Economics of boar taint prevention without surgical castration in the pork chain

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Abstract
An economic analyses of boar taint prevention without surgical castration is lacking. This paper explores currently feasible alternatives to surgical castration along the pork chain. The considered alternatives include genetic selection (pig breeding stage); altering management strategies (pig growing stage); slaughter at younger age and lower weight (slaughtering stage). Control measures relevant to these alternatives were designed and examined, using cost-effectiveness and cost-benefit analysis. Results show that the option of single-sex raising of entire males is more cost-effective compared to the mixed-sex option. The breeding programs combining selection on boar taint and economics are more cost-effective than programs focusing on boar taint only, and also much more cost-effective than slaughtering at a younger age and lower weight.

Keywords
Pork chain, boar taint, cost-effectiveness, costs and benefits

1. Introduction
Surgical castration of boars is the most common practice to prevent boar taint. Boar taint is a distinctive and unpleasant taint. It is perceived through a combination of sensory odor, flavor and taste during cooking and eating of pork and pork products derived from non-castrated male pigs. Boar taint has been described as ‘animal’, ‘urine’, ‘fecal’ and/or ‘sweat’ like in character. The existing literature considers excessive accumulation of naturally occurring chemical compounds such as androstenone and skatole in pigs as major contribution to boar taint (European Food Safety Authority, 2004).

In recent years, however, due to the public concern over the effects on pig welfare, surgical castration, in particularly, castration performed without pain relief, is increasingly regarded as unacceptable. So, developing acceptable alternatives to surgical castration has become a central topic for the pig meat sector in many European countries.

Gaps in the technical knowledge on potential alternatives to surgical castration and their advantages and disadvantages are widely discussed in the literature. For an overview, see Valeeva et al. (2009). Generally, while considering the entire pork chain, potential alternatives include genetic selection and gender selection for ‘low-taint’ pigs (pig breeding stage), immunocastration (castration of boars near to slaughter age by means of vaccine) and altering management strategies (pig growing stage), slaughter at a younger age and lower weight and detection of boar taint at slaughter line(slaughtering stage), mixing of tainted with untainted meat and masking unpleasant odors and flavors with spices (processing stage). Existing technical literature often considers potential alternatives separately. At present, no totally valid alternative guaranteeing entire elimination of boar taint is yet available. So, it is expected that combination of several potential alternatives is necessary to solve the boar taint problem. Since pot entail alternatives relate to different actors in the chain, prevention of boar taint becomes a challenge for the entire pork chain. And, given that the alternatives differ significantly in terms of both cost and impact on boar taint reduction, basic questions, such as what alternative or combination of alternatives is the best and at what cost, become very important for each chain actor and the chain as a whole. However, little is known about economic feasibility of boar taint prevention without surgical castration. The scarce literature mainly deals with costs and benefits associated with few alternatives, such as different slaughter weight (Baltussen et al., 2008) and immunocastration (Novoselova, 2007; de Roest et al., 2009). An economic analyses from the whole-chain perspective is lacking.

The current economic study presents the first step of an integrated chain analysis of boar taint prevention in the Netherlands. Specifically, the paper analyses (i) cost-effectiveness of different alternatives to surgical castration along the chain; (ii) economic costs and benefits associated with raising entire males and castrated males as well as the distribution of these costs and benefits among chain actors.

The study focused on the alternatives referring to genetic selection, altering management strategies and slaughter at a lower weight. These alternatives are considered as the presently feasible alternatives because they might be implemented in practice on a relatively short term and they are not expected to cause problems with consumer acceptance.

2. Methodology

2.1. Cost-effectiveness of preventing boar taint in the chain

The primary part of the pork chain analysis explores the cost-effectiveness of preventing boar taint in the pork chain using potential alternatives to surgical castration such as genetic selection (pig breeding stage); altering management strategies (pig growing stage); slaughter at younger age and lower weight (slaughtering stage). Figure 1 shows the basic three steps of cost-effectiveness approach used in this study. These steps are described below.

