Moving towards boar taint-free meat: an overview of alternatives to surgical castration from a chain perspective

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Abstract
Due to the public concern over the effects of surgical castration on pig welfare, castration, in particularly performed without pain relief, is now increasingly regarded as unacceptable in the EU. Therefore, developing acceptable alternatives to surgical castration has become a central topic for the pig meat sector. This paper reviews important issues in boar taint prevention without surgical castration, namely possible alternatives to surgical castration, factors influencing boar taint development and economic considerations associated with the presently feasible alternatives to surgical castration. Potential alternatives considered are genetic selection and gender selection for 'low-taint' pigs, immunocastration, altering management strategies, slaughter at a younger age and lower weight, detection of boar taint at slaughter line, mixing of tainted with untainted meat and masking unpleasant odors and flavors with spices. Prevention of boar taint itself without surgical castration is vary difficult. Basically, at present there is no totally valid and reliable alternative guaranteeing entire elimination of boar taint. The paper concludes that prevention of boar taint is a challenge for the entire pig production chain and an integrating approach would be useful to define the best alternative.

Introduction
Surgical castration of boars is commonly used to prevent boar taint. Boar taint is mainly caused by high concentrations of androstenone, skatole and indole in fat. In recent years, however, animal welfare merits a more prominent position in the discussion regarding pig production methods. Due to the public concern over the effects of surgical on pig welfare, castration, in particularly, castration performed without pain relief, is now increasingly regarded as unacceptable. This has resulted in a pressure on the pg sector to stop castration. There are, however, differing views on alternatives to surgical castration of boars within European countries.
Along with various European initiatives, an Agreement of Noordwijk was signed in the Netherlands in November 2007. In this Agreement, Dutch Federation of Agriculture and Horticulture, Dutch Union of Pig Farmers, the Central Organization for the Meat Sector and the Central Office for Food Retail aim at stopping castration in the Netherlands from 1 January 2015. The Dutch Ministry of Agriculture, Nature and Food Quality fully supports this ambition (Dutch Ministry of Agriculture, Nature and Food Quality, 2008). The expectation is that by that time there will be a welfare-friendly approach available to produce boar taint-free pork without surgical castration. So, developing such an approach has become an important issue in the current discussion about the ways of attaining the above ambition.
Different alternatives affecting boar taint development have been widely discussed in the literature (Xue et al., 1997b; Bonneau, 1998; Bonneau, 2006; Jensen, 2006).

Quantitative studies, however, often consider each alternative separately; whereas alternatives usually relate to different actors in the chain. So, a whole-chain perspective might be necessary to render boar taint prevention successful. Furthermore, little is known about the economics of boar taint prevention. 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). Economic insights into other alternatives affecting boar taint as well as into the chain perspective are lacking.

The objective of this study is to review important issues in boar taint prevention without surgical castration, namely alternatives to surgical castration, factors influencing boar taint development and economic considerations associated with the presently feasible alternatives to surgical castration. The paper looks at these issues from the pig production chain perspective and suggests a framework for the analysis of boar taint prevention without surgical castration within the whole-chain context.

Pig production chain and potential alternatives to surgical castration

This study considers the pig production chain consisting of pig breeding, pig growing, slaughtering, processing, retail and the actual consumption of pork meat. Figure 1 presents potential alternatives to surgical castration classified per chain stages.

In the pig breeding stage, genetic selection and gender selection for 'low-taint' pigs are being considered as viable alternatives. Zamaratskaia (2004) summarizes the research findings on these alternatives as follows. Genetic selection experiments reduce boar taint, particularly due to high androstenone levels. However, negative effects on growth performance of entire males and onset of puberty in males and females were found. Therefore, genetic markers, which are related to both boar taint and age of sexual maturity, have to be identified to avoid undesirable effects of selection against boar taint. Gender selection process separates male sperm cells and is followed by artificial insemination of the selected sperm. This selection technique might become a promising strategy, allowing the production of female-only herds. Currently, it is not commercially available. Large quantities of sperm are required for such selection because of sperm losses and cell damage during selection.

