and other 16-androstene steroids may be of some significance [4, 5].

In fat samples with low levels of androstenone and skatole, but which nevertheless had been classified as tainted, Angels Rius et al [6] identified aldehydes and short chain fatty acids as the main classes of substances related to off-flavour. However, only a few substances were found in significantly higher concentrations in tainted compared to untainted samples. Styrene and 1,4 dichlorobenzene, whose presence may be due to contamination, showed a high concentration in tainted samples. Rius Solé and Regueiro [7] identified 4-phenyl-3-buten-2-one in samples of boar fat and reported that the presence of this compound in samples low in androstenone and skatole, could promote the perception of these substances.

**Androstenone:** Androstenone is produced in the testes. In plasma the level of free androstenone is reported to exceed often the level of testosterone. In plasma it is found in free form and in a sulfoconjugated form. Recently is has been found that around 70 % of androstenone in plasma it is found in free form and in a sulfoconjugated form. The secretory pattern of androstenone follows in general the secretory pattern of testosterone, although the biosynthesis of the two steroids follows different pathways. The ratio between testosterone levels and androstenone levels in plasma varies. Often the level of free androstenone in plasma is reported to exceed the level of testosterone. In plasma the level of free androstenone varies from a few ng and up to at least 40–60 ng per ml.
The odour of $5\alpha$-androstenone: Odor in humans with reference to odorous $16\alpha$-androstenes, has been reviewed by Gower and Ruparelia [9]. The smell is often described as urinelike. It is well known that the ability to detect the smell of $5\alpha$-androstenone varies. The results of an extensive survey were published by Gilbert and Wysocki in 1987 [10]. In Europe (UK not included) 24.1 % of the female participants of the study and 15.8 % of the males were unable to detect the smell of androstenone. However it has also been shown that the ability to perceive androstenone can be induced in a proportion of people with odour blindness or specific anosmia to androstenone. The participants of the study sniffed androstenone 3 minutes, 3 times a day for 6 weeks. In 10 out of 20 individuals that were anosmic to androstenone, the ability to perceive androstenone were induced [11]. The authors suggest a mechanism where olfactory neurons with specific receptors for androstenone undergo clonal expansion or selection of lineages with more receptors or receptors of higher affinity, much in the manner of lymphocytes responding to antigenic stimulation.

Physiology of $5\alpha$-androstenone: The well known physiological effect of androstenone and other $16\alpha$-androstenes, is to act as pheromones and stimulate reproductive functions in the female pig. They are secreted into saliva in the submaxillary salivary glands. Submaxillary salivary glands from pigs contain a protein; pheromaxin, which binds $16\alpha$-androstenols. The primary function of pheromaxin is the solubilization and transportation of pheromones in saliva. An effect on female pigs directly from $16\alpha$-androstenes released from the boar as well as an effect over time due to saliva deposited in the environment has been proposed [12]. The odour of $16\alpha$-androstenes facilitates the expression of the standing response in oestrous sows. It has also been shown that the smell of $5\alpha$-androstenone elicits oxytocin release in oestrous sows [13].

Androstenone has no androgenic effect as measured by the “Chicken comb test” [14]. Whether it has any effect on its own production/secretion through a feed-back on the production/secretion of GnRH and gonadotropins, appears to be unknown. An effect in the testes can not be ruled out: a specific binding of $5\alpha$-androstenone to human testicular cytosolic fraction has been reported [15].

It has been shown that $5\alpha$-androstenone reduces agnostic behaviour in newly regrouped pigs [16]. Androstenone has also been found to affect the metabolism of skatole in the liver [17].

Fate of $5\alpha$-androstenone in plasma and fat: $5\alpha$-androstenone is a very lipophilic molecule. The water solubility of $5\alpha$-androstenone is only 230 $\mu$g/l at 25°C [18]. The steroid appears to be easily transferred from plasma to adipose tissue. It has been found that if the level of $5\alpha$-androstenone in peripheral plasma exceeds about 15 ng/ml, a heavy accumulation of androstenone in fat usually follows [19]. Sinclair et al [20] reported that peripheral plasma levels of androstenone below 15 ng/ml were associated with low androstenone concentrations in fat, while a wide range of androstenone concentrations can be found in fat in animals with plasma levels above this value. The levels of androstenone in adipose tissue can be doubled within a day following stimulation of androstenone production by the testes by hCG injection [21]. However, when the concentration of androstenone in peripheral plasma decreases from high levels, the concentration in adipose tissue do also gradually decrease. Thus there appear to be a dynamic relationship between androstenone in plasma and adipose tissue, but the detailed regulation of the transfer of androstenone between plasma and adipose tissue has not been clarified.

In many species sex steroids are partly bound to specific proteins as sex hormone binding globulin (SHBG) and to albumin. A binding/association of $5\alpha$-androstenone to plasma proteins would affect the transfer of the steroid into adipose tissue. However, it has been reported that pigs lack a sex hormone binding globulin (SHBG) in plasma [22]. To what extent androstenone in pigs is bound or associated to other plasma proteins is unknown.

Claus [23] has reported the disappearance rate of androstenone from adipose tissue following castration. He found half-lives from 7 days in young boars (weights in the range of 90 to 97 kg) till 16–19 days in older boars (weights in the range of 240–250 kg). Bonneau et al [24] found half-lives from 4 to 14 days in 9 boars castrated at 175 days of age.

Androstenone is metabolised by the liver. Isolated pig liver microsomes reduce androstenone mainly to $\beta$-androstenol [25]. These authors found that the rate of androstenone metabolism in pig liver microsomes was determined by the level of expression of hepatic $3\beta$-hydroxysteroid dehydrogenase. They observed a much lower rate of androstenone metabolism in liver microsomes from pigs from a breed with high androstenone levels (Meishan) compared with liver microsomes from pigs from a breed with low androstenone levels (Large White), indicating differential expression or activity of the enzyme catalysing androstenone in the two breeds.

Differences in production rate of androstenone may however, be more important for the differences in androstenone levels in adipose tissue between pigs than differences in the catalysis of the steroid in the liver. Babol et al. [26] found no significant relationship between the oxidative metabolism of androstenone in the liver and the levels of androstenone in fat. The results of a study by Bonneau and Terqui [27] have indicated a very high metabolic clearance rate (MCR) for plasma androstenone. In one boar they calculated a MCR of about 80 000 liters per day. The high disappearance was mainly ascribed to transfer and storage of androstenone into adipose tissue and salivary glands. If the production rate for androstenone is high, the capacity of the liver to metabolise androstenone may be insufficent and androstenone will accumulate in adipose tissue.

Levels of androstenone causing boar-taint: Different levels of androstenone have been proposed as cut-off levels for sorting carcasses. Claus et al [28] and Rhodes [29] suggested levels of 0.5 and 1.0 $\mu$g androstenone per g fat as cut-off levels to sort out tainted meat, respectively.

Skatole: Skatole (3-methyl-indole) is a breakdown product of tryptophan. It has a fecal-like odor. Unlike the smell of androstenone the vast majority of people are able to detect the smell of skatole. Skatole is produced in the colon by microbial activity. Lactobacillus sp. strain 11201 is considered as the organism producing skatole causing boar taint [30]. Both tryptophan from the diet and from cell debris from degradation of intestinal mucosa can be metabolised to skatole.

Skatole does also seem to be easily transferred from plasma to adipose tissue. Following daily i.m. injection of skatole to intact male pigs for 9 days at a dose corresponding to the upper physiologically occurring levels (1 mg/kg), the mean level of skatole in adipose tissue rose from 0.02 $\mu$g/g fat to 0.41 $\mu$g/g fat [26].
Levels of skatole causing boar taint: The rejection level for skatole in fat varies. In Denmark 0.25 μg per gram fat and in Norway 0.21 μg per gram fat has been used. In Denmark it has been calculated that a level of 0.25 μg skatole per gram fat corresponds to a level in plasma of 7.5 ng per ml [31]. In Sweden Babol et al. [32] found that a level of skatole of 12.6 ng/ml plasma correspond to a level in fat of 0.2 μg skatole equivalents per gram.

Skatole dose not appear to play any physiological role in the pig. While skatole is toxic for many ruminant species and causes acute bovine pulmonary edema and emphysema, skatole is not toxic for pigs [30].

Metabolism of skatole: In pigs skatole is absorbed by the intestinal mucosa into the portal vein and passes through the liver where it is efficiently metabolised. There seem to be no differences between skatole production in the gut between male and female pigs [33]. The half life for skatole in plasma is approximately 60 minutes [34]. It has been demonstrated that the liver has a potential and a capacity to extract skatole from blood in quantities that greatly exceed what is found under physiological conditions [31]. In some boars a proportion of skatole, nevertheless passes the liver without being metabolised and accumulates in adipose tissue. The effect of androstenone may be that the effect will be a reduced metabolism of skatole and accumulation might prevent CYP2E1 induction by the substrate skatole. The androstenone included. Hepatic cytochrome P4502E1 (CYP2E1) and accumulates in adipose tissue. The reason must be related physiological conditions [31]. In some boars a proportion of skatole prod uction in the gut between male liver where it is efficiently metabolised. There seem to be no differences between skatole production in the gut between male and female pigs [33]. The half life for skatole in plasma is approximately 60 minutes [34]. It has been demonstrated that the liver has a potential and a capacity to extract skatole from blood in quantities that greatly exceed what is found under physiological conditions [31]. In some boars a proportion of skatole, nevertheless passes the liver without being metabolised and accumulates in adipose tissue. The effect of androstenone may be that the effect will be a reduced metabolism of skatole and accumulation might prevent CYP2E1 induction by the substrate skatole. The effect will be a reduced metabolism of skatole and accumulation in adipose tissue. The effect of androstenone may be that the steroid binds to a transcripton factor (COUP-TF1) and interferes with its binding to DNA [37]. It has been found that the level of P4502E1 in hepatic microsomes do increase following castration [38], giving further support to an inhibiting effect of testicular steroids on the hepatic metabolism of skatole.

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with low pre-caecal digestibility stimulate skatole production [7, 8] whereas diets with high content of fermentable carbohydrates that escape digestion in the small intestine have been shown to reduce the production of skatole, however, the results vary. Øverland et al., [9] and Van Oeckel et al., [10] found no effect of diets rich in sugar beet pulp, whereas Jensen et al. [8], Kjeldsen [11], Knarreborg et al. [1] and Whittington [12] observed significant reduction in skatole levels in pigs fed sugar beet pulp. Fructooligosaccharides has also been shown to reduce skatole production in both in vitro [13] and in vivo models [14, 2]. Raw potato starch has also been shown to reduce the production of skatole [2, 15, 16]. In the study of Jensen and Jensen, [2] seven different fibre sources were investigated for their effect to reduce skatole production. Raw potato starch, fructooligosaccharides and lupins were found to be most effective (Figure 1). The exact mechanism of how fibre-rich diets affect skatole deposition in back fat is not known, but several contradictory hypotheses have been presented. Firstly, in the presence of extra dietary fibre, more undigested protein will reach the large intestine with consequently more degradation of tryptophan to skatole. Secondly, more fermentable carbohydrates in the hindgut will increase the microbial activity in the gastrointestinal tract [17] resulting in more tryptophan incorporated as bacterial protein, further increased amounts of carbohydrates will decrease the activity of the proteolytic bacteria resulting in less tryptophan available for skatole production. Thirdly, extra dietary fibre results in more bulky material in the large intestine and an increased water binding capacity, leading to a dilution of skatole resulting in less contact of skatole with the intestinal wall and consequently, decreased skatole absorption [2]. Further, dietary fibre decreases the intestinal transit time and as such may decrease skatole absorption from the gut. Recently it has been hypothesized that carbohydrates with high pre-caecal digestibility will increase cell debris formation in the small intestine, resulting in more tryptophan entering the large intestine and as such higher skatole formation [18]. On the other hand carbohydrates with low pre-caecal digestibility will decrease skatole production due to an increased butyrate production that inhibits apoptosis and as such less tryptophan available for skatole production. That the production of skatole in the hindgut is dependent on the composition of the diet is illustrated by a series of experiments [19] where the production of skatole in the hindgut and the absorption of skatole to the portal blood was investigated after tryptophan was infused into the caecum of pigs fed either a low or a high fibre diet. Figure 2 shows the absorption pattern of skatole over a period from 1 hour before to 12 hours after infusion of either tryptophan or saline. Both the effect of available tryptophan and the effect of fibre on skatole are convincing. With the low fibre diet, the hindgut bacteria transform 26% of the infused tryptophan into skatole (Table 1) resulting in significant increase in skatole concentration in the portal blood (Figure 2).

Effect of dietary fibre on absorption patterns (Vp-Vj differences) of skatole to the portal blood following tryptophane (4.9 mmol) or saline infusion in the caecum. The area under curves (AUC) represent the total amount of skatole absorbed. Both diets were similar except that the high fibre diet was added 100 g sugar beet pulp per kg.

Figure 1 (abstract S6)

Effect of various dietary fibre sources on the concentration of skatole in blood plasma. The diets were: a control diet based on barley and soya bean (Cont), seven diets with the same basal composition as the control, but with addition of 100 g kg⁻¹ of either raw potato starch (PS), fructooligosaccharides (FOS), lupins (LUP), barley hull meal (BHM), palm cake (PC), coconut cake (CC) or sugar beet pulp (SBP). All blood samples were taken 3 hours after the morning feeding. The control diet for each individual animal was given the value 100 and the other diets were related to this. The value for each fibre source represent three to four replicates with different animals.
With the high fibre diet only 230 mol of skatole were affected by the fibre content in the diet. The basal skatole production in the hindgut and absorption to the portal blood was produced in the hindgut and absorbed to the portal blood. Also the skatole concentration. Again approximately 70% of the skatole infused tryptophan was converted to skatole in the gastrointestinal tract, resulting in a lower increase in portal blood skatole concentration. Again approximately 70% of the skatole produced in the hindgut was absorbed to the portal blood. Also the skatole production in the hindgut and absorption to the portal blood were affected by the fibre content in the diet. With the high fibre diet only 230 mol skatole was produced during the 12 hours, while more than twice as much (480 mol) was produced on the low fibre diet. These results strongly show the usefulness of in vitro measurements of skatole production and the use of portal absorption to study the effect of diet on the production and absorption of microbial metabolites in the large intestine, and confirm the important effect of diet composition on the amount of skatole produced and absorbed from the gut. Further, the results point at the use of fibre rich diets as a relevant way to reduce boar taint due to skatole in practical pig production.