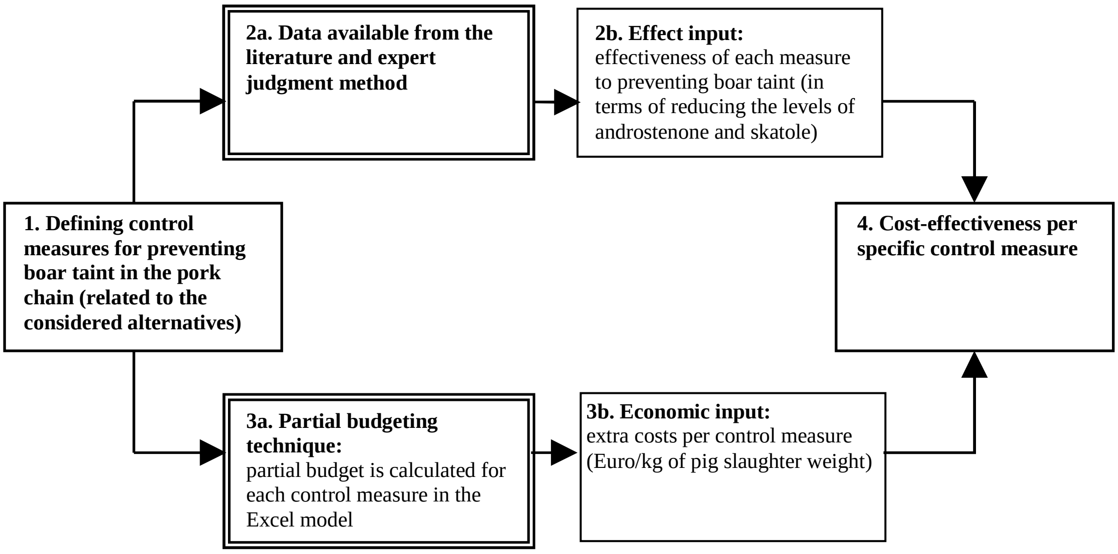

Figure 1. Cost-effectiveness analysis of preventing boar taint in the pork chain

2.1.1. Defining specific control measures

Based on the literature about the considered above alternatives, the first step identifies specific control measures for preventing boar taint in the chain. Extensive literature review is to find in Valeeva et al. (2009).

In general, reduction of boar taint in the pork chain deals with specific factors that influence the androstenone and skatole levels in pigs. For a complete overview of potential factors affecting boar taint in the pork chain, see Valeeva et al. (2009). On the basis of the identified factors, a number of corresponding measures were designed for control of each factor; implying that specific control measures can be adopted to have a positive effect on boar taint. Not all identified in the literature factors taken into consideration. The factors considered relevant and control measures associated with them are presented in Table 1.

Insert Table 1 here

Only measures that are currently available for adoption and that comply with the European and Dutch law and follow standard pig husbandry practices are considered. For this reason, the factor “special diet” (implying a short-term administration of antibiotic additives) or the factor “floor type in pens and associated pig cleanness” (implying the use of wholly slatted floor) is not considered, although they have a positive effect on skatole reduction. Some other factors known in the literature such as “extra water supply” (implying extra water supply in the form of an extra nipple drinker) and “feed strategy for fattening hours” (implying fasting for 12 hours before delivery) are not further considered due to changes in standard pig husbandry that have occurred since the time when some research was performed, sometimes more than 10 years ago. Also, the factor ‘feed system/dry diets vs. wet diets” (implying the feeding of whey) is not feasible nowadays because dairy industry derives as many components as possible from whey and there is nothing left for use as a feed ingredient. Few other factors were excluded from consideration due to lack of exact information (or absence of any significant effect) on any of the boar taint substances. After discussion with experts, it was decided to consider these measures for further research.

Table 1 also shows the basic situation for each factor, which is defined as an control measure representing the most typical practice at the moment.

2.1.2. Effect input

The second step deals with the quantification of impact of control measures in preventing boar taint. The obtained data are used as effect input for evaluating the cost-effectiveness of different alternatives to surgical castration. In this study, the impact in preventing boar taint is expressed by reduction of concentrations of main boar taint compounds such as androstenone and skatole in subcutaneous fat of pigs (not in blood or urine). This reduction is expressed relative to the basic situation and measured in terms of milligrams of the boar taint compounds per kilogram of fat. The basic situation with respect to the effect input is defined by the levels of boar taint compounds associated with implementation of the most typical practice while raising entire males, i.e. when castration of male piglet is not a practice anymore.

The exact common effects of separate control measures on the reduction of concentrations of boar taint compounds (known from the literature) are very difficult to quantify precisely for the specific country like the Netherlands, since the existing technical studies were conducted in different countries. That is animals of different breeds, slaughter weight and fed different diets were used in experiments as well as methods applied to measure boar taint compounds were sometimes different. This available knowledge (when available) is however used.

The expert judgment method is used to obtain data on quantitative effects for the designed control measures related to feed composition. The exact knowledge from the literature is not generally applicable for the Netherlands due to considerable differences in feed diets used in the countries were experiments were performed and the Netherlands. So, via personal interviews, two experts (one from research and one from industry) were consulted.