In the pig growing stage, immunocastration and altering management strategies have been suggested as possible alternatives (Figure 1). Immunocastration is an immunological approach, implying castration of boars near to slaughter age by means of vaccine. The vaccine temporally stops testicular function and thus eliminates boar taint and, also, reduces the level of aggressive behavior and mountings (Hennessy, 2008). Some variability in response to the vaccine has however been found (Zamaratskaia, 2004). Acceptability of this technique by consumers is also questionable. Immunocastration involves application of the vaccine produced with the help of genetic modification technologies; whereas such technologies, especially applications relevant to animal production, elicit high levels of consumer concerns (Novoselova, 2007). Furthermore, vaccine may be active for humans in case of accidental self-infection. The altering management strategies alternative involves reducing the development of boar taint through the

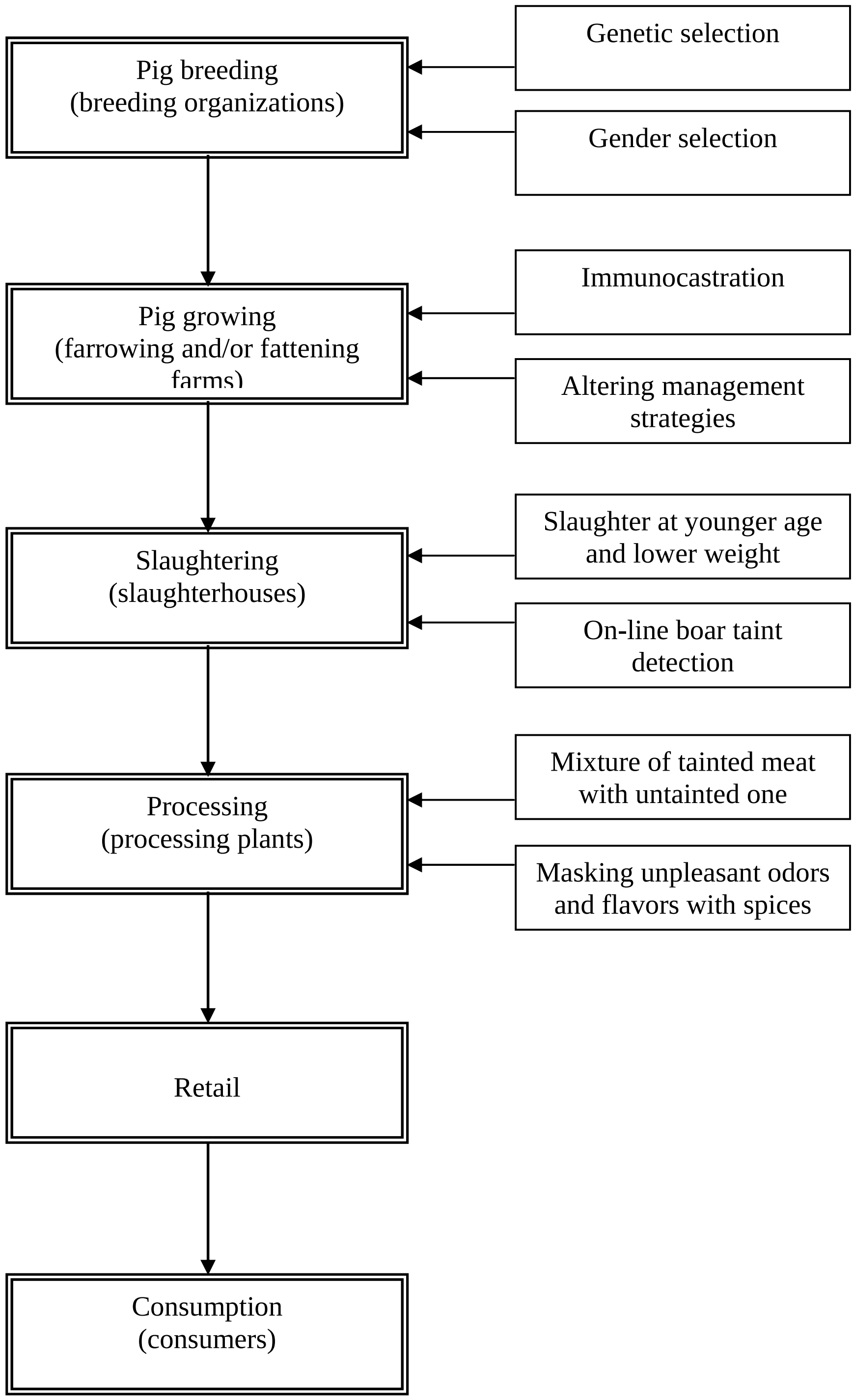

Figure 1. Pig production chain and alternatives to surgical castration in piglets.

external aspects such as housing environment and hygiene, social environment and feeding (Figure 1). Different factors affecting the boar taint compounds' levels have been numerously reported in the literature. These factors and some implementation issues associated with this alternative are discussed in more detail in the next section.