### Feeding strategies

Two feeding strategies that have a marked effect on the gastrointestinal ecosystem are liquid feeding [20] and the structure of the feed (pellets vs. meal/fine vs. gorse) [21]. While use of liquid feed has been shown to reduce the level of skatole [22], it has never been investigated if the feed structure has any effect on skatole levels.

### Feed intake (fasting)

Studies with different feeding levels during the growth period of the pigs showed that the general feed intake had no effect on the skatole level, whereas a 12 hours redraw of feed from the pigs prior to slaughter did reduce the skatole level [11]. This is in agreement with that reduced amount of digesta entering the large intestine results in a lower fermentation of non-digested protein and the very rapid degradation of skatole in the liver. However, Anderson et al. [22], were unable to confirm that a 12 hours redraw of feed reduced skatole.

### Environmental factors

Skatole levels depends on environmental conditions [23], and it has been shown that pigs raised in a clean environment have a lower skatole level than those raised in dirty environments [24].

### Puberty (age)

Androstenone and other testicular steroids might be involved in the skatole level by regulation of skatole metabolism in the liver [16]. Androstenone is a pheromonal steroid produced in the testes of mature male pigs together with other steroids and its levels are primarily affected by puberty stage. Using in vitro experiments Doran et al. [25] have shown that androstenone suppress the induction of enzymes involved in skatole metabolism. Zamaratskaia et al. [16] found a positive correlation between the testicular hormones testosterone and oestrone sulphate and skatole level suggesting that these compounds have an influence on skatole pattern, and the authors suggest that slaughter of entire male pigs at a weight below 100 kg can be used to avoid boar taint.

**Genetics:** There are strong indications of genetic influences on skatole levels in pigs. These include differences in skatole levels between breeds [26], significant heritability estimates for levels of skatole in fat [27] as well as indications of the presence of a major gene affecting boar taint due to skatole [28].

### References


S7 Factors affecting the level of androstenone
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Introduction: As pointed out in Øystein Andresen’s previous presentation, androstenone (5α-androst-16-en-3-one) is one of the major compounds responsible for boar taint. It belongs to the family of the 16-androstene steroids that are synthesized in the testis together with androgens and estrogens. The present paper borrows a lot of its content from previous reviews [1].

Androstenone levels in entire male pig populations: At usual slaughter weights fat androstenone levels are very variable between animals and distributed in a log-normal manner (Figure 1). The distribution of androstenone is more skewed than that of skatole, which means that a higher proportion of them exhibited skatole levels higher than 0.2 ppm. Fat androstenone contents may vary quite extensively between pig populations as shown in the results of Walstra et al. [2] where 15% of them exhibited skatole levels higher than 0.2 ppm. Fat androstenone contents may vary quite extensively between pig populations as shown in the results of Walstra et al. [2] where the proportion of entire males with androstenone levels higher than 1 ppm varied from 12% to 43% in 12 populations of entire male pigs (6 countries × 2 seasons). The distribution of androstenone levels in the 2 extreme populations is presented in Figure 2.
Biosynthesis, accumulation in fat and elimination of androstenone: According to the scheme presented in Figure 3, fat androstenone content results from the balance between its synthesis and elimination. It does not seem to be related to its catabolism in the liver [3]. However, sulfoconjugation, that binds steroids to sulphate groups so that they can be eliminated, may be involved in the regulation of androstenone accumulation in fat [4].

The biosynthetic pathways of the 16-androstene steroids have been described by David Gower at Guy’s hospital in London [5]. A simplified scheme is presented in Figure 3. The overall steroid synthesis is dependent on sexual maturity. The balance between 16-androstene steroids (with no hormonal action) and androgens and estrogens (responsible for the improved performance of the entire male compared to the castrate) depends on the activity of the enzyme complex andien-β synthase. To achieve high rates of androstenone synthesis a pig has to be sexually mature and exhibit high andien-β synthase activity.

The effect of age and weight on androstenone levels: The intensity of androstenone synthesis is low in the young piglet, and then increases steadily during the establishment of

Distribution of androstenone and skatole levels in 4313 entire male pigs from 6 European countries (after Walstra et al. 1999).

Distribution of androstenone levels in two entire male pig populations (after Walstra et al. 1999).
Androstenone accumulation in fat (see presentation by Jim Squires). The advantage is that androgen and oestrogen steroid production may be kept at a sufficient level to benefit from the better feed efficiency and higher leanness of the entire males. The drawbacks are that boar taint related to substances other than androstenone is not affected.

The second approach is to eliminate or reverse sexual development (EFSA, 2004 [14]). This can be achieved via i) down regulation of the hypothalamic-pituitary-gonadal axis by exogenous hormones (not an option in the EU), ii) castration with chemicals (not sufficiently investigated so far) or iii) Immunocastration (see presentation by Stig Einarsson). The advantage is that all boar taint substances are affected, the drawbacks are that all or part of the better performance associated with entire males is lost.

Management factors affecting sexual maturation have some, but little, effect on fat androstenone levels. Social factors do not have consistent effects. However, “birth to slaughter” systems, avoiding the mixing of unrelated animals, seem to result in lower androstenone levels [4].

Genetic factors affecting androstenone levels: Fat androstenone levels are mostly dependent on genetic factors affecting sexual maturation, potential for androstenone synthesis and, possibly, androstenone clearance (Figure 3). This will be developed in Jim Squires’ presentation later on today.

Conclusion: Drastic reductions in androstenone contents have to be achieved in order to get boar taint free meat. Management factors have a very limited impact on androstenone levels, in contrast with skatole. The required drastic reduction in androstenone levels can be achieved only with very efficient methods.

A first approach is to select animals with a low potential for androstenone accumulation in fat (see presentation by Jim Squires). The advantage is that androgen and oestrogen steroid production may be kept at a sufficient level to benefit from the better feed efficiency and higher leanness of the entire males. The drawbacks are that boar taint related to substances other than androstenone is not affected.

The second approach is to eliminate or reverse sexual development (EFSA, 2004 [14]). This can be achieved via i) down regulation of the hypothalamic-pituitary-gonadal axis by exogenous hormones (not an option in the EU), ii) castration with chemicals (not sufficiently investigated so far) or iii) Immunocastration (see presentation by Stig Einarsson). The advantage is that all boar taint substances are affected, the drawbacks are that all or part of the better performance associated with entire males is lost.

References
Possibilities for selection against boar taint

E James Squires
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Introduction: The amount of boar taint due to high levels of androstenone and skatole is affected by a number of factors including the degree of sexual maturity, environment, dietary and management factors, and genetics. These factors have been discussed in previous papers by B.B. Jensen (Factors affecting the level of skatole) and M. Bonneau (Factors affecting the level of androstenone). To briefly summarize, sexual maturity can affect levels of both androstenone and skatole, while skatole is more affected by diet and environment and management factors than androstenone, unless these factors also affect the degree of sexual maturity.

Both androstenone and skatole are affected by genetic factors, and distinct breed differences in the levels of these compounds have been identified in a number of studies. Between five to eight percent of purebred Hampshire, Yorkshire and Landrace boars have high concentrations of androstenone in fat, whereas 50 percent of Duroc intact males have high concentrations; fat skatole levels also differ between breeds [1, 2, 3, 4, 5]. Low levels of androstenone measured in some market weight boars may be a consequence of sexual immaturity, since the testis may not be producing peak levels of steroids. Low levels of skatole may be due to low production of skatole in the gut due to dietary and other factors and not due to a genetic predisposition to decreased boar taint. However, genetic selection for animals with low boar taint should be possible due to the relatively high heritability (range from 0.25 to 0.87) of fat androstenone [6]. Likewise, the heritability of skatole is 0.55 for Landrace and 0.23 for Duroc [7]. Tajet et al. [7] also reported a positive genetic correlation between skatole and androstenone of 0.36 for Landrace and 0.62 for Duroc. Thus, genetic selection for low levels of one boar taint compound may result in an overall decrease in boar taint compounds.

Previous attempts at selection against androstenone resulted in decreased performance and sexual maturation due to lower production of androgens and estrogens. For example, Willeke et al. [8] observed a delayed puberty in the gilts of a “low androstenone” line. Using a selection index associating androstenone and bulbo-urethral gland thickness [9] resulted in increased bulbo-urethral gland size and no reduction in androstenone due to inaccuracies in estimated genetic parameters for these traits. It is therefore desirable to identify animals that have a decreased genetic capacity to accumulate androstenone in fat while maintaining the normal levels of testicular steroids that are characteristic of intact males. The development of genetic markers to identify these pigs would allow the selection of pigs that are free of taint from androstenone but otherwise grow as normal boars.

Development of genetic selection tools: QTL Identification and Use for Selection: Genetic markers can be developed using a number of different experimental approaches. Two common approaches are the use of anonymous markers and the candidate gene approach. Quantitative trait loci (QTL), which are chromosomal regions that contain genes that affect a particular trait, can be identified by comparing the genotype of anonymous markers located throughout the chromosome to the phenotype or trait of interest. The QTL is then described by the position of the markers that are most closely associated with differences in the trait phenotype. Because these markers are located on the chromosome close to the gene responsible for the trait, they are “linked” or in linkage disequilibrium with this gene. Candidate genes can be identified by examining genes located within a QTL region previously detected using anonymous markers (position candidate gene approach) or by directly developing markers within genes expected to influence the phenotype of interest (functional candidate gene approach). The candidate gene approach is most effective when gene function is well characterized or if the QTL has been mapped to a very small region in which the identity of the genes is known.

Once a marker genotype has been associated with a preferred phenotype, the marker genotype can be used for making selection decisions, a process referred to as marker assisted selection. Individuals with the marker genotype that is linked to the preferred or improved phenotype are selected for their superior QTL genotype on the basis of their linked marker genotype. This process does not require knowing the gene or genes responsible for the QTL effect and for successful, multiple generation selection the marker should be tightly linked to the QTL in order to reduce the possibility of recombination events disrupting the marker-QTL association. Ultimately the best marker involves identifying the genetic change in the gene that directly affects the trait and using that polymorphism as the marker for marker assisted selection.

Several QTL’s for androstenone have been reported. Quintanilla et al. [10], using a three generation experimental cross between Large White and Meishan pig breeds, found significant gene effects using two different statistical methods on chromosomes 3, 7, and 14. The QTL on chromosome 7, close to the major histocompatibility complex of the pig (swine leucocyte antigen system, SLA), showed the largest effects. Two candidate genes in this region were investigated, CYP21 and CYP11a, but found not
to be responsible for the QTL. A dominant gene affecting fat androstenone has been described by Fouilloux et al. [11], but this gene is not associated with the SLA region. Varona et al. [12], using a commercial Landrace population, could not find any significant QTL for androstenone in the 10 chromosomal regions they analysed. However, they did find a significant QTL for fat skatole on chromosome 6. Lee et al. [13], using a Large White × Meishan crossbred population, also found a QTL for skatole, but it was located on chromosome 14. They also found a QTL for androstenone and boar flavour on chromosome 6. The genes responsible for these QTL’s have not yet been identified.

Identification of Candidate Genes from Metabolic Studies: Another approach to developing genetic markers is to investigate polymorphisms, usually Single Nucleotide Polymorphisms (SNP), in candidate genes. Candidate genes can code for key enzymes in the metabolic pathway of boar taint compounds and ideally should not involve other pathways, such as anabolic steroid metabolism. A number of key enzymes involved in the metabolism of both androstenone and skatole have been identified to date.

Genes for Androstenone: We have identified cytochrome b5 as a key protein regulating the synthesis of androstenone in the testis. Androstenone and the sex steroid hormones are produced from pregnenolone by the andien-synthase enzyme complex, which consists of cytochrome b5, CYP17, and reductase enzymes. We isolated each of these proteins from pig testis and studied the synthesis of the 16-androstene steroids (precursors of androstenone) and the sex steroids using an in vitro reconstitution system. When only CYP17 was present, only the sex steroids were produced, but when cytochrome b5 was added, the 16-androstene steroids were made [14]. Levels of cytochrome b5 in the testis were also correlated with fat androstenone levels and 16-androstene steroid synthesis rates in vitro [15]. Recently, we have reported a G/T polymorphism at -8bp upstream from the translation start site that dramatically affects androstenone synthesis and accumulation in fat [16].

For the metabolism of androstenone, Doran et al. [17] reported that the conversion of androstenone to 3β-androstanol was greater in liver microsomes from Large White compared to Meishan pig breeds. The expression of 3β-hydroxysteroid dehydrogenase (3β:HSD) mRNA was also higher in the Large White breed, which is characterized by lower androstenone levels than the Meishan breed. They have thus suggested that 3β:HSD could be a key enzyme involved in the metabolism of androstenone. No polymorphisms in 3β:HSD have yet been reported.

We have recently reported on the role of hydroxysteroid sulfotransferase (SULT2A1) in the formation of androstenone-sulfate and the effect on androstenone accumulation in fat [18, 19, 20]. SULT2A1 activity was negatively correlated with fat androstenone concentrations in fat. Animals with high concentrations of 5α-androstenedione in fat and low SULT2A1 activity had corresponding low levels of SULT2A1 protein. Real-time PCR analysis indicated that the expression of the SULT2A1 mRNA was increased 3.5-fold in animals with high levels of the protein. A mutation was identified within the porcine SULT2A1 coding region; however, this did not affect the amino acid sequence. These findings suggest that the accumulation of 5α-androstenedione in fat is influenced by the proportion of the sulfonconjegated forms of 5α-androstenedione present in the circulation. Low SULT2A1 activity will result in decreased levels of the sulfoconjugated form of 5α-androstenedione and thus more of the unconjugated form that can accumulate in adipose tissue in high boar taint pigs.

Genes for Skatole: The metabolism of skatole in the liver is an important factor regulating skatole accumulation in the carcass. Gilts and barrows can efficiently metabolise and clear skatole, while some boars have low levels of the enzymes important in skatole metabolism and produce carcasses tainted with high levels of skatole. We have studied the metabolism of skatole with liver cell fractions to identify the metabolites produced [21] and the enzymes important in this metabolism using specific inhibitors against the enzymes. The enzymes CYP2E1 [22, 23, 5], CYP2A6 [24], aldehyde oxidase [25] and phenol sulfotransferase (SULT1A1) [26, 27] are related to skatole metabolism and clearance. The molecular cloning and functional characterization of CYP2A6 and SULT1A1 have been reported. CYP2A6 was cloned and sequenced from pig liver and a deletion mutation was found in the coding region which caused a complete lack of enzyme activity [28]. For SULT1A1, a SNP was identified at 546bp within the coding region that caused a significant decrease in enzyme activity [29].