First, experts were asked to identify the most important general aspects in feed composition that help reduce boar taint. An extensive list of possible diets known from the literature and impacts relevant to them were provided to experts as reference information. At the same time, a possibility of using these aspects while developing new diets in the Netherlands was an important condition. As result, protein and NSP aspects in the diets were identified and the potential feed composition measures were designed, see Table 1.

Second, experts were asked to evaluate actuality of the obtained potential impacts of the designed feed composition measures (see the section 3.1 and Table 3 for more details).

2.1.3. Economic input

The third step evaluates costs of control measures throughout the whole pork chain in Euros per kilogram of pig slaughter weight. Partial budgeting technique was used (Boehlje and Eidman, 1984; Huirne and Dijkhuizen, 1997). The extra costs of boar taint prevention due to the change in control measures within a certain factor relative to the measure representing the basic situation were calculated; assuming that implementation of all changes is feasible. A detailed economic calculation model was specified in a Microsoft Excel spreadsheet. The obtained costs data are used as input for evaluating the cost-effectiveness of different alternatives to surgical castration.

Data on costs control measures were collected in 2009. Data were mainly obtained from published studies, national handbooks and reports. Also, pig husbandry researchers and representatives of compound feed companies and slaughterhouses were interviewed to obtain data needed to calculate the costs. The cost estimates are considered representative of the typical conventional Dutch pig-fattening farm (close to an average farm size) with mixed-sex groups rearing (i.e. 50% male pigs and 50% female pigs) and slaughterhouses. The general characteristic of representative farms for basic situation are presented in Table 2. By changing these characteristics, cost estimates can be adjusted according to farm size.

Insert Table 2 here

The subsequent cost estimates made use of average parameters on meat price, costs related to purchase of piglets and feed, transportation of fattening pigs interest, housing, health care and labor costs.

2.1.4. Cost-effectiveness of control measures

Within each factor, cost-effectiveness of each control measure is calculated as ratio of obtained reduction of the androstenone and skatole levels to extra costs associated with implementation of this measure. As explained above, reduction of the androstenone and skatole levels and extra costs were expressed relative to the measure representing the basic situation.

2.2. Cost-benefit analysis of raising entire males

The next part of the pork chain analysis estimates cost and benefits associated with raising entire males and compares them with those associated with raising the castrates. For this analysis, positive changes in feed conversion, daily growth, animal health, environmental benefit, costs related to castration as well as price increase for a better carcass quality (leanness) and price reduction for possibly tainted carcasses are taken into account when estimating costs of raising entire males instead of castrates. A detailed economic calculation model was specified in a Microsoft Excel spreadsheet.

3. Results

3.1 Effect and economic inputs per control measure

The obtained effect and economic input data are presented in Table 3. Specifically, potential decrease in the levels of boar taint compounds, i.e. androstenone and skatole (effect input), and extra costs (economic input) are presented for each control measure along the pork chain.

Insert Table 3 here

As described above, the effect data are based on the literature, with exception of the effect data for the control measures related to the factor “feed composition (both protein and non-starch polysaccharides aspects in the diets)”. The presented feed compositions are designed on the basis of the literature knowledge (see Valeeva et al. (2009), for an overview) and the feed expert knowledge. In contrast to the diets from the existing studies, these diets are potentially applicable for the Netherlands. However, no actual effect data is available for them yet. So, the effect data shown for the designed diets in Table 3 is the potential decrease in the skatole level. That is, the designed diets should have at least the indicated decrease in the skatole level in order to be considered as more cost-effective, compared to other control measures, given the estimated extra cost for the designed diets and cost-effectiveness of other control measures. Based on the literature study (Valeeva et al., 2009), it seems feasible to expect an effect of 0.02 mg per kg fat and higher while feeding the designed diets only in the last two weeks before slaughter; whereas it seems less realistic to expect a rather high effect of 0.29 mg per kg fat and higher while feeding the designed diets constantly during the whole fattening period (Table 3).

The obtained economic input data is calculated for two possible options of raising the entire males in the farm stage: mixed-sex groups rearing (50% boars and 50% gilts) and single-sex rearing (100% boars) (Table 3). For many control measures, the choice between these options makes a substantial difference in extra costs. The control measures relevant to the factors “cleanness in the last week before slaughter”, “stocking rate”, “air temperature during summer”, “feed system: dry diets vs. wet diets” and “feed composition (both protein and non-starch polysaccharides aspects in the feed)” are examples of such measures (Table 3) where extra costs for the single-sex option are about twice as low as extra costs for the mixed-sex option. At the same time, when the single-sex option is to be chosen, the control measure relevant to the “stable social groups” factor, i.e. "no mixing of unrelated animals: a strict all-in all-out (“birth to slaughter”) system", cannot be implemented. Table 3 also shows that implementation of certain control measures involves negative costs (i.e. savings). These are control measures related to the factors “air temperature during summer”, “stable social groups” and “feed system: dry diets vs. wet diets”.