Microarray and Proteomics Approaches: A major limitation of studying metabolic pathways to identify candidate genes is that you can only find those genes that are directly involved in the particular pathway being studied. A much broader approach is to conduct transcriptional profiling using DNA microarrays, in which the expression of thousands of genes (the ‘transcriptome’) is compared between animal with two different phenotypes. We have conducted preliminary studies using human DNA microarrays to compare gene expression profiles between pigs with low or high levels of steroidogenesis [30]. We are continuing this work to identify genes related to the accumulation of skatole and androstenone in pig carcasses.

In addition to transcriptome analysis, proteomic approaches examine the levels of different proteins that are expressed between animals with two extremes of a trait. This involves separation of the proteins by 2-D electrophoresis or chromatographic methods, followed by quantification of the proteins and identification by mass spectrometry. Taken together, these analyses can identify differences in the expression of genes that may be responsible for the trait of interest.

Conclusion: Boar taint due to high levels of skatole and androstenone is highly heritable and not all market weight entire males have boar taint; it should thus be possible to select for pigs which do not have boar taint. A number of candidate genes for boar taint have been identified and work is continuing to develop genetic markers for low boar taint based on SNP’s in these genes.

References
S9
Estimation of genetic parameters of boar taint; skatole and androstenone and their correlations with sexual maturation
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Abstract:
Boar taint is mainly caused by two components; skatole (3-methylindole) and androstenone. By castrating the male pigs, boar taint will be avoided. In Norway, castration of pigs will no longer be permitted after 2009. This represents a substantial cost for the Norwegian swine production. Other Norwegian studies have shown that a large proportion of pigs are above the consumer detection limits for these two chemical components. The obvious question for the geneticist arises: Is it possible to select against skatole and androstenone in a breeding programme? Skatole is produced in the gut by bacteria. It is then absorbed in the blood stream. Skatole is either metabolised in the liver or transported and stored in fatty tissue. Androstenone is produced in the testis, and its biochemical pathway is related to the pathway of testosterone. In this study, fatty tissue was collected from the carcasses of Norwegian Landrace and Duroc boars, and analysed for androstenone and skatole. The length of glandula bulbourethralis was measured on the same animals, as this is regarded as a good indicator of sexual maturation. Heritabilities of androstenone and skatole were substantial. The two components were genetically correlated. Sexual maturation was also highly heritable. However, correlations to both androstenone and skatole were significantly unfavourable.

Introduction: In order to avoid boar taint from pork products, castration of male piglets has been common practice in most countries. In recent years focus has grown on animal welfare issues related to castration in several countries. In 2003 the Norwegian parliament voted for a new law regarding castration. After August 2003 anaesthetics have to be used and only veterinarians are allowed to castrate male piglets. Further, from 2009 castration of male piglets will no longer be permitted. This law introduces a substantial cost for the Norwegian pig production. Boar taint is mainly caused by two components; androstenone and skatole. Skatole is produced in the large intestine by bacteria when metabolising tryptophan and absorbed in the blood stream. Skatole is either metabolised in the liver or transported and stored in fatty tissue. Androstenone is produced in the testis, and its biochemical pathway is related to the pathway of testosterone. An interesting question is whether the levels of androstenone and skatole in fatty tissue are heritable, and whether it is possible to reduce the levels by selection. Willeke [1] reports heritabilities of androstenone ranging from 0.25 to 0.87. Sellier et al. [2] found heritability of androstenone of 0.5. Since androstenone is biochemically related to testosterone, investigating correlations between boar taint and sexual maturation is of major interest. Testicular steroids like androgens and oestrogens, are responsible for the development of glandula bulbourethralis (GBU), an accessory sexual gland [3]. GBU is therefore often used as an indicator of sexual maturation in male pigs [2]. Sellier et al. [2] found heritability of GBU to be 0.6 and genetic correlation between androstenone in fat and GBU of 0.65.

In Norway slaughter line measurements of skatole is based on a spectrophotometric method [4] where the output includes both skatole and indole. Indole is, like skatole, a product of bacterial degradation of tryptophan [5]. It is of interest to investigate the genetic correlation between skatole and indole to see whether this spectrophotometric method can be used directly in a selection process, or whether other methods discriminating skatole and indole should be applied.

The major objective of this study was to estimate heritabilities for androstenone and skatole and their genetic correlation in the Norsvin breeding populations; Landrace and Duroc. A second objective was to estimate the genetic correlation between skatole and indole and also genetic correlations between the boar taint components and sexual maturation of boars.

Materials and methods: The data used in this study was recorded on animals at Norsvin’s boar test stations, which are a part of Norsvin’s operative breeding programme. The boars are collected from nucleus farms at 25 kg live weight and grouped 12 pigs per pen where they stay until they reach 100 kg live weight. Some boars are culled directly from these pens after test, while others are moved to an individual pen where they stay until they are out competed in the boar selection process. This change of environment may potentially influence the level of boar taint. The Landrace and Duroc boars were on average 143 and 156 days at 100 kg live weight, respectively. For both breeds the boars were slaughtered on average 14 days later. The GBU were collected on the slaughter line and the length was measured. Subcutaneous fat were collected from the neck immediately after slaughter and stored at -20°C. Androstenone levels in fat were analysed using a modified time-resolved fluorimunnoassay [6] using antiserum produced by Andresen [7]. Skatole and indole levels in fat were analysed using high-performance liquid chromatography [8].

The linear model to be used assumes normality. The distribution of androstenone, skatole and indole were skewed. Log-transforming the data reduced the problem of skeweness. Some animals had phenotypic levels below the detection limits of the chemo analytical methods used, and were recorded as zero. To avoid losing information by log-transformation the detection limits were added to all phenotypes before transformation. The detection limit is 0.05 ppm for androstenone and 0.01 ppm for skatole and indol. A summary of the phenotypes used in the analysis is presented in Tables 1 and 2.

Candidate fixed effects to be used in the variance component estimation were initially tested using the SAS Proc GLM.

Table 1 (abstract S9) Number of records, means and standard deviations for Landrace boars

<table>
<thead>
<tr>
<th>Trait</th>
<th>No.</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Androstenone</td>
<td>1728</td>
<td>1.19</td>
<td>1.10</td>
</tr>
<tr>
<td>Ln(androstenone)</td>
<td>1728</td>
<td>-0.11</td>
<td>0.72</td>
</tr>
<tr>
<td>Skatole</td>
<td>1372</td>
<td>0.10</td>
<td>0.17</td>
</tr>
<tr>
<td>Ln(skatole)</td>
<td>1372</td>
<td>-2.76</td>
<td>0.89</td>
</tr>
<tr>
<td>Indole</td>
<td>1372</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Ln(Indole)</td>
<td>1372</td>
<td>-3.23</td>
<td>0.60</td>
</tr>
<tr>
<td>Length(GBU) (cm)</td>
<td>995</td>
<td>10.89</td>
<td>1.48</td>
</tr>
</tbody>
</table>
procedure in SAS (SAS Inst., In., Cary, NC). The effects were kept in the model when significant (p > 0.10). Variance components were estimated using the DMU package, version 6, release 4.5 [9]. The following multi trait model was used for the final analysis of all four phenotypes.

\[ y = Xb + Z_1sd + Z_2u + e \]

where \( y \) is the phenotypic observations on log-transformed levels of androstenone, skatole and indole and GBU. The vector \( b \) includes the solutions of the fixed class effects herd\textsuperscript{year}\textsuperscript{season} and the effect of the boar being moved to an individual pen after 100 kg live weight. The \( b \)-vector also includes solutions of the covariates age at 25 kg live weight, days from 25 to 100 kg live weight and days from 100 kg live weight to slaughter. The vector \( sd \) is the random effect of slaughter day and \( e \) is the vector of residuals. The \( u \) vector includes the additive genetic effects. The matrices \( X, Z_1 \) and \( Z_2 \) are known incident matrices.

**Results and discussion:** Heritabilities and correlations for Landrace and Duroc are presented in table 3 and 4 respectively. All genetic variance and covariances components were significant. Androstenone levels are higher for Duroc than for Landrace. This agrees with the results of Xue et al. [10] and Squires and Lou [11]. Heritabilities of androstenone in both Landrace and Duroc were almost equally high. For skatole the level was lower in Duroc. Although skatole heritabilities in Duroc were less than half the size of the skatole heritability in Landrace, selecting against boar taint should clearly be possible if no other traits are considered. The genetic correlations between skatole and androstenone are positive. This makes selection against boar taint easier. The relatively high heritability of indole combined with the strong genetic correlation between indole and skatole shows that the spectrophotometric method for predicting skatole as the sum of skatole and indole may be a cost efficient alternative to a more costly but precise analysis of skatole. The genetic correlations between boar taint components and GBU were positive, meaning unfavourable. Selection against boar taint will therefore most probably have a negative influence on sexual maturation of the boars. With correct weightings of traits it should be possible to reduce boar taint while putting restriction on sexual maturation. However, it is important to note that this will slow down progress compared to selection against boar taint only. Sellier et al. [2] did a selection experiment where the size of GBU increased while the level of androstenone were maintained. These results indicate that a combined selection may be possible.

**References**


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**Table 2** (abstract S9) Number of records, means and standard deviations for Duroc boars

<table>
<thead>
<tr>
<th>Trait</th>
<th>No.</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Androstenone (ppm)</td>
<td>1202</td>
<td>3.27</td>
<td>2.52</td>
</tr>
<tr>
<td>Ln(androstenone)</td>
<td>1202</td>
<td>0.91</td>
<td>0.78</td>
</tr>
<tr>
<td>Skatole (ppm)</td>
<td>906</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Ln(skatole)</td>
<td>906</td>
<td>-3.40</td>
<td>0.91</td>
</tr>
<tr>
<td>Indole (ppm)</td>
<td>906</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Ln(indole)</td>
<td>906</td>
<td>-3.35</td>
<td>0.53</td>
</tr>
<tr>
<td>Length(GBU) (cm)</td>
<td>707</td>
<td>11.50</td>
<td>1.63</td>
</tr>
</tbody>
</table>

**Table 3** (abstract S9) Genetic parameters for Landrace: Heritabilities on the diagonal, genetic correlations on the upper, right triangle and slaughter day & error correlations on the lower left triangle

<table>
<thead>
<tr>
<th>Trait</th>
<th>In(A)</th>
<th>In(S)</th>
<th>In(I)</th>
<th>GBU</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(Androstenone)</td>
<td>0.54</td>
<td>0.36</td>
<td>0.49</td>
<td>0.45</td>
</tr>
<tr>
<td>ln(Skatole)</td>
<td>0.51</td>
<td>0.55</td>
<td>0.82</td>
<td>0.35</td>
</tr>
<tr>
<td>ln(Indole)</td>
<td>0.69</td>
<td>0.84</td>
<td>0.38</td>
<td>0.48</td>
</tr>
<tr>
<td>length(GBU)</td>
<td>0.49</td>
<td>0.20</td>
<td>0.50</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**Table 4** (abstract S9) Genetic parameters for Duroc: Heritabilities on the diagonal, genetic correlations on the upper, right triangle and slaughter day & error correlations on the lower left triangle

<table>
<thead>
<tr>
<th>Trait</th>
<th>In(A)</th>
<th>In(S)</th>
<th>In(I)</th>
<th>GBU</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(Androstenone)</td>
<td>0.56</td>
<td>0.62</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>ln(Skatole)</td>
<td>-0.25</td>
<td>0.23</td>
<td>0.79</td>
<td>0.57</td>
</tr>
<tr>
<td>ln(Indole)</td>
<td>-0.06</td>
<td>0.43</td>
<td>0.26</td>
<td>0.53</td>
</tr>
<tr>
<td>length(GBU)</td>
<td>0.38</td>
<td>0.04</td>
<td>-0.15</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Vaccination against GnRH: pros and cons
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Introduction: The meat of intact male pigs may exhibit odours, known as boar taint. The compounds responsible for boar taint include skatole (3-methylindole), a product of tryptophan breakdown in the gut and testicular 16-androstene steroids, mainly androstenone (3α-androst-16-en-3-one), and these compounds are accumulated in fat tissue. Active immunization against androstenone has been tried, but the effects on fat androstenone level and boar odour intensity were insufficient [1]. Other methods which have been tried in several species are pharmacological manipulations of gonadotropin releasing hormone (GnRH) activity, such as GnRH antagonists or large doses of agonists to block the activity of GnRH and thereby “switch-off” the reproductive endocrine systems. More successful method of inhibiting sexual development in young boars and boar taint is immunization against GnRH. In most experimental studies using GnRH vaccines during the eighties and early nineties several injections were required and/or severe local reactions at the site of injection were obtained due to the adjuvants (e.g. Falvo et al. [2]; Hagen et al. [3]; Bonneau et al. [4]). In this paper GnRH vaccine developed during late nineties and early twenties is presented and discussed.