For the breeding stage, extra costs relate only to the breeding programs based on the sire lines (selection on androstenone and skatole) (Table 3). These extra cost estimates are preliminary results. Only few rather extreme options of selection pressure (trade offs between selection pressure on boar taint and economics) are presented in this study to give an indication of the possible range of the extra costs. The extra costs estimates are based on the following facts. Traditionally, sire line breeding goals are dominated by growth rate, feed intake, backfat depth, loin muscle depth and growing-finishing mortality rate, all of which have clear economic implications for the entire pork chain. In this sense, the traditional/current breeding programs focus on selection for an economically based objective (i.e. selection on economics only). Considering boar taint incidence as the only selection objective (i.e. selection on boar taint only) would negatively affect some of these traits and result in extra costs in the farm stage. Furthermore, this would involve extra costs associated with detection of possibly tainted carcasses and with differences in meat quality in the slaughtering stage. So, it is important to identify the best combination of the selection objectives.

The options of the breeding programs presented in Table 3 show that “selection pressure on boar taint only (100%)” resulting in the 2% boar taint incidence in 5 years involve 9.73 Eurocent per kg of slaughter weight; whereas “selection pressure on both economics (90%) and boar taint (10%)” resulting in the 12% boar taint incidence involve 0.78 Eurocent per kg of slaughter weight.

It should however be noted that t is expected that breeding programs based on the dam lines will involve more extra costs due to undesired genetic parameters between fertility and boar taint (personal communication with the experts from the Institute of Pig Genetics, the Netherlands). Specifically, it is likely that female fertility will be unfavorably affected by boar taint elimination. That is, economically important traits such as litter size, piglet mortality will be. Furthermore, when more information is available, both sire line and dam line goals should ultimately be considered, because the final goal is to prevent boar taint at the end product level.

3.2 Cost-effectiveness of implementing control measures in the chain

Table 4 illustrates the main results of this chain study, namely calculated cost-effectiveness of different control measures for preventing boar taint in the Dutch pork chain. The results are presented for those control measures where both effect and economic inputs are available. The cost-effectiveness ratios are provided for each boar taint compound (androstenone and skatole) separately. For each measure, the obtained ratios indicate a reduction in androstenone and/or skatole in (mg/kg fat) per Eurocent invested in adoption of this measure, compared to the basic situation.

Insert Table 4 here

As outlined in Table 4, a number of control measures have a negative cost-effectiveness ratio, (mg/kg fat)/Eurocent, due to better growth performance of pigs resulting from implementation of these control measures. "Keeping boars in rather constant temperature environment (no heat peaks), extra regulation by means of a sprinkler system" is an example of such a control measure, with a negative cost-effectiveness ratios of 0.01 and 0.02 (for skatole) for the mixed- and single-sex options, respectively. This negative ratios mean that by adopting such a measure rather than the measure representing the current practice there is an improvement in the skatole level in fat and a reduction in costs. That is, this measure provides the respective reductions of 0.01 and 0.02 in the skatole level in fat per Eurocent extra. It should be noted that these negative ratios are marked with a plus sign in Table 4.

According to Table 4, in general, the single-sex option of raising entire males is more cost-effective. This option involves more cost-effective control measures for the reductions of skatole, among which "keeping boars constantly in extra clean environment, also in the last week before slaughter is the most cost-effective (cost-effectiveness ratio of 0.15). At the same time the control measure "single-sex groups rearing: boar and gilt in different compartments" is itself the most cost-effective for androstenone reduction, with the cost-efectiveness ratio of 16.3.

As can also be seen from Table 4, the choice for the mixed-sex groups rearing involves implementation of less cost-effective control measures (in terms of the skatole reduction), compared to the single-sex groups rearing. However, such choice allows to reduce androstenone by 0.13 mg/kg fat per extra saved Eurocent, mainly due to saving on animal health costs.