Hormonal background – mechanism of a GnRH vaccine: Androstenone is produced by the Leydig cells of the testis. The production of androstenone and other testicular steroids is controlled by the neuroendocrine system, particularly by LH. LH-secretion is mainly regulated by GnRH produced by the hypothalamus. LH binds to the receptors on the surface of the Leydig cells, resulting in the induction of steroidogenic enzymes and increased levels of testicular steroids. The biosynthesis of androstenone is low in young male pigs, but increases at puberty in parallel with other testicular steroids. Measurements of GnRH and LH (rat, ram) have shown that GnRH and LH are secreted in a pulsatile manner, with a high degree of concordance between GnRH and LH pulses. The testes exert negative feedback actions on the hypothalamo-pituitary unit. The predominant site at which testicular steroids act to regulate the secretion of LH seems to be within the central nervous system, not at the level of the pituitary gland [5]. How testosterone and/or its primary metabolites act within the brain to suppress the synthesis and/or secretion of GnRH remains essentially unknown. GnRH, a small peptide (decapeptide) is released from the hypothalamus into the hypophyseal portal blood. It is produced in cell bodies of hypothalamic neurons and is transported by axonal flow to the terminal buttons, which synapse on the vessels of the primary capillary plexus within the median eminence [6, 7, 8]. Extolation of the GnRH neurons causes release of stored peptide from the secretory granules into the extracellular space, with eventual diffusion into the capillary blood. This blood then travels via the hypophyseal portal system to the sinusoidal (secondary) capillary plexus within the adenohypophysis, where a portion of the GnRH leaves the capillaries and thereby becomes available for binding to its pituitary target cells, the gonadotropes. The short distance (and time) that the GnRH travels in these vessels is where (when) it is vulnerable to be attacked by antibodies. If enough specific antibodies are present in the circulating blood entering the median eminence, then virtually all the GnRH secreted into the primary plexus is tightly bound by antibody. Binding to antibody “neutralizes” the GnRH either by preventing it from diffusing through the capillary walls (due to the complex) or by masking the receptor binding site on the GnRH molecule itself. GnRH is too small to be immunogenic. Therefore, the GnRH molecule must be conjugated to a carrier protein along with the use of an adjuvant. GnRH vaccination involves the injection of GnRH (or a modified form of the hormone, an analogue) conjugated to a foreign protein, and combined with an adjuvant, to induce anti-GnRH antibody formation. Two major factors to be considered in the development of vaccines against GnRH for commercial use in farm animal species are the adjuvant used, and the number of immunizations needed for effective immunocastration.

Vaccination of young boars with a GnRH vaccine (Improvac®): Improvac contains a modified form of GnRH (200 μg GnRH-protein conjugate/ml) in an aqueous adjuvant system. The analogue of GnRH, used in this vaccine has no hormonal effect or chemical activity [9]. The results from three vaccination studies are briefly presented here: I, Dunshea et al. [9] (Australia); II, Jaros et al. [10] (Switzerland); III, Cronin et al. [11] (Australia). In these studies the male pigs were vaccinated twice. The second dose, which is expected to elicit an immune reaction with high antibody titres against GnRH should be given no later than 4 to 5 weeks prior to slaughter, to allow any boar taint substances already present to be metabolised/eliminated.

Experimental protocol: I: Three hundred male (200 boars and 100 barrows) pigs were used in a 2 × 3 factorially arranged experiment at a commercial pig enterprise. The respective factors were sex group (castrated between 1 and 2 weeks of age; vaccinated with Improvac; placebo vaccinated) and slaughter age (23 or 26 weeks). They were allocated within sex to pens of 10 animals each. The pigs were vaccinated at 15 and 19 weeks of age, whereas pigs slaughtered at 26 weeks of age were vaccinated at 18 and 22 weeks of age. Boars were vaccinated under a double-blind study protocol. The injection sites of each pig were inspected by palpation at weekly intervals for 4 weeks. At slaughter “fighting lesions” around the neck and shoulders were recorded.

II: A total of 533 male pigs from two different breeding farms were used. After parturition, male piglets of each litter were randomly assigned to two groups, with 270 animals for immunocastration and 263 animals for surgical castration (controls) within the first 14 days of life. After weaning at 25 kg of weight, all littermates (intact males and barrows) were transported to two different farms. In the new farms pigs were kept in pen-groups of 10 animals, independent of their sex. Pigs were vaccinated twice at an interval of at least 4 to 5 weeks with the second dose being given 4 to 6 weeks prior to slaughter. The animals were slaughtered at 100–110 kg bodyweight.

III: The behaviour of group-housed, male finisher pigs was studied. Twelve groups of 15 male pigs were formed at 26 weeks of age (47 kg mean live weight). Pig behaviour was compared among groups of entire males, immuno-castrated males (treated with Improvac at 14 and 18 weeks of age) and surgically castrated males (castrated at 14 days old). A 24-hour...
time-lapse video record was made for each pen of pigs at 17 and 21 weeks of age.

Results: Antibody response and testes: In pigs treated with two doses of Improvac, an immune response against GnRH was detectable in all animals (I). The response was lower in some pigs but never below a titer of 100. The primary dose of the GnRH vaccine seemed to have had no physiological effect on testicular function as assessed by the testicular size and serum testosterone concentrations at the time of the secondary dose. However, within 2 weeks of the second vaccination, testicular growth and secretion of testosterone were suppressed. At slaughter, testes weight and bulbulo-urethral gland weight were approximately 50% lighter in the vaccinated pigs (I, II).

Androstenone and skatole in subcutaneous fat (I, II): Placebo-treated boars had fat androstenone levels almost eight times greater than those of the Improvac-treated boars, which were not different from the barrows. Placebo-vaccinated boars had fat skatole levels almost twice as high as those of the Improvac-treated boars, which were not different from the barrows.

Site reactions and carcass lesions (I): The majority of vaccinated boars showed no reaction following subcutaneous treatment (no difference between Improvac or placebo vaccination). Many of the pigs that exhibited site reactions did so at only one time point. At slaughter there were no visible site reactions in any pigs, whereas in 12 out of 192 vaccinated pigs there was a reaction that could be detected by palpation. “Fighting lesions” around the head and shoulders were recorded in 30 pigs, 26 of which belonged to the placebo group and 6 were Improvac-treated boars. They probably arose due to fighting during transport to the abattoir and/or in the overnight lairage at the abattoir prior to slaughter. No fighting scars were found among the barrows.

Efficiency of lean meat production: There were indications that the per cent of lean meat was higher in Improvac vaccinated than in surgically castrated animals.

Behaviour (III): The Improvac vaccinated pigs spent less time engaged in socio-sexual behaviour than intact male pigs after the secondary vaccination (recorded at 21 weeks of age); at this age there was no difference in socio-sexual or feeding behaviour between the Improvac vaccinated and the surgically castrated male pigs.

Advantages and disadvantages with Improvac vaccination: Advantages:
- Avoid surgical procedure of male piglets, which is associated with some pain and stress even when performed under local or general anaesthesia.
- Two vaccinations with 4 to 6 weeks interval, the last administered approximately 4 weeks before slaughter is effective in reducing the androstenone and skatole concentrations in fat to levels similar to those observed in pigs surgically castrated before 2 weeks of age. Only 3 per cent of the Improvac-treated boars and none of the barrows had fat androstenone concentrations of 0.5–1.0 μg/g fat [9]. The European Union accept a threshold level of 0.5 μg androstenone/g fat. In another study [10] only 2 out of 270 immunocastrated animals had androstenone concentrations above 0.5 μg/g fat (1.0 and 1.4 μg/g fat respectively). Those 2 animals had also high testicular weights (> 500 g). The reason for this is not clear, but may most likely be due to lack of immunological response; the antibody titer varies between individuals. Corresponding results were obtained for skatole concentrations. The few GnRH vaccinated pigs that had intermediate concentrations of either androstenone or skatole at slaughter did not have significant levels of both compounds.
- The aqueous proprietary adjuvant system of Improvac caused very little irritation at the injection site of the vaccinated pigs.
- A decrease in aggressive and sexual behaviour was observed after the secondary Improvac vaccination, as a consequence of suppression of testicular function. The decrease in “fighting lesions” exhibited after transport and lairage in the vaccinated boars is also ascribed to the reduced aggressive behaviour in these animals.
- The male pig is left intact for most of its production life, thus gaining the natural growth advantages of boars.

Disadvantages: • For effective immunization against androstenone (development of anti-GnRH antibodies) two vaccinations 4 weeks apart are required, the second given 4 to 5 weeks prior to slaughter. It is not very easy to vaccinate group-penned pigs of that weight.
- To avoid accidental self injection by operators, this product should be administered using a vaccinator which employs a needle safety shield. According to the recommendations given by the vaccine producer, “the operators should be trained in procedures for safe use of this material. Not to be used by women of child bearing age”.
- Due to individual variation in immunological response to Improvac, a few vaccinated male pigs will still have too high concentrations of androstenone in the fat. On the other hand, it also occurs that cryptorchids are sent to slaughter as barrows. Cryptorchids have taint of the same magnitude as entire males.

Recommendations: Further clinical tests under careful supervision are needed before considering the introduction of this method in Scandinavian countries. Special attention should be paid to the communication with consumers. It is very important with correct information regarding both advantages and disadvantages of Improvac to consumers and farmers.

References


S11 Sperm sorting and low-dose insemination in the pig – an update
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Introduction: During the last decade efforts have been made to develop techniques for pre-selection of the sex of the offspring. Such pre-selection may be desirable for different reasons; production of female hybrid pigs in multiplying herds or production male pigs for breeding reasons (e.g. AI boars or breeding boars). These are niche areas, and application of new techniques may therefore be done with less focus on efficiency and economy. However, pre-selection of the sex for use in commercial routine piglet (or slaughter pig) production due to banning of castration requires a different view on application of such a technique. It must be cost-effective and easy to implement in routine semen production. In addition, it must be possible to use sorted semen without having to use a sophisticated insemination technique.

This article will review the challenge concerning sperm cell sorting and low dose insemination for use in commercial pig production.

Sex sorting of sperm cells: At present time, the only means of farrowing pre-selected piglets is by sorting sperm cells according to the Beltsville Sperm Sexing Technology (BSST) [1]. This method includes a flow cytometer and a cell sorter, and the sorting is based on differences in the DNA content between X and Y chromosome bearing sperm cells. In the pig this difference is 3.6 %; the X-bearing sperm cell (“female sperm”) having the highest DNA content. This difference varies across species, and in chinchilla the difference is as high as 7.5 % while in humans is 3.6 %; the X-bearing sperm cell (“female sperm”) having the highest DNA content. This difference varies across species, and in chinchilla the difference is as high as 7.5 % while in humans only 2.8 % [2].

The sorting process includes dilution of the semen, staining the sperm cells, identifying X and Y chromosome bearing sperm cells, sorting X and Y chromosome bearing sperm cells and recovering and storage of the sorted sperm cells. There are several major challenges among these operations that have to be solved before the method can be used on a regular basis for commercial slaughter pig production.

In the flow cytometer, laser light is used to illuminate stained sperm cells as they pass through a laser beam, one at a time, in a fine fluid stream. A critical part of the process is to ensure a uniform staining intensity within the cell population. Variation in the staining intensity will reduce the efficiency in separating the cell populations significantly.

Light scattered by the cells and light emitted by the fluorescent dye are analysed by several detectors and processed by a computer. The X and Y bearing sperm cells are distinguished on the basis of the DNA content. Since the head of the sperm cell is paddle shaped, the cells must be oriented with the flat side against the laser beam. Two laser beams (0’ and 90’) and a special needle are used so that when the fluid stream containing the sperm cells pass the laser beam, a high proportion of the cells will be facing the beam in the proper plane. The efficiency in distinguishing the two populations is depending on that a high proportion of the sperm cells are oriented in the proper way.

After passing the laser beam, the X and Y chromosome bearing sperm cells are given different charge and the cells are sorted as they pass between two continuously charged plates. The sperm cells are sorted in three populations: X chromosome bearing sperm cells, Y chromosome bearing sperm cells and waste (non-sorted sperm cells). The challenge in this operation is to reduce the waste, by enhancing proportion of sorted cells.

During sorting, the sperm cells are highly diluted. Once sorting is terminated, the sperm cells must be centrifuged (300 × g) to increase the density. The density will vary depending on the method selected for use of the sorted sperm cells. This process affects the viability of the sperm cells and it has been shown that the fertilising ability of sorted sperm cells is beginning to decrease at 5 hrs of storage [3]. It is therefore necessary to deposit sorted semen as close as possible to the ovulation time and the site of fertilisation. Premature capacitation of sorted sperm cells is one of the changes that shortens the viable lifespan for in vivo insemination.

Concerns have been raised whether exposure to the dye (Hoechst 33342) and the laser beam might damage the DNA. However, there seems not to be any higher proportion of abnormalities among offspring from sorted sperm cells compared to not sorted sperm cells. Furthermore, the mutagenic effect has been investigated without evidence of any negative effect on offsprings from stained sorted sperm cells [4].

State of the art from a practical point of view: To be used in commercial semen production, the speed of the sorting as well as the purity of the sorted sperm cells are crucial. The purity (efficiency of the sorting) will largely depend on the speed, making these two elements contradictory; the higher the speed, the lower the purity of sorted sperm cells. The present technology makes it possible to sort 15 million sperm cells per hour [1]. Although deep intrauterine insemination may reduce the number of sperm cells required for fertilisation significantly, the number is still too large to be considered for practical conditions.

Other methods for sex sorting of sperm cells have been discussed, and the focus has mostly been towards a possible difference in surface proteins between X and Y chromosome bearing sperm cells. If so, one could produce an antibody to attach to the X or Y chromosome bearing sperm cells and then use magnetic beads to separate the two populations. This method could provide a large scale separation process easily.
adaptable to AI centres. Approximately 1000 surface proteins have been mapped but no difference has been detected between proteins isolated from X versus Y chromosome bearing sperm cells [5, 6].

Low dose insemination in the pig: Optimum fertilisation rate is depending on several factors; the interval between insemination and ovulation, the quality of the sperm cells, the life span of the sperm cells in utero and the site of deposition of the sperm cells. Traditional artificial insemination in the pig is carried out using 2.5 – 4 billion sperm cells deposited in the posterior part of cervix uteri. Only a very small proportion of the sperm cells reaches the site of fertilisation (the oviduct) due to a combination of loss through back flow and phagocytosis of sperm cells by polymorphonuclear leukocytes. It has, however, been shown that acceptable fertility can be achieved by deposition of only 10 million sperm at the uterotubal junction by using surgical insemination close to ovulation [7]. Surgical insemination can not be used in commercial farms, and during the last 5–7 years efforts have been made to develop new devices to be able to deposit the semen either in the uterine body or deep in the uterine horns. The main obstacles are the cervical folds in cervix uteri and the long uterine horns (up to 1.5 meters). However, two new procedures for deposition of the semen cranial for the cervix have been developed; post cervical insemination and deep intrauterine insemination.

Post cervical insemination: By post cervical insemination, the semen is deposited in the uterine body, just cranial for the cervix. Several different (commercial) catheters are available, and the aim is to reduce the number of sperm cells. The method may be used on a regular basis in commercial herds, and it has been shown that it is possible to reduce the number of sperm cells from 3 to 1 billion without compromising the fertility [8]. However, for use in combination with sorted semen this technique requires too many sperm cells.

Deep intrauterine insemination: Deep intrauterine insemination requires a long flexible catheter to pass the cervix and enter the uterine horns. It has been reported that it is possible to deposit semen close to the uterotubal junction with a 20-fold reduction of the number of sperm cells without affecting farrowing rate or litter size [9]. However, by reducing the number of sperm cells further it seems like the litter size is compromised although pregnancy and farrowing rates are not affected compared to traditional AI with ~3 billion sperm cells [10, 11].

Conclusion: In conclusion: It is possible to sort sperm cells in X and Y chromosome bearing populations. The only method proven is the Beltsville Sperm Sexing Technology which uses a flow cytometer and a cell sorter. The sorting speed is at present approximately 15 million cells per hour. To be able to use sex-sorted semen in commercial pig production the number of sperm cells per insemination must be reduced tremendously. None of the newly developed technologies makes it possible to reduce the number of sperm cells inseminated to such an extent that sorted semen may be used.

The major challenge in sex sorting boar spermatozoa is to increase the speed of BSST-sorting or to develop new technologies. Furthermore, the damage caused by the sorting must be reduced, the storage time for sorted sperm cells must be increased and the waste (non-sorted population) must be reduced.
According to public opinion and animal welfare organisations, be performed under anaesthesia. Due to economical priorities and lack of suitable methods, the animal welfare legislation in most European countries allows castration up to seven days of age without anaesthesia. Castrations are performed by a “competent person” (citation Swiss legislation) on awake, non anaesthetized animals. The predominant method of castration is surgical incision of the scrotum to reveal the testes which are then removed by tearing, cutting or twisting. Castration is justified on the grounds that it improves the animal’s overall welfare and the economic benefits outweigh the welfare costs. Castration is performed to increase meat quality by avoiding boar taint, indiscriminate breeding and to maintain general control of stock.

The current situation is not satisfactory from an animal welfare perspective and there is increasing consumer sensitivity toward ethical aspects of food animal production. The increasing knowledge of pain perception in newborn individuals [1] has to be considered as well. It was initially concluded, based on early studies of neurologic development, that neonatal responses to painful stimuli were decorticate in nature and that perception or localisation of pain was not present. The International Association for the Study of Pain defines pain as an unpleasant sensory and emotional experience associated with an actual or potential tissue damage, however, the evaluation of pain in animals is very difficult because pain is generally defined as a subjective phenomenon.

The density of nociceptive nerve endings in the testis and the scrotum of the piglets is assumed to be similar to other species. They are stimulated by mechanical, thermal or chemical stimuli produced by castration. Both the enkephalinergic and the endorphinergic systems may modulate pain transmission at spinal and supraspinal levels. Experiments carried out in piglets produced by castration. The predominant method of castration is surgical incision of the scrotum to reveal the testes which are then removed by tearing, cutting or twisting. Castration is justified on the grounds that it improves the animal’s overall welfare and the economic benefits outweigh the welfare costs. Castration is performed to increase meat quality by avoiding boar taint, indiscriminate breeding and to maintain general control of stock.

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Taylor and Weary [14] recorded vocalisation in piglets during castration and demonstrated that piglets call at a higher frequency during the procedure, especially during cutting of the spermatic cord. Castration has negative effects on behaviour and weight gain. Castration leads to reduced suckling, reduced standing and increased lying times. However if castration occurred at the age of 14 days, the piglets were heavier at weaning with a higher weight gain during lactation compared to castration at one day of age [6].

The directive 2001/93/EC states, that “if castration is practiced after the seventh day of life, it shall only be performed under anaesthetic and additional prolonged analgesia by a veterinarian”.

Surgical castration can be either performed under general or local anesthesia. The choice of method should result in a significant reduction or elimination of pain and stress for the piglets.

Additionally, the following conditions should be met:
- short induction and recovery periods
- acceptable costs
- no negative ecological impact
- no residuals
- the method should be easy to perform
- large therapeutic range of used drugs

In the EU veterinarians treating food-producing animals have limited access to a number of anaesthetics which could be suitable for anaesthetizing piglets. Drugs used in these animals are subjected to the MRL regulation, which means they can only be used if maximum residue levels have been established for the specific drugs (Annex I) or that the drugs are not subject to these limits (Annex II) in this particular species.

Although some efforts have been made in a search for an adequate anaesthetic regimen for painfree castration, the drugs used rarely have this MRL tag. Injectable anaesthetics have been used in some studies but the prolonged induction and recovery periods remain a problem. Waldmann [5] and his group performed a study including tiletamin/zolazepam, thiopentone and propofol in piglets 4 to 13 days of age. They demonstrated that tiletamin/zolazepam (10 mg/kg) intramuscularly and propofol intraabdominally (4 mg/kg) did not produce enough relaxation and anaesthetic depth and piglets experienced a long and difficult recovery. Thiopentone intraabdominally (30 mg/kg) produced good anaesthesia but the death rate was 9.5% due to crushing of the piglet by the sow.

McGlone and colleagues [2] studied the effect of the combination of ketamine, xylazine and guaifenesin given intravenously in two and seven week old piglets. The death rate of the two week old animals was very high (five of eighteen animals) and the recovery period of the surviving animals was very long. Pain killers (NSAID’s and butorphanol) given 30 minutes before castration in eight week old piglets showed no beneficial effect in the postoperative period [6].

Inhalation anaesthesia was suggested to give better results because of the speed of induction and the fast recovery. Carbon dioxide (CO2), applied in different concentrations with oxygen was studied by Lauer [15], Körtel [11], Kohler et al. [10], Steenblock [16] and Thurmon et al. [17]. The authors describe a very fast induction and a complete analgesia for a short intervention together with a fast recovery. Unwanted side effects consisted of hyperventilation and agitation during induction and gasing during castration. These findings, together with increased stress hormone levels, have made this method questionable [10].

Inhalation of 5% halothane, applied by a simple mask in oxygen through a simple breathing system induced anaesthesia within two minutes, together with an uneventful recovery and the method seemed to fulfil the main requirements for a painfree castration [18]. In a field study, evaluating time and costs, the method has proven to be suitable for routine castration of piglets up to two weeks of age [19]. The time required for castration under anaesthesia was one minute longer per piglet (2.3 min vs 1.3 min/piglet) compared to castration without...
anaesthesia and costs were considerably higher. Discussion with representatives of the pork industry revealed strong opposition against this technique due to the health hazards of exposed personnel, complicated technical instruments and high costs. Shortly afterwards halothane was withdrawn from the European market.

The study was therefore repeated with isoflurane (iso) and isoflurane/N2O (iso/N2O) in 85 piglets [20]. This method was shown to be fast, safe and practical. The study included involvement of the Swiss Office of Secure Working Environments (SECO) and a special mask was developed. It consisted of a double mask, applying the anaesthetic gas in the inner mask with any leaks scavenged by means of a pump. Pollution could thus be reduced to a minimum. The mask was also equipped with a valve to allow gas flow only when in contact with the animals snout. Induction of anaesthesia proved to be smooth and the palpebral reflex disappeared within 36.5 seconds in the iso/N20 group and within 51 seconds in the iso group. Anaesthesia and analgesia were sufficient (mean total anaesthesia time 128 (30–390) seconds in the iso group; 123 (70–220) seconds in the iso/N2O group). The method was very safe and no deaths occurred. Beta-endorphin and ACTH were measured but did not show any significant differences between groups and therefore the measurements may have been performed too early to identify any differences between groups (anesthetized and non-anesthetized).

An ongoing study in the University of Bern compares intramuscular vs. intranasal administration of ketamine, azaperone and climazolam and preliminary results indicate that both routes produce a good and safe anaesthesia with short recoveries [21]. Intranasal application of anaesthetics in children has proved to be easily performed and very effective [22]. The study will continue to determine stress hormone levels and behaviour observation.

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S13

Local anaesthesia for pigs subject to castration
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Introduction: The legislation in Norway requires that anaesthesia and analgesia must be used when piglets are castrated. The procedure must also be performed by a qualified veterinarian [1]. Since anaesthesia became mandatory in 2002, the injection of the local anaesthetic lidocaine into the testicle has been the preferred anaesthetic method among veterinary practitioners in Norway [2]. The method has been controversial as it has been claimed that the injection in itself was as painful as the castration procedure and that the local anaesthesia did not produce sufficient anaesthesia for surgical castration. This presentation will focus on the published work where the effect of local anaesthesia on piglets during castration was studied.

Pharmacology of local anaesthetics: Local anaesthetics block the initiation and propagation of action potentials in nerve cells by preventing the voltage-dependent increase in Na⁺ conductance. Chemically, local anaesthesia molecules consist of an aromatic part linked by an amide or ester bond to a basic side chain. The ester containing compounds, e.g. procaine, are inactivated by plasma and tissue esterases. The amides are more stable, and these drugs, e.g. lidocaine, have longer half-lives and duration of effects. The addition of a vasoconstrictor such as adrenaline prolongs the effects and reduces the systemic absorption rate, thereby reducing the risks of systemic toxicity [3].

Procaine has been assessed by the European Medicines Agency (EMEA) as a local anaesthetic which can be used without an established maximum residue limit (MRL) in production animals. Procaine was previously widely used, but has been replaced by other local anaesthetics such as lidocaine, which has a faster onset and longer duration. In addition, lidocaine causes fewer side-effects and spreads more easily in the tissues. Lidocaine has been placed in Annex II for horses by the EMEA. Used in other production animals, the withdrawal time for meat and milk are therefore 28 and 7 days, respectively [4].

Effects of local anaesthetics in piglets subject to castration: Research on the effects of castration and various anaesthetic techniques in piglets has been published since the late 1980’s. McGlone and Hellmann found that local anaesthetics restored nursing activity and maintenance behaviors such as lying and nursing of castrated 10- to 14-day old piglets to the level of uncastrated, unanaesthetized pigs. This effect was not evident in 7-week old pigs [5]. In another experiment, McGlone et al. did not find that the analgesics butorphanol or aspirin affected behaviors after castration without local anaesthesia in 8-week old pigs [6]. It is well known that pigs express their discomfort through vocalization. White et al found that pigs castrated without local anaesthesia had an increased heart rate and gave more high energy frequency (HEF) calls than pigs not given an anaesthetic irrespective of age at castration [7]. A few studies have also been conducted where the different procedural sources of pain have been described. The cutting and severing of the spermatic cord seems to be the procedure which induces the most consistent alterations in behaviors such as vocalization [8, 9]. Noxious stimuli induce expression of the protein c-Fos in neurons in the dorsal horn.

In a study published by Nyborg et al. the expression of c-Fos positive neurons in the dorsal horn of the spinal cord was compared in pigs castrated with or without local anaesthesia. In unanaesthetized pigs the numbers of c-Fos positive neurons were significantly higher than in pigs which received local anaesthesia intrafunicularly [10]. Most of these studies revealed that castration is a painful procedure in piglets, regardless of age, which induces both physiological and behavioral alterations in the animals. However, these studies did not address to what extent the administration of local anaesthetics in itself was stressful or painful for the piglets or whether administration intratesticulary or into the spermatic cord gives better analgesic effect. In addition, it would be of interest to determine to which extent the local anaesthetic reduces physiological responses induced by nociceptive/surgical stimuli, and to study the distribution of the local anaesthesia when injected into the testicle, as it was claimed that such administration would not result in sufficient concentrations in the spermatic cord where the greatest effect was needed. Therefore two studies were performed at the Norwegian College of Veterinary Medicine.

In the first study the aim was to evaluate the analgesic effect of intratesticular or intrafunicular lidocaine for the surgical castration of piglets. It was of particular interest to investigate the degree of nociception induced by the lidocaine injection in the tissues. Anaesthesia was induced and maintained using halothane, during anaesthesia mean arterial pressure (MAP), pulse rate and electroencephalography (EEG) were monitored. Lidocaine with adrenaline was injected into the testicle (n = 16) or into the spermatic cord (n = 15). The control group (n = 16) did not receive local anaesthesia. During castration, MAP increased significantly, while pulse rate and EEG theta power fell significantly more in the control group, compared to groups in which pigs received lidocaine into the testicle or into the spermatic cord. The blood pressure response to castration was significantly larger in the control group than the response to lidocaine injection in the treatment groups (Fig. 1a,b) [11], indicating that the injection of lidocaine is less painful than castration without local anaesthesia. No difference was found in analgesic effect between intratesticular injection and injection into the spermatic cord.

To study the distribution of lidocaine administered intratesticularly, radiolabelled lidocaine with adrenaline was injected into the testicles and subcutaneously (SC) in the scrotum of 12 piglets [12]. The animals were euthanized at 3, 10, 20 and 40 minutes, respectively, after the injection. The testicles and spermatic cords were immediately removed and frozen. Autoradiograms were subsequently produced and tissue was subjected to liquid scintillation counting to quantify the amount of radioactivity within the different structures.
Quantification of radioactivity in the spermatic cord and testicle showed that the highest concentration of radiolabelled lidocaine was found in the spermatic cord 3 minutes after the injection into the testicle. Autoradiograms produced in this study verified that lidocaine injected into the testicle was transported rapidly into the spermatic cord. The autoradiograms also showed that...
lidocaine does not readily diffuse through the tunica vaginalis and into the cremaster muscle (Fig. 2). This might explain the nociceptive response which is elicited during the castration procedure performed under local anaesthesia, as this procedure also involve the cutting and/or tearing of the cremaster muscle. **Conclusion:** Injection of local anaesthesia into the testicle before castration in piglets reduces the physiological and behavioral responses associated with the surgical stimulus. Although these responses are not completely abolished, it is reasonable to assume that local anaesthesia improves animal welfare for piglets subject to castration.

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three, indole is known to be the less offensive to the human nose. The smell of skatole is described as faecal while the smell of androstenone is described as urinous. Only a fraction of the consumers are capable of smelling androstenone, as this ability is hereditary [5].

Till now, to the knowledge of this author, the only real time, full scale sorting “experiment” conducted under industrial conditions, i.e. directly in an abattoir environment, was carried out in Denmark. A wide variety of minor experiments, all based on laboratory methods for detecting the compounds of interest, have indeed taken place, but none of these come close to being on- or at-line methods. Consequently, a major part of the following discussion is concerned with Danish experience.