As for the pig breeding stage, Table 4 shows that the presented two extreme options of selection pressure differ substantially in their cost-effectiveness, especially for androstenone reduction. The corresponding cost-effectiveness ratios for “selection pressure on boar taint only (100%)” and “selection pressure on both economics (90%) and boar taint (10%)”are 0.13 and 1.02, respectively. The cost-effectiveness rations for the skatole reduction are much lower, compared to those for the androstenone reduction (0.02 and 0.13). However, these ratios also differ considerably between two options of the breeding programs. These results indicate that the studied breeding programs with the goal of selection on androstenone and skatole are more cost-effective in androstenone reduction than in skatole reductions. Furthermore, the programs that combine selection pressure on both economics and boar taint tend to be much more cost-effective. See the previous section of this paper for more explanations on the concept of possible combinations of breeding program objectives.

For the slaughtering stage, the results of Table 4 suggest that “slaughtering before sexual maturity: slaughter at 90 kg live weight” (cost-effectiveness ratio of 0.11) is less cost-effective in androstenone reduction than control measures in the other stages of the chain. As can be seen from the table, this control measure is even less cost-effective than a breeding program with “selection pressure on boar taint only (100%)”.

3.3 Comparison of costs and benefits associated with raising entire males

Table 5 reports the cost and benefits of raising boars, compared to barrows. The comparison is performed for typical Dutch pig-fattening farms with mixed-sex groups rearing (i.e. 50% male pigs and 50% female pigs). Characteristics of these farms are described in Table 1. The comparison is based on the assumption that these farms switch to raising boars only (100% male pigs), and have none of the control measures to prevent boar taint implemented on the farm.

As shown in Table 5, an improvement in growth performance of boars compared to barrows, and an improvement in boar carcass quality (resulting in a better slaughter pig price) generate an extra net return of 27.77 Euro per fattening pig per year. It should however be noted that this comparison is based on an assumed boar taint incidence of 2%. This percentage may vary between farms, supply chains and even countries. It was also assumed that it is possible to detect all tainted carcasses by means of a human nose and to use this meat for producing and marketing other than fresh meat products, given market acceptance of these products. The costs of achieving the assumed boar taint incidence of 2% are not directly included here, and it is still to be decided which alternatives are the best.

The costs and benefits associated with raising entire males are not equally distributed across the various segments of the pork chain. In the current situation, i.e. without adopting any of the control measures and with a remaining chance of having a boar taint problem, pig farmers benefit from a better feed conversion ratio; whereas slaughter plants are to be confronted with a price reduction for boar tainted meat.

4. Conclusions and discussion

The results of this study provide first insights into economics of currently feasible alternatives to surgical castration along the pork chain. The considered alternatives refer to genetic selection, altering management strategies and slaughter at a lower weight. These alternatives were expressed via relevant control measures. The effect of control measures was derived from the literature or assessed by experts. The extra costs of implementing these measures were calculated using partial budgeting. This information on various measures, impacts and costs was used to examine the cost-effectiveness of preventing boar taint without surgical castration in the pork chain. Next, cost and benefits associated with raising entire males were examined and compared them with those associated with raising the castrates.

Our findings show that the cost-effectiveness of alternatives to surgical castration varies greatly. Some control measures even have a negative cost-effectiveness ratio. In the pig growing stage, the control measures related to the single-sex option of raising entire males are more cost effective than the measures related to the mixed-sex option. In particularly, this is true for the measures for skatole reduction. At the same time, the control measure "single-sex groups rearing: boar and gilt in different compartments" is itself the most cost-effective for androstenone reduction. In the pig breeding stage, the breeding programs that combine selection on boar taint and on economics are more cost-effective than programs focusing on boar taint only. The optimal combination of selection pressure on economics and boar taint is still needs to be determined. In the slaughtering stage, slaughter at a younger age and lower weight is considerably less cost-effective than the alternatives in the other stages, even compared to the breeding program with focusing on boar taint only, which is not very cost-effective.

With no solution for boar taint problem, stopping castration male piglets would result in an uneven costs and benefits distribution among chain participants. Pig farmers would benefit from a better feed conversion ratio; whereas slaughter plants would have to be confronted with a price reduction for boar tainted meat.

This study helps guide both government decision makers and chain participants in selecting the most cost-effective control measures to achieve a certain (acceptable) level of boar taint. The complexity of the issue is however posing and will pose important challenges for years to come. In future research, these alternatives have to be studied in more detail.