Discussion: Before getting too involved in analytical procedures for detecting “boar taint” compounds, it appears reasonable to look into different sorting scenarios and their consequences. These will be focussed on the two compounds of most significance, skatole and androstenone, as very little has been disclosed on the levels of indole in uncastrated, male carcasses.

Three scenarios come to mind:

1. Sorting based on skatole
2. Sorting based on androstenone
3. Sorting based on both skatole and androstenone.

With regard to the first, Danish experience has suggested that a range of sorting limits for “skatole equivalents” may be used, and that “skatole equivalents” have a correlation to a trained sensoric panel of 0.76 thus explaining 58% of the variation (see note 1) [3]. If 0.20 ppm of “skatole equivalents” in backfat is used as a sorting criterion, the occurrence of falsely accepted carcasses, i.e. carcasses that possess a deviating smell although accepted from an analytical point of view, is 0.8% as determined by the sensoric panel. 6.0% of the carcasses would be rejected.

If, on the other hand, a somewhat higher level of 0.25 ppm of “skatole equivalents” is utilized, the occurrence of falsely accepted carcasses increases to 1.2% while only 4.3% is rejected. Androstenone content by itself explains 24% of the variance [3], and sorting based on androstenone with a sorting limit of 0.50 ppm in the backfat as proposed by Desmoulin et al. [6] yields the following result on Danish uncastrated male pigs: 1.2% of the carcasses are falsely accepted, which incidentally is identical to the situation with a 0.25 ppm “skatole equivalents” limit; however, the number of rejected carcasses increases to 48%!!

By combining the analytical results of “skatole equivalents” and androstenone 66% of the total variation can be explained. The best combination of the two sets of results will falsely accept 0.4% of the carcasses and reject 8.7%. Interestingly, in a consumer study carried out on the Danish population of uncastrated male pigs androstenone contents did not appear to have a negative impact on the odour/flavour of the meat at “skatole equivalents” below 0.15 ppm. For higher “skatole equivalents” levels the importance of androstenone became noticeable [7]. This means that “skatole equivalents” is a more effective sorting parameter compared to androstenone. However, an effect of both “skatole equivalents” and androstenone on the consumer evaluation appears at extreme values of androstenone (i.e. > 1.5 ppm) as the content of “skatole equivalents” approaches 0.25 ppm. Such a situation appears in less than 1% of the Danish population of entire males [7]. The Danish at-line system for analysis of “skatole equivalents” in backfat from male pigs is based on colourimetry [8]. In the very beginning it started as a laboratory method, which through a series of steps was finally developed into a fully automated analysis robot for use in abattoirs.

In the industrial version the robot has a nominal capacity of 200 samples per hour, of which 20 are used for quality control samples in the form of both liquid standard solutions and fat samples with known contents of analyte. The robot is very accurate and precise, and has built-in alarms for poor performance. Backfat samples are taken from the uncastrated male pigs early on the slaughter line. The time for each individual analysis is approximately 20 minutes, which means that the result is available when the carcass leaves the chilling tunnel at the end of the slaughter line. Carcasses with a content of “skatole equivalents” above the sorting limit (0.20 or 0.25 ppm) are marked accordingly and kept separate from the other carcasses.

In the 1990’s, 17 such robots were installed in Danish abattoirs and a production of uncastrated male pigs took place. In 1993 the number of analyses carried out peaked at around 100,000 per week, but since then the production has almost stopped due to negative reactions to the meat from parts of the international market. These reactions, as far as could be ascertained, arose mostly from the mere fact that the meat originated from male pigs; not because of the presence of any off odours or flavours. HAVING STATED previously that no other on- or at-line equipment for identifying tainted carcasses from uncastrated male pigs exists, it appears worthwhile to take a look in the crystal ball to find out what the future has in store with regard to boar taint analysis.

Before doing this, however, it must again be mentioned that several successful attempts were made in the last century to develop new analytical methods for either skatole or androstenone contents in uncastrated male pigs, and in a few cases even methods enabling simultaneous determination of both compounds were published and being utilized [9]. They were almost exclusively based on extensive sample pretreatments before detection by means of colourimetry [10], RIA/ELISA [11,12] or chromatographic techniques [13], and although some effort was invested in bringing them from the laboratory to the slaughter line they were never fully implemented.

A number of recent and current attempts are concentrated on technologies that are not dependent on complicated, labour intensive and tedious pretreatment of the fat samples before the actual analysis. (To the mind of the present author this is the only viable way forward.)

The rationale behind such a strategy is obvious: analysis time is minimized, and simultaneous determination of the compounds of interest, – or indeed the direct determination of “odour” or “taint” intensity without quantitation of the compounds responsible for it, – are in principle within the realm of reality. Different kinds of spectroscopies, such as infrared (IR), near infrared (NIR) or photo-acoustic spectroscopy (PAS), have been proposed and/or attempted; either directly on a fat sample, or on the vapour (head space) above a heated fat sample. Further, promising results were obtained with a number of different “noses”, i.e. detectors or arrays of detectors sensitive to molecules in the gas phase above a heated fat sample or originating from the pyrolysis of a fat sample. (Unpublished results presented at the “Workshop on Boar detection Methods” Ås, Norway, 21–22 October 2004).

In conclusion, however, although the area has gained enormously in interest during the latest years and many results were...
achieved with modern and sophisticated technologies, the real break-through is still missing. In other words the only example of a procedure able to discriminate between tainted and untainted carcasses from uncastrated male pigs in an abattoir environment is the somewhat belated Danish one.

Note: The colourimetric method used previously in Denmark was not designed for determination of only skatole, but was optimized for detection of tainted carcasses using a trained sensoric panel as criterion. It was shown that indole contributes to the odour/flavour of meat from uncastrated carcasses, and the method measures both skatole and indole in the best combination according to the sensoric panel. The results from the method are referred to as “skatole equivalents”; skatole was used as an adequate compound for calibration of the method.

References

S15

The use of chemical sensor array technology, the electronic nose, for detection of boar taint
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Introduction: Boar taint represents a complex issue related to a few key odour compounds present in pork meat. Studies have indicated that the substances skatole and androstenone contribute most to the sensory perception of boar odour and flavour, but also other substances have been suggested to play a role in the overall perception of boar taint. Analysis of off-odours and flavour in meat and meat products has traditionally been performed either by a trained sensory panel or by headspace gas chromatography mass spectrometry. In some cases, sensory assessment may fail in identifying boar taint represented by the chemical compounds androstenone and skatole. This may be due to anosmia, low odour thresholds to these compounds or misclassification due to other interfering off-odour compounds not related to boar taint (i.e. rancidity). The mentioned methods for detecting boar taint are time consuming and costly and it would therefore be useful to have objective rapid methods in order to sort out the boars on the slaughter line based on both chemical and sensory criteria. New methods should allow a high number of samples to be analysed within a short period of time with a sufficient reproducibility and accuracy.

Recently, there has been a rapid development of chemical sensor technology for analysis of volatile compounds. Chemical sensor arrays combined with multivariate data processing methods have demonstrated to have a potential for rapid non-destructive analysis of meat quality [1, 2]. Non-specific gas-sensor arrays have the potential of detecting several compounds in the vapour phase related to boar taint. Accordingly, this could allow the measurement of the odour of the meat instead of analysing the specific compounds that might be responsible for boar taint. This technique cannot completely replace reference methods like the use of sensory panels, as the technique requires training and calibration against sensory analysis or some valid reference method.

Commercially available gas-sensor devices cover a variety of chemical sensing principles, system design and data analysis techniques. Gas-sensors are based on physical or chemical adsorption and desorption, optical adsorption or chemical reactions of an analyte in the gas phase that take place on the surface and/or in the bulk of the sensor material. These interactions cause characteristic physical changes of the sensor to be detected. A series of different transducing principles can be used in chemical gas sensors: heat generation, conductivity, electrical polarisation, electrochemical activity, ionisation, optical properties, dielectric properties and magnetic properties. Gas-sensor technology has been suggested as a potential technology for future on-line use in sorting of boar-tainted carcasses on the slaughter-line. In recent years there have been reported several attempts to apply gas-sensor technology for
the detection of boar-taint. The research in this field comprise limited feasibility studies analyzing pure lipid phases (oils and fats) spiked with pure androstenone and skatole and mixtures of both at different concentration levels and real backfat samples from boars with different levels of skatole and androstenone. A brief state of the art presentation of reported feasibility trials will be given and a discussion on the issues and challenges related to the development of a dedicated gas sensor technology for on-line detection of boar-taint at the slaughter line.

**Discussion:** Berdague and Talou [3] analysed backfat samples from female, castrate, and entire male pigs with a prototype solid state based gas-sensor (MOS) array system after heating the samples. The measurements showed different gas-sensor signal profiles for the different sexes and they were able to discriminate the boar samples from the females and castrates. In another study with solid state based gas sensors [4], backfat from entire male pigs with 105 kg slaughter weight ranging from 0.1–15 µg/g androstenone was measured. 2–3 gram sample was heated at 150°C for 30 seconds in a 2.5 l flask and 50 ml gas volume was analysed. A correlation of r = 0.9 between the sensor readings and androstenone levels was obtained. By selecting two classes on the basis of androstenone content, <0.7 and >1.7 µg/g, they obtained 85 % classification rate. Annor-Frempong et al. [5] applied a commercial 12-conducting polymer-sensor array on the measurement of pure lipid samples spiked with different levels of skatole and androstenone and entire male backfat samples. In addition the samples were assessed for extent of boar tainted odour by a trained sensory panel. Fat samples from Large White crossbred male pigs (68–105 kg slaughter weight) were used. The responses of the gas-sensor array showed a significant canonical correlation with the sensory panel (r = 0.78). In addition, the sensor system was able to discriminate pork samples with low (<0.2 skatol and < 0.5 androstenone), intermediate (<0.2 skatole and <1.0 androstenone) and high (>0.2 skatole and > 1.0 androstenone) levels of androstenone and skatole. In another study [6], using a commercial conducting organic polymer sensor array, it could also be shown that the sensor system could discriminate between belly fat from female, castrate and entire male pigs 70–110 kg in slaughter weight. The samples varied from 0.2–2.8 µg/g in androstenone and 0.03–0.7 µg/g in skatole content. 20 gram of fat was kept in 600 ml flasks and incubated for 7 minutes at 30°C before purging headspace gas into the sensor chamber. In this study, they were able to discriminate samples with different levels of boar taint with regard to low and high levels of respectively skatole and androstenone.

In a Norwegian study, the incidence of boar-taint in young boars, 34–45 kg in slaughter weight, was investigated [7]. A hybrid commercial solid state gas-sensor array system with MOSFET and MOS type sensors was used. 5 gram backfat samples varying from 0.06–0.8 µg/g in skatole and 0.02–3.3 µg/g in androstenone were incubated for 30 minutes at 65°C in 30 ml vials before the gas measurement. The sensor readings showed a significant correlation, r = 0.7, with androstenone levels and r = 0.5 with skatole. However, low correlation was obtained with the sensory scores of respectively boar odour and boar flavour. In a recent study a prototype of four different porphyrine coated quartz resonator sensors (QMB) have been used to detect skatolone in pork fat [8]. The sensor system was tested on pork fat samples spiked with various concentrations of androstenone ranging from 0.7 to 10 µg/g. Samples were prepared in sealed vials and incubated at 35°C for 30 minutes followed by extraction of sample headspace gas into the sensor chamber. The difference in sensor signals of the androstenone spiked fat and pure pork fat showed high non-linear correlation with androstenone concentrations for the single sensors. By using the sensor signal of all four sensors, they obtained a correlation of r = 0.98 with androstenone concentration. It was also demonstrated that the sensor system was able to discriminate the samples with different levels of androstenone. In another recent study by Vestergaard et al. [15] backfat samples from young boars [9] were analysed by using a commercial ion mobility spectrometer in combination with a MOS gas sensor (MGD-1, Environics Ltd., Finland). The male pig samples varied in androstenone and skatole levels (0.09–0.88 µg/g and 0.01–0.26 µg/g fat, respectively). Sensory perceptible boar taint (especially boar odour) was found to be more related to androstenone than to skatole. Multivariate models implementing some generally prescribed cut-off limits for androstenone (0.50 µg/g) and skatole (0.21 µg/g) indicated that the e-nose could be used for categorising samples with respect to these cut-off limits. E-nose data were good predictors of the chemical compounds androstenone (r = 0.97) and skatole (r = 0.79). The high correlation found for androstenone with gas-sensor data may not necessarily imply that the sensors are sensitive enough to detect this compound specifically in the vapour phase of real fat samples, since there will also be other major volatile compounds present in the gas phase. The same will be the situation in the case of skatole. The high correlation found between androstenone and the gas sensor readings, rather indicates that there may be other major compounds present in the gas phase that may be highly correlated to androstenone. Accordingly, this could possibly be used as an indirect way of measuring androstenone levels and boar-taint. It has been demonstrated in other studies that androstenone is highly correlated to a few major volatile compounds [10, 11]. It has been questioned whether other volatile compounds also may contribute to the sensory perception of boar-taint. It is therefore still a need for more detailed GC/MS analyses of fat from boars with varying levels of skatole and androstenone to obtain a deeper insight in the chemical composition of the volatile compounds related to boar taint. A complete characterisation of the profile of volatile compounds in boar fat would be very useful to reveal possible marker compounds correlated to boar taint. This could also be a fruitful basis for the development of a dedicated gas-sensor system for the detection of boar taint.

Sampling is a crucial issue related to gas-sensor technology. The substances to be measured in the vapour phase, skatole and androstenone, are lipophilic compounds with a relative high molecular weight compared to other odour active compounds. Due to their low volatility, boiling points above 250°C, and their presence at low concentration in pork fat tissue, only small fractions (0.1–1%) may be present in the vapour phase. Direct sampling at ambient temperatures will therefore not be sufficient to allow the detection of these compounds due to the limited sensitivity of gas-sensors. In order to enhance the sensitivity, other sampling approaches will be required. Heating of the pork fat or applying enrichment techniques (purge and trap) using adsorbents combined with heating of the fat would be a more appropriate way of gas sampling for the application of boar taint.
[12, 13]. However, by heating of fat, also other volatile compounds present in the fat may be released, which may interfere with skatole and androstenone. In particular, volatile secondary lipid oxidation products may be generated at high levels in the vapour phase. This may partly be overcome by applying oxygen free conditions during heating and sampling. Due to limited specificity of gas-sensors, recent research and development has combined separation techniques like gas chromatography with gas-sensing devices, using gas-sensors as GC detectors. These micro-machined GCs’ allow the detection of single volatile compounds within 10–60 seconds. In particular, uncoated surface acoustic wave (SAW) sensors have been used for this purpose [14]. The use of this technology in combination with gas enrichment techniques could also have a potential for future on-line detection of boar taint.