As mentioned above, not all required data on the effect of particular control measures on boar taint are readily available and harmonized in the literature. This study uses the best available knowledge from the literature, though the data are based on experiments performed in different countries, where animals of different breeds, slaughter weight and fed different diets are used. Also, only the average effect values are considered. Furthermore, expert judgments (with a limited number of experts) were used to estimate effect of specific control measures (in particular, control measures related to feed composition). Given that it will take a while to collect all the necessary experimental data for any particular country, other methods can be used in further research to better elicit the expert knowledge on effect of different control measures. Though all the above effect input data issues are explicable, scarce information and uncertainty about the current effects of control measures on boar taint may have led to a rather approximate estimation of effect input for the model. Therefore, further research is needed to examine the robustness of the results of the current study with respect to the effect input data. Ideally, more consistent data on effects of different control measures have to be collected. In addition, it is useful to collect more effect data measured as percentage of pigs with high levels of boar taint compounds (vs. absolute effect values as used in this study). This dimension of effect measurement provides more insight into the actual reduction of boar taint incidence at the end of the chain after implementation of different control measures.

As for economic input data for this study, some aspects were not completely taken into consideration. First, extra costs for the breeding stage relate only to the breeding programs based on the sire lines. Only these data were available during the current research. Since it was initially expected that the sire lines cause the main problem of boar taint development, the results for these lines were obtained at first. It was however discovered that the dam lines show the greater levels of androstenone and skatole. Further research is needed to explore the effect of breeding programs with different breeding goals (i.e. trade offs between selection pressure on boar taint and economics) on the dam lines and subsequently on the final products.

Second, estimates of costs and benefits associated with raising entire males do not include economic consequences related to possible change in pork meat quality due to implementation of different control measures. Especially effect of different feeding diets can be considerable; whereas exact effect of some other measures is still now known. The current estimates consider only difference in payment (namely, price reduction) for tainted meat. Also, this study does not specifically examine the net market costs and benefits resulting from raising entire males. Such estimates would depend on the number of the countries that would decide to totally stop with piglet castration.

When sufficient knowledge is available, the study can be elaborated by including on-line detection of carcasses with (possibly) high levels of boar taint. In contrast to the alternatives considered in this study, detection techniques do not really affect the boar taint compounds' levels; they only permit sorting out tainted carcasses. It should however be noted that available techniques for boar taint detection at slaughter line are not yet applicable in the slaughter setting since they involve complicated sample preparation and purification steps, and are usually time-consuming and labor-intensive (Andersen, 2006; Haugen, 2006).

For each control measure, this study only relates the level of reduction of boar taint compounds to extra cost. It does not examine the cost-effectiveness of particular packages of control measures. Therefore, further research is needed to explore cost-effectiveness of combining different control measures and to ultimately define optimal set of the control measures along the chain.

It follows that chain participants will probably have to share their responsibility for boar taint prevention among each other, whereas the scope of this responsibility is not yet determined. Further research on this issue would also be useful for more efficient boar taint prevention along the chain.

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Table 1. Factors affecting androstenone and skatole and control measures corresponding to them

Factors and control measures	Reference	Basic situation (Y/N)
Pig breeding stage		
Breeding goal of selection on androstenone and skatole	Expert knowledge based on the simulation model[1)]	
Selection pressure on boar taint only (100%)		N
Selection pressure on both economics (90%) and boar taint (10%)		N
Selection pressure on economics only (100%)		Y
Pig growing stage		
Housing environment and hygiene		
Cleanness in the last week before slaughter	(Hansen et al., 1994)	
Keeping boars constantly in extra clean environment, also in the last week before slaughter		N
Keeping boars in extra clean environment only in the last week before slaughter		Y
Stocking rate	(Hansen et al., 1994)	
Keeping boars at the low stocking rate (ca. 1.0 m^2 per animal)		N
Keeping boars at the high stocking rate (ca. 0.7 m^2 per animal)		Y
Air temperature during summer	(Hansen et al., 1994)	
Keeping boars in constant temperature environment (ca. 20^oC), extra regulation of temperature by means of a climate control system		N
Keeping boars in rather constant temperature environment (no heat peaks), extra regulation of temperature by means of a sprinkler system		N
Keeping boars in varying temperature environment, no extra regulation of temperature		Y
Social environment		
Stable social groups	(Aldal et al., 2005; (Fredriksen et al., 2006)	
No mixing of unrelated animals: a strict all-in all-out (“birth to slaughter”) system		N
Mixing of unrelated animals: mixing pigs from different litters		Y
Sex grouping of animals	(Patterson and Lightfoot, 1984)	
Single-sex groups rearing: boar and gilt groups in different compartments		N
Single-sex groups rearing: boar and gilt groups in different pens		N
Mixed-sex groups rearing: boar and gilt groups in the same pens		Y
Feeding		
Feed system / dry diets vs. wet diets	(Andersson et al., 1997)	
Restricted wet feeding / water		N
Restricted dry feeding		Y
Feed composition: protein aspects in the diets (options: constantly or 2 weeks before slaughter)	Expert knowledge based on the literature	
Better protein source		N
Maximum protein content		N
Basic diet		Y
Feed composition: NSP aspects in the diets (options: constantly or 2 weeks before slaughter)	Expert knowledge based on the literature	
High NSP content		N
High NSP content and low protein content		N
Basic diet		Y
Slaughtering stage		
Slaughtering before sexual maturity: slaughter at 90 kg live weight	(Aldal et al., 2005, Zamaratskaia, 2004)	N
Slaughtering after sexual maturity: slaughter at 115 kg live weight		Y

[1)] The simulation model is developed by Institute of Pig Genetics, the Netherlands.

Table 2. General farm characteristics in basic situation

Characteristic	
Number of fattening pigs	2000
Starting live weight of piglet, kg	25.5
Final live weight, kg	116.8
Slaughter weight, kg	91.0
Daily growth, g/day	780
Fattening period, days	117
Mortality rate (fattening pigs), %	2.5
Occupancy rate, %	94.0
Feed conversion ratio, kg/kg	2.7
Number of fattening pigs per pen	12

Table 3. Factors affecting fat androstenone (A) and skatole (S) and control measures relevant to them

	Potential decrease in A, S levels (mg/kg fat)		Extra costs (Eurocent/kg slaughter pig weight)	
	A	S	Mixed-sex	Single-sex
Pig breeding stage				
Breeding goal of selection on androstenone and skatole (program based on sire selection)				
Selection pressure on boar taint only (100%)	1.3[(a)]	0.24[(a)]	9.73	9.73
Selection pressure on both economics (90%) and boar taint (10%)	0.8[(b)]	0.10[(b)]	0.78	0.78
Selection pressure on economics only (100%)	0[(c)]	0[(c)]	0	0
Pig growing stage				
Housing environment and hygiene				
Cleanness in the last week before slaughter				
Keeping boars constantly in extra clean environment, also in the last week before slaughter	–	0.02	0.26	0.13
Keeping boars in extra clean environment only in the last week before slaughter	–	0	0	0
Stocking rate				
Keeping boars at the low stocking rate (ca. 1.0 m^2 per animal)	–	0.12	2.74	1.39
Keeping boars at the high stocking rate (ca. 0.7 m^2 per animal)	–	0	0	0
Air temperature during summer				
Keeping boars in constant temperature environment (ca. 20^{o}C), extra regulation of temperature by means of a climate control system	–	0.06	1.75	0.88
Keeping boars in rather constant temperature environment (no heat peaks), extra regulation of temperature by means of a sprinkler system	–	0.03	-2.86	-1.43
Keeping boars in varying temperature environment, no extra regulation of temperature	–	0	0	0
Social environment				
Stable social groups				
No mixing of unrelated animals: a strict all-in all-out (“birth to slaughter”) system	0.18	n.s.	-1.43	
Mixing of unrelated animals: mixing pigs from different litters	0	0	0	
Sex grouping of animals				
Single-sex groups rearing: boar and gilt groups in different compartments	0.98	–		0.06
Single-sex groups rearing: boar and gilt groups in different pens	0.70	–		0.07
Mixed-sex groups rearing: boar and gilt groups in the same pens	0	–		0
Feeding				
Feed system: dry diets vs. wet diets [1)]				
Restricted wet feeding / water	–	0.01	-3.08	-1.54
Restricted dry feeding	–	0	0	0
Feed composition: protein aspects in the diets				
Better protein source (constant during the whole fattening period)	–	0.11[3)]	1.41	0.67
Maximum protein content (constant during the whole fattening period)	–	0.10[3)]	1.28	0.61
Better protein source (last two weeks before slaughter)	–	0.02[3)]	0.24	0.12
Maximum protein content (last two weeks before slaughter)	–	0.02[3)]	0.22	0.11
Basic diet	–	0	0	0

Table 3. (continued)

	Potential decrease in A, S levels (mg/kg fat)		Extra costs (Eurocent/kg pig slaughter weight)	
	A	S	Mixed-sex	Single-sex
Feed composition: NSP[2] aspects in the diets				
High NSP content (constant during the whole fattening period)	–	0.29[3]	3.66	1.79
High NSP content and low protein content (constant during the whole fattening period)	–	0.53[3]	6.63	3.28
High NSP content (last two weeks before slaughter)	–	0.02[3]	0.24	0.12
High NSP content and low protein content (last two weeks before slaughter)	–	0.03[3]	0.37	0.18
Basic diet	–	0	0	0
Slaughtering stage				
Slaughtering before sexual maturity: slaughter at 90 kg live weight	0.46	n.s.	4.16	4.16
Slaughtering after sexual maturity: slaughter at 115 kg live weight	0	0	0	0