Conclusion: The results from the reported feasibility studies show significant correlation between the sensor signals and levels of skatole and androstenone and sensory attributes related to boar odour and flavour. The results suggest that gas-sensor technology may have a potential for future rapid sorting of boars at the slaughter line. However, there is still a need for research and development in this field in order to end up with a successful application. The studies so far represent limited laboratory trials, and the existing gas-sensor systems do not fulfill the software and hardware specifications required for on-line implementation. In particular, this applies for the gas sampling, which is a key issue. Coming up with an automated on-line system based on gas-sensor technology would require the development of a tailor-made dedicated sensor system including optimized gas-sampling unit, sensor module, signal processing and alarm system. The system could be calibrated either with respect to the chemical substances related to boar odour/ flavour or sensory perception. In the latter case, this would not necessarily imply the need for a skatole and androstenone specific sensor array, since also other possible compounds may be involved in the sensory perception of boar-taint, but rather a broad-selectivity sensor array that matches the sensory perception of boar taint.

References

S16
The Norwegian Research Programme for Entire Male Pig Production
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Background: Until 2002, castration of male piglets in Norway was routinely performed, mainly by the pig producers themselves, without any requirements for anaesthesia or analgesia. The only restriction was that the piglets should not be older than 28 days. In 2002 the Norwegian Parliament passed a law, prohibiting castration of piglets from 2009. At the same time it was decided that until 2009, the castration of piglets in Norway should be performed only by veterinarians, and that use of anaesthesia should be mandatory. The argument for the decisions was animal welfare. The meat industry, and the pig
breeding association Norsvin, have co-operated with the research institutions and the Research Council of Norway to establish a research programme for entire male pig production. The main aim of the programme is to ensure that the ban on castration can be accomplished without large negative consequences for the industry and the pig producers, and that the consumers after 2009 still will be offered high quality pork without boar taint.

**Economical consequences:** The economical consequences of the decision are difficult to estimate because the percentage of tainted carcasses that will have to be sorted out at the slaughter line when castration is prohibited, is unknown. Former estimates have been that 30 – 40% of the male carcasses will have too high levels of androstenone and/or skatole. Recent results from a project at the Norwegian Meat Research Centre indicate that the numbers might be even higher. It has been calculated that the yearly loss for the pig producers will be 1.2 mill Euro for each percentage sorted out, which corresponds to 1 Euro/slaughtered pig. In addition there will be costs for detection assays and increased costs at the slaughterhouses. Lost market shares for the pork industry because of consumer complaints, is also a likely consequence if tainted meat reaches the consumers. The costs of this could be considerable, but are difficult to estimate.

**National priorities:** In 2003, a report was written as a basis for the research programme (in Norwegian). In the report recommendations were given for national priorities within the programme. The necessity of reducing the percentage of tainted carcasses, as well as developing on-line methods for detection, and solutions on how to use tainted meat was emphasised. In a long-term view, genetic research and selective breeding is probably the best way to control the levels of androstenone and skatole. Such research is done on a national population level, and any progress will benefit all pig producers in Norway. However, research on genetics is time consuming, and other approaches with a potential of more rapid progress are also required. With regard to skatole, feeding regimes, in particular special feeding regimes in the last weeks before slaughter, seem to have such potential. There is consensus in Norway that both skatole and androstenone levels in the carcasses need to be below certain limits. The cut-off limits, however, are not yet decided, because we still know too little about the Norwegian consumers’ perception of boar taint. Because there already exists an on-line method for skatole, research within detection will focus on on-line methods for androstenone or on-line methods that measure both androstenone and skatole (and possibly also other compounds).

Immunocastration and sex separation of semen are potential ways to reduce the necessity for castration. These fields are not given priority in the research programme. For sex separation of semen, the probability of successful research within 2009 was regarded as low. Immunocastration on the other hand is a method that is already shown to be effective. There is, however, uncertainty about the approval of the method in Europe, and to what extent the Norwegian consumers will accept it. At the moment, local anaesthesia is used when piglets are castrated in Norway. Because this is a practice of limited duration, as castration will be forbidden from 2009, research on methods for anaesthesia is not given any high priority within the programme.

**The national research programme:** The national research programme started in 2004, and will run until January 1st 2009. It is divided into two periods; 2004–2006 and 2007–2008. For the first period, funds have been granted for five different projects. At the end of the period, an evaluation of the programme and the different projects will be performed. For the second period funds have been proposed, but the final allocation will be done after the evaluation. Extensive co-operation between the different projects is demanded to utilize data and resources in the best way.

The programme is financed by three sources; The Research Council of Norway, a fund built on the purchase tax and research funds from the Ministry of Agriculture with one third each. For the first period, 18 mill. NOK is granted (2.2 mill. Euro), and for the second period 27 mill. NOK is proposed (3.3 mill. Euro). In addition considerable resources are put into the projects at the project owners own risk.

**The projects in the programme: Genetics in boar taint (Norsvin):** The aim of the project is to combine knowledge from other studies, and use of new methods in genome research to identify genetic factors affecting boar taint and to study complex interactions between genes. Levels of androstenone and skatole should be reduced while levels of testosterone and fertility should be unchanged. The goal is to implement the results in breeding as soon as possible. The following methods will be included:
- Quantitative genetics
- Proteomics and functional genomics
- Characterisation of candidate genes
- Transcript profiling
- Genome scan
- Genetic network modeling

**Testicular activity in the boar related to the occurrence of 5α-androstenone in fat (The Norwegian School of Veterinary Science):** The aim of the project is to identify boars with low levels of androstenone in plasma and adipose tissue for the selection of boars with low tainted meat but with normal anabolic potentials, normal sexual maturation and normal reproductive function. Sub-aims of the project will be:
- Obtain more information about the production of testicular steroids
- Identify boars with low capacity to produce androstenone and normal production of testosterone
- Elucidate the relationship between levels of testicular steroids and testicular morphology
- Elucidate a possible binding of androstenone to plasma proteins
- In vivo stimulation of testicular steroidogenesis with human chorionic gonadotropin (hCG) and evaluation of spermatogenesis by histology and flow cytometry analyses are methods that will be used in the project.

**Entire male pigs – feeding and managing (Norwegian Meat Research Centre and The Agricultural University of Norway):** The project focuses on efforts to be done within the herds to reduce the levels of androstenone and skatole in the carcasses. It will also evaluate the effect of the different raising methods on animal welfare. The following subprojects are included:
- feeding with organic acids (period I)
- artificial light programmes (period I)
- stable social groups (period I+II)
- feeding with grain with high levels of beta-glucan (period II)
- restricted feeding (period II)
- feeding raw potatoe starch under practical conditions (period II)
Rapid sorting methods for sorting boar carcasses (Norwegian Food Research Institute): The main objective of the project is to develop rapid method(s) for detection of boar taint for use on the slaughter line. The project is divided into three subprojects with the following subgoals:

- Identification of relevant rapid methods for pointing out male pig carcasses on the basis of androstenone, skatole and boar taint levels. (International workshop October 2004)
- Practical evaluation of a number of methods given priority in the workshop, concluding in 1 or 2 methods for further development
- Mapping and identification of other possible chemical markers correlated with boar taint, which can be used for sorting boar carcasses
- Development of rapid method(s) for detection of boar taint at the slaughter line

Boar meat – consumer aspects and resource utilization (Norwegian Meat Research Centre): The first two years the project will focus on the Norwegian consumers and their reaction to boar meat. The sensitivity for androstenone and acceptance for tainted meat will be addressed. It will be important to work out cut-off limits for androstenone and skatole levels based on Norwegian pork and Norwegian consumers’ perception of boar taint. In the last period different approaches to utilization of tainted meat will be investigated. This will include for example mixing of tainted meat with other meat in different products, and marinating (or other procedures) to mask boar taint.

POSTER PRESENTATIONS

P1

The potential to detect boar tainted carcasses by using an electronic nose based on mass spectrometry

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Introduction: Based on a parliamentary decision, in the year 2009 castration of male piglets without anesthesia will be banned in Switzerland. Thus, pig producers are forced to search for alternatives to the common practice. Rearing intact male pigs to market weight could constitute one possible alternative solution. However, producers, retailers, and consumers are concerned about the incidence of taint in pork. Therefore, a reliable, fast, and objective method to detect carcasses with the undesirable odor is a prerequisite for boar production.

The aim of this study was to evaluate the potential of an electronic nose (SMArt Nose 151, LDZ, Switzerland) with a mass spectrometer (quadrupole) as a detector to classify boar tainted carcasses.

Materials and Methods: In back fat (BF) samples of 35 boars and 3 castrates (essentially from Large Swiss White breed) obtained from the loin region, the concentrations of androstenone, skatole, and indole were determined by HPLC technique [1]. The androstenone, skatole, and indole concentration in the BF of boars ranged from 0.2 to 4.4, 0.02 to 0.68, and 0 to 0.14 mg/kg, respectively. As expected, the androstenone, skatole, and indole levels in the BF of castrates were lower and ranged from 0 to 0.32, 0 to 0.04, and 0 to 0.01 mg/kg, respectively. These results revealed that the highest androstenone and skatole concentrations in the BF samples of the castrates were higher than the lowest concentrations determined in the BF of the boars.

The BF samples were also submitted to a sensory panel composed of 8 trained judges who performed an R-index olfaction test. This olfaction test was about the detection of boar taint on the BF samples as compared to a reference sample from a castrate. Subsequent analyses of the BF samples with the SMArt Nose were carried out using two different sampling modes: solid phase micro extraction (SPME) and pyrolysis. SPME was performed with a divinylbenzen/carboxen/polydimethylsiloxane fiber placed during 1 h in the headspace of a 10 mL glass vial containing 2 g of adipose tissue, heated to 90°C; data acquisition per sample lasted 7 min. Pyrolysis was performed at 700°C on a few μg of fat placed in a silica capillary tube; data acquisition lasted 200 sec. The obtained spectra were subjected to Principle Component Analysis (PC) and Discriminant Factor Analysis (DFA).

Results and discussion: PCA revealed that with SPME 97% of the BF samples and with the pyrolysers, directly coupled to the injector, 100% of the BF samples of boars were correctly discriminated against the BF samples of the castrates. A DFA model classification (Fig. 1) based on Smart Nose-pyrolysis data (mass scanning from 10 to 160 amu) shows 100% correct classification with the following discriminating variables: 55*, 57*, 69*, 71*, 79*, 84, 85*, 89**, 90**, 91*, 93*, 94*, 111*, 124*, 130** amu (*belong to Androstenone mass spectra (MS), **belong to Skatole MS, ***belong to Indole MS).

Using the DFA model, 15 out of 23 unknown samples were correctly classified into two groups: low level (<1.11 ppm) and high level (>1.11 ppm) of androstenone. This DFA model shows also trends for very high androstenone and high skatole. From the eight misclassified samples (false positives), five were also detected as loaded with boar taint by the sensory panel. This is maybe due to the high sensitivity of panelist, or to the presence of an additional compound implicated in boar taint. These preliminary results demonstrated the potential of the electronic nose to detect high and low levels of boar taint,
were analysed by the Kruskal-Wallis test. Additional work with considerably larger sample sets is necessary to improve the robustness of the method. Furthermore, electronic nose model classifications need to be better understood in relationship with consumers acceptance and HPLC concentrations altogether.

References


P2 Effects of finishing boars in mixed and single sex groups and split marketing on pig welfare
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Introduction: In Ireland, pigs were traditionally slaughtered at low weights and hence at a young age, which facilitated the rearing of boars. However, slaughter weights are increasing and this is associated with an increased risk of boar taint [1] and welfare problems [2]. Hence, changes in management and housing practices to facilitate rearing of heavy boars need to be investigated. The aims of this study were to investigate the welfare of pigs of both sexes in single or mixed sex groups and to evaluate effects of split marketing on pig welfare.

Materials and Methods: Pigs were assigned to female (n = 10), male (n = 10) and mixed (n = 10) sex treatment groups (14 pigs/pen) at transfer from the weaner accommodation (c. 35 kg). Once the mean weight of the pen reached 70 kg the group size was reduced to 12. Data collection began when the mean weight of the pen reached 75 kg. Once the average weight of the pen was 100 kg, the three heaviest pigs from five of the groups in each treatment were sent for skin lesion inspection at 75, 90, 100 (prior to split marketing) and 125 kg. Once the average weight of the pen was 100 kg, the three heaviest pigs from five of the groups in each treatment were sent for skin lesion inspection at 75, 90, 100 (prior to split marketing) and 125 kg. Twelve regions on the body were scored from 0 to 5 depending on the number and depth of the lesions in each location. The total score for each pig was the sum of the scores for the 12 areas. Behaviour observations were conducted at 75, 95 and 100 (post split marketing) kg. The behaviour of each focal animal was recorded continuously for 10 minutes on three days per week between 1030 and 1300 h and 1500 and 1800 h (60 minutes/pig). Recordings were made by direct observation using The Observer program downloaded to a Psion organiser. All occurrence behaviour sampling was also used to record the frequency of agonistic (threats, knocks, bites, fights) and sexual (mounts and nudes) behaviours during feeding. Observations started ten minutes before feeding and finished 20 minutes later. Each pen was observed for 1.5 minutes at each of six feeding events, three at 0900 and 1400 h yielding nine minutes/pen.

All data were analysed by SAS. Data on skin lesion scores collected at the 75, 90 and 100 kg inspections were analysed by a mixed model. Skin lesion data collected at the 105 kg inspection were analysed by analysis of variance using the general linear model procedure. Behaviour data were non-parametric and were analysed by the Kruskal-Wallis test.

Results: There was no effect of treatment on skin lesion scores at 75, 90 or 100 kg (P > 0.05). However, there was a significant interaction between treatment and split marketing on skin lesion scores at 105 kg (P < 0.05). Pigs in split-marketed male groups tended to have higher scores than pigs in male groups that were not split-marketed (24.6 vs. 18.1 SEM 1.65, P < 0.10).