Y/N = yes/no with respect to relevance of a control measure to the basic situation (most typical practice).
(a) = in 5 years the incidence of boar taint is 2% (boar taint is defined by A and S threshold levels of 1.0 and 0.2 mg/kg fat, respectively).
(b) = in 5 years the incidence of boar taint is 12% (boar taint is defined by A and S threshold levels of 1.0 and 0.2 mg/kg fat, respectively).
(c) = in 5 years the incidence of boar taint is 32% (boar taint is defined by A and S threshold levels of 1.0 and 0.2 mg/kg fat, respectively).
n.s. = not significant.
[1] This factor is applicable only for the farms that use wet feeding (only for very small farms).
[2] NSP = non-starch polysaccharides.
[3] No actual data is available for these particular diets, which are potentially applicable for the Netherlands and France. So, these are potential decreases in the skatole level. Control measures related to feed composition should have at least such a decrease in the skatole level in order to be considered as more cost-effective, compared to other control measures.

Table 4. Cost-effectiveness of control measures, the androstenone (A) and skatole (S) levels reductions (mg/kg fat) / Eurocent[1].

	Mixed-sex		Single-sex	
	A	S	A	S
Pig breeding stage				
Breeding goal of selection on androstenone and skatole (program based on sire selection)				
Selection pressure on boar taint only (100%)	0.13	0.02	0.13	0.02
Selection pressure on both economics (90%) and boar taint (10%)	1.02	0.13	1.02	0.13
Pig growing stage				
Housing environment and hygiene				
Cleanness in the last week before slaughter				
Keeping boars constantly in extra clean environment, also in the last week before slaughter	–	0.08	–	0.15
Stocking rate				
Keeping boars at the low stocking rate (ca. 1.0 m^2 per animal)	–	0.04	–	0.08
Air temperature during summer				
Keeping boars in constant temperature environment (ca. 20°C), extra regulation of temperature by means of a climate control system	–	0.03	–	0.07
Keeping boars in rather constant temperature environment (no heat peaks), extra regulation of temperature by means of a sprinkler system	–	+0.01	–	+0.02
Social environment				
Stable social groups				
No mixing of unrelated animals: a strict all-in all-out ("birth to slaughter") system	+0.13	–		
Sex grouping of animals				
Single-sex groups rearing: boar and gilt groups in different compartments			16.3	–
Single-sex groups rearing: boar and gilt groups in different pens			10.0	–
Feeding				
Feed system / dry diets vs. wet diets[2)]				
Restricted wet feeding / water	–	+0.003	–	+0.006
Slaughtering stage				
Slaughtering before sexual maturity: slaughter at 90 kg live weight	0.11	–	0.11	–

[1)] The "+" sign indicates that this control measure has a negative cost-effectiveness ratio. This means that by adopting such a measure rather than the measure representing the current practice there is an improvement in the androstenone or skatole level and a reduction in costs. That is, this measure provides the presented in the table reduction in the level of androstenone or skatole per Eurocent saved.
[2)] This factor is applicable only for the farms that use wet feeding (only for very small farms).

Table 5. Economic costs and benefits associated with raising boars compared to barrows[1])

	Barrows	Boars
Growth performance		
Daily growth, g/day	780	801
Feed conversion ratio, kg/kg	2.70	2.44
Basic cost parameters		
Piglet price, Euro/piglet	41.92	41.84
Feed price, Euro/kg	0.26	0.26
Labor costs, Euro/fattening pig/year	2.82	2.90
Delivery costs, Euro/fattening pig/year	6.55	6.72
Slaughter pig price, Euro/kg slaughter pig	1.506	1.518
Price reduction for tainted meat, Euro/fattening pig/year		0.87
Return, Euro/fattening pig/year	422.03	436.82
Extra net return, Euro/fattening pig/year		24.77

[1]) Barrows = raising barrows in the basic situation, with mixed-sex groups rearing (i.e. 50% male pigs and 50% female pigs) (50% barrows and 50% gilts); Boars = single-sex groups rearing with only boars on the farm (100% male pigs). Price reduction for tainted meat is calculated on the basis of the assumption that boar taint incidence is 2% in both countries that results in extra detection costs.