There was more mounting in male and mixed compared to female groups at all weights (P < 0.05). However, the frequency of mounting in mixed groups decreased over time (P < 0.01). Split marketing reduced the number of mounts in the mixed groups to a level comparable to that recorded both in female groups that were split marketed and in those that were not (P < 0.05, Figure 1).

There was more agonistic behaviour in male (14.5 ± 1.10) compared to female (10.3 ± 1.15) and mixed sex (10.5 ± 1.34) groups during feeding (P < 0.05). Split marketing had no effect on agonistic behaviour (P > 0.05).

Discussion: Mounting is a normal part of the sexual behavioural repertoire of males in most farm animal species [3]. Not surprisingly then, and in accordance with Rydhmer et al. [2], the frequency of this behaviour was higher in male and mixed groups than in female groups. Sexual behaviour has adverse welfare implications [2] particularly for pigs housed in confined spaces on slatted floors. Hence, the welfare of females in single sex groups was improved relative to that of females in mixed sex groups.

On the other hand, male pigs were exposed to higher levels of agonistic behaviour in single compared to mixed sex groups at feeding. Furthermore, there was a reduction in mounting behaviour in the mixed groups over time but the same effect was not observed in the male groups. These findings suggest that the welfare of the male pigs was improved in the mixed compared to the single sex groups.

Split marketing resulted in a reduction in mounting behaviour in the mixed groups. Generally the heaviest pigs in mixed groups were male, so split marketing resulted in three males being removed from the group. These animals were likely to have been responsible for most of the mounting. In contrast, split marketing caused an increase in skin lesion scores of pigs in male groups suggesting that the practice had negative welfare implications [2] particularly for pigs housed in confined spaces on slatted floors. Hence, the welfare of females in single sex groups was improved relative to that of females in mixed sex groups.

Figure 1 (abstract P2)

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Effect of split marketing on the frequency of mounts (mean ± s.e.) observed in female (F), male (M) and mixed (X) sex groups (P < 0.05, S = split marketed, N = not split marketed).
implications in such groups. The removal of individuals from a group causes some disruption to the dominance hierarchy that can stimulate aggression [4]. It is likely that this effect is aggravated in groups of boars compared to groups of females, the former being naturally more aggressive.

In conclusion, rearing females in single sex groups eliminates any potential welfare problems for these animals of rearing boars. On the contrary, boars themselves are exposed to more aggression if finished in single rather than mixed sex groups. Single sex rearing of boars in conjunction with split marketing further aggravates the problem. Single sex rearing combined with slaughtering boars earlier than their female counterparts might reduce the need for split marketing and ameliorate some welfare problems.

References

P3

Artificial light programmes in entire male pig production – effects on androstenone, skatole and animal welfare

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The aim of the study was to evaluate whether artificial light programmes could be a useful tool to reduce boar taint substances in entire male pig production. Decreasing day length and short days are reported to stimulate the onset of puberty and reproductive activity [1]. The hypothesis in the present study was therefore that pigs raised under conditions with increasing day length and high light intensity (spring), would be less sexually mature at slaughter than pigs raised under conditions with decreasing day length and low light intensity (autumn). Since the levels of androstenone, and to a certain degree skatole, are closely related to the onset of puberty, an effect on sexual maturation would also be expected to give an effect on boar taint substances. However, the literature on the topic is ambiguous [1, 2, 3].

The study was performed in one integrated herd with farrow-to-finish-system in the period January to May 2005. A total of 173 entire male pigs were distributed to 30 pens in two sections. The study period started at weaning. In section I, all windows were covered up to block the penetration of daylight, and an artificial light programme imitating the day length from August (18.5 hours) to December (8 hours) was implemented. The average light intensity was 60 Lux. In section II, the windows were kept unblocked, and with an improved lighting system, the average light intensity was 440 Lux. The artificial light programme in this section, was parallel to the actual day length from January (8 hours) to May (19 hours). Registrations of activity, including registrations of aggressive and sexual behaviour, was performed for all the pens in week 10, 14 and 17 of the study period, while individual registrations of skin wounds for all animals were performed in week 10 and 15. The animals were slaughtered in week 17–19. Back fat samples collected at slaughter were analysed for androstenone and skatole, and weight of testes and length of *gl. bulbourethralis* was registered as indirect measurements of sexual maturity of the animals.

The results of the data registered at slaughter are presented in Table 1. The activity registrations demonstrated that the activity level in section I increased when the day lengths were reduced (week 14 and 17). Simultaneously aggressive behaviour increased, while sexual activity remained low in both sections (Figure 1). In addition, the registration in week 15 demonstrated higher frequency of skin wounds in section I than in section II. In conclusion, the artificial light programme with increasing day length and improved light conditions, did not restrain sexual maturation. On the contrary, entire male pigs from this section

<table>
<thead>
<tr>
<th></th>
<th>Section I – Autumn</th>
<th></th>
<th>Section II – Spring</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean (median)</td>
<td>SD</td>
<td>Mean (median)</td>
<td>SD</td>
</tr>
<tr>
<td>Age at slaughter (kg)</td>
<td>136</td>
<td>6.5</td>
<td>135</td>
<td>4.9</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>72.4</td>
<td>5.3</td>
<td>71.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Daily weight gain (g)</td>
<td>791</td>
<td>72.0</td>
<td>785</td>
<td>68</td>
</tr>
<tr>
<td>Skatole (g/g)</td>
<td>0.085 (0.080)</td>
<td>0.04</td>
<td>0.081 (0.070)</td>
<td>0.05</td>
</tr>
<tr>
<td>Androstenone (g/g)</td>
<td>1.46 (1.12)</td>
<td>1.27</td>
<td>1.72 (1.30)</td>
<td>1.37</td>
</tr>
<tr>
<td>Weight of testes (g)</td>
<td>281.6</td>
<td>100.6</td>
<td>273.1</td>
<td>100.8</td>
</tr>
<tr>
<td>Length of <em>gl. bulbourethralis</em> (cm)</td>
<td>10.8</td>
<td>1.1</td>
<td>10.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Average percentage of animals showing aggressive behaviour related to access to feed, other aggressive behaviour and mounting, per section and week. In week 10 the day lengths were 13 and 12 1/2 hours, in week 14, 10 3/4 and 14 3/4 hours, and in week 17, 8 1/2 and 18 1/2 hours in section I (autumn) and II (spring) respectively.
had higher levels of androstenone than entire male pigs raised under poor light conditions and decreasing day length. In the section with decreasing day length, the animal welfare was affected as the day length for the slaughter pigs were reduced. According to these results, artificial light programmes can not be recommended to reduce boar taint in entire male pig production.

References

P4
Effects of surgical castration on the behavioural and physiological responses of weaned pigs
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Surgical castration is an acute stressor that can affect the behaviour, endocrine and immune responses of pigs [1, 2]. Therefore, it may impair the health and welfare of these animals. This could be of particular concern at weaning, which constitutes a severe nutritional, physical and psychological stressor often associated with increased disease susceptibility [3]. Thus, an experiment was carried out to evaluate the effect of surgical castration on post-weaning behaviour and on the behavioural, endocrine and immune responses elicited by a low-dose lipopolysaccharide (LPS) challenge after weaning. At 5 days-of-age, 64 male piglets were randomly assigned to undergo surgical castration or were left untreated. Pigs were weaned at 28 days-of-age. Behaviour post-weaning and mixing was assessed during a 1-h period, during which agonistic interactions were recorded. One day post-weaning, pigs were injected with a single dose of 0 or 5 μg/kg of body weight (BW) of LPS from Escherichia coli. Sickness behaviour was studied by scan sampling every 5 minutes for 45 minutes at 0, 1, 2, 3, 4, 6 and 8 h after the challenge was initiated. Blood samples were taken at 0, 2, 12 and 24 h after injection and were analysed for plasma concentrations of testosterone in saliva were higher in entire males (P < 0.001). Furthermore, salivary testosterone levels in entire males varied with age and were markedly elevated at 4-weeks-of-age (P < 0.001), which coincided with weaning. These results show that surgical castration reduces aggressiveness at weaning. It is likely that peak levels of testosterone are in part responsible for the higher frequency of agonistic encounters among entire male pigs [4]. In addition, castration affects the coping mechanisms of weaned pigs against a low-dose LPS challenge. It is also possible that entire males may be more efficient in overcoming the bacterial endotoxin challenge, taking into consideration the beneficial effects of sickness behaviour in the recovery from infection [5]. In conclusion, surgical castration reduces aggressiveness at weaning and also impairs the behavioural, but not the endocrine and immune responses elicited by low-dose LPS challenge in pigs.

References

P5
Early and reliable detection of boar taint and its genetic predisposition
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Boar taint is a distinct and unpleasant odour, flavour or taste that can be present in pork products originating from entire male pigs. It is mainly perceived when the fat fraction in the meat is heated. Two main compounds are presumed to cause this phenomenon, although the extent of their relative contribution to boar taint is still disputed: androstenone (physiologically acting as a pheromone) and skatole (metabolite of amino acid tryptophan).
Apart from the impact boar taint has on the pork industry, this phenomenon also brings along a major welfare problem regarding the production of male pigs. Until now, surgical castration of male piglets is the most common and widespread method to prevent the occurrence of boar taint. This practice, however, is controversial because of the obvious negative impact on the welfare and integrity of the animal. Calls for a ban on surgical castration of pigs are gaining increasing support in many EU countries. Such a ban, however, requires the development of alternative solutions to surgical castration. The purpose of this research project is to investigate the feasibility of reducing the occurrence of boar taint and of timely detecting its presence. This would enable the production of entire male pigs which is a neat alternative to castration from both animal welfare and a zootechnical point of view. The research will focus on three main strategies:

1. Reducing boar taint by altering management strategies. Feed ingredients, genetic background combined with slaughter weight and hygienic status of the animals will be related to the presence of boar taint in the meat and fat, in several successive experiments.

2. Finding a reliable predictor that will permit an early detection of boar taint in live animals. This would make timely identification of pigs prone to develop boar taint possible, allowing specific measures (immunocastration, early slaughtering,...) to be taken to prevent these animals from developing boar taint. Hence, we will investigate whether the intensity of boar taint can be predicted by measuring the development of physical parameters (e.g. testis size), by observing the sexual/social behaviour as well as by other measurements such as skin lesions and hygiene status.

3. Post-mortem detection of boar taint to prevent tainted meat from reaching the consumer. Several detection systems will be implemented to determine whether or not boar taint is present in meat or fat samples. The presence of skatole, indole and androstenone levels will be quantified using a liquid chromatography-mass spectrometry technique. An expert panel will be trained to detect and characterize boar taint compounds. Based on the assessments of pork samples by a consumer panel, the threshold level at which Belgian consumers find the amount of boar taint unacceptable will be determined. This threshold will be used to fine-tune the e-noses and train sniffer pigs to detect boar taint in meat and fat samples.

Results: This project started in June 2005 and will take 4 years to complete. The feed experiment including different dietary ingredients has started and samples of meat and fat are taken to perform analyses as described above. Training of the sniffer pigs is currently in progress. Observations of behaviour and related measurements in fattening pigs are being carried out in order to detect differences between boars that develop boar taint and boars that do not. The first results will be reported in 2006.

Table 1 (abstract P6) Published heritability of boar taint and underlying components.

<table>
<thead>
<tr>
<th>Component</th>
<th>h² (range in literature)</th>
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<tbody>
<tr>
<td>Boar taint¹</td>
<td>0.13 to 0.54</td>
</tr>
<tr>
<td>Androstenone²</td>
<td>0.13 to 0.87</td>
</tr>
<tr>
<td>Skatole³</td>
<td>0.19 to 0.34</td>
</tr>
</tbody>
</table>

¹ Jonsson and Pederson, 1974; Jonsson and Pederson, 1979
² Bonneau and Sellier, 1986; Fouilloux et al., 1997; Jonsson and Pederson, 1974; Jonsson and Pederson 1979, Johnsson and Joergensen 1989; Sellier and Bonneau 1988; Willeke et al., 1987
³ Pedersen, 1998

Figure 1 (abstract P6)

Four populations (h² = 0.2 or 0.4; and percentage of boar taint in the population of p = 0.2 or 0.3) during 5 year of selection against boar taint.

accept meat with an off-flavour. Therefore in most of Europe, castration of male pigs shortly after birth is done to prevent the production of meat with an unfavourable odour and flavour, the so called ‘boar taint’. However, castration is a surgical intervention which is of growing concern in the society and becoming an issue for animal welfare.

Boar taint and underlying components are heritable (Table 1) which implies possibilities for breeding against high levels of boar taint in a population.

The goal of this study is to show, in a simulation study, the possibilities to select against boar taint.

Materials and methods: Purebred pig populations were simulated in the program SelAction [1].

The following heritabilities and percentages of boar taint were used:
- h² = 0.2, percentage boars with boar taint = 20%; group 22
- h² = 0.4, percentage boars with boar taint = 20%; group 42
- h² = 0.2, percentage boars with boar taint = 30%; group 23
- h² = 0.4, percentage boars with boar taint = 30%; group 43

The following assumptions were made: 5 years of selection, 500 sows, 30 breeding boars, 470 production boars, litterindex 2.2, 3500 boar piglets, selection on ADG (average daily gain) and BF (backfat), per year 75% culling (in the selection for breeding) because of other reasons (eg. exterior, inbreeding, etc). The selection trait is the odour detected by an electronic sensor or by a panel. Boar taint is a binomial trait with the variation = p * (1-p) in the population. Genetic correlations with production traits are assumed.
Results: The percentage of boar taint can decrease with a maximum of 5.7%, 8.6%, 6.6% and 7.5% in the first year of selection for the populations 22, 42, 23 and 43, respectively. After 5 years of selection there is simulated that there are 3.9%, 0.5%, 9.3% and 3.2% boars with boar taint left in the population for 22, 42, 23 and 43, respectively (Figure 1). Under the restriction of keeping 80% of the genetic improvement of growth and backfat.

Conclusion and Discussion: This simulation study shows that it is possible to select against boar taint.

This simulation is done in 1 population but slaughter pigs are a combination of 3 to 4 lines. Therefore, selection should take place in all lines; this will increase the cost of selection against boar taint. Correlated response on reproductive traits was ignored.

References