In the slaughtering stage, the experience of some countries shows that slaughter at a younger age and lower weight, might reduce boar taint (Figure 1). This alternative is not very attractive from an economic point of view (Baltussen et al., 2008). Furthermore, it does not entirely eliminate boar taint (Aldal et al., 2005). Detection of boar taint at slaughter line is another option; though available techniques 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). Also, in contrast to the alternatives considered above, detection techniques do not really affect the boar taint compounds' levels, they only permit sorting out tainted carcasses. The same applies to mixture of tainted meat with untainted one and masking unpleasant odors and flavors with spices in the processing stage where the detected tainted carcasses can be used for processed meat products (Figure 1). Boar taint is not a problem for processed products. In this sense, it seems more appropriate to use these alternatives in combination with other ones.

As shown above, each alternative has both advantages and disadvantages that chain participants should be aware of when investigating opportunities to prevent boar taint without surgical castration. Also, certain alternatives are more suitable for decreasing one boar taint compound and less suitable for the others. Furthermore, not each alternative is readily available to be successfully applied in practice. Basically, at present there is no totally valid alternative guaranteeing entire elimination of boar taint.

So, the next section focuses more on the alternatives referring to genetic selection, altering management strategies and slaughter at a younger age and lower weight. These alternatives that might be implemented on a relatively short term and that are not expected to cause problems with consumer acceptance.

Issues in evaluating currently feasible alternatives to surgical castration

Many studies have been conducted to determine external aspects influencing boar taint development and their potential effects. Table 1 summarizes various factors that can be altered to reduce the level of boar taint compounds. Some factors are only relevant to androstenone, others – to skatole and/or indole or to androstenone and skatole (i.e. factors with multiple effects). Note that synergy effects that are non-additive effects from manipulating a few factors at the same time are not described in Table 1. Existing studies mainly look at each factor separately or sometimes at few related ones; whereas control of different combinations of factors throughout the production process can be expected to be a better option than controlling only one factor. So, evaluation of such synergy effects would be another challenge in the assessment of the total effect of these factors.

It should be noted that the presented studies were conducted in different countries. This means that animals of different breeds, slaughter weight and fed different diets were used in experiments as well as methods applied to measure boar taint

Table 1. Potential effect of key factors on fat androstenone, skatole and indole levels along the pig production chain[1].

	Selected references	A	S	I	Principal results
Animal breeding					
Genetic selection against boar taint	(Robic et al., 2008)	+	+	+	The incidence of boar taint is heritable, as are the levels of androstenone and skatole. Genetic selection against boar taint, and especially against androstenone, is expected to be successful.
Animal growing (fattening farms)					
1. Housing environment and hygiene (associated with pig cleanliness):					
- floor type	(Hansen et al., 1997)	no	+	+	Boars lying in copious amounts of warm faeces and urine (concrete-floor pens) had higher skatole and indole than pigs which were kept clean (slatted floor pens).
- stocking rate	(Hansen et al., 1994)	no	+	+	Skatole and indole levels were higher in boars kept at higher stocking rates.
- seasonal variation (air temperature)	(Hansen et al., 1994)	no	+	?	Skatole levels were higher in fat at high temperatures in the summer, compared to the winter.
- seasonal variation (daylight hours)	(Andersson et al., 1998)	(+)no	(+)no	?	Boar taint was indirectly affected (probably related to puberty), with higher scores in the autumn/winter than in the spring/summer, although this was not clearly indicated by the measurements of androstenone and skatole (no significant effect).
- ventilation rate	(Hansen and Larsen, 1994)	no	(+)no	?	Different ventilation rates have been shown to have effects on skatole levels (no significant effects).
2. Social environment:					
- dominance (social rank)	(Giersing et al., 2000)	(+)no	no	no	Androstenone levels were higher in high-ranked boars (probably related to puberty).
- stable social groups	(Aldal et al., 2005; Fredriksen et al., 2006)	+	(+)no	?	'Birth to slaughter' systems reduced the androstenone level.
- sex grouping	(Patterson and Lightfoot, 1984; Andersson et al., 1997)	+	+	?	Androstenone levels were greater for the heavyweight boars (110 kg live weight) raised mixed-sex; but not for lower weight ones. Skatole levels were slightly greater in boars raised in single-sex pens.
3. Feeding:					
- feed structure (diet form and dietary particle size)	(Jensen, 2006)	no	?	?	It has never been investigated if the feed structure has any effect on skatole levels.
- feed system (dry diets vs. wet diets)	(Andersson et al., 1997)	no	+	?	The feeding of whey seemed to reduce skatole, as compared with tap water or dry feeding.
- extra water supply	(Kjeldsen, 1993)	no	(+)no	?	Free access to water (with extra nipple drinker) reduced skatole levels in herds with a skatole level above 0.10 ppm (no significant effects).

Table 1. (continued)

	Selected references	A	S	I	Principal results
- feeding level (restricted vs. ad libitum)	(Bonneau, 1987)	+	?	?	Androstenone levels increased in boars of the same age fed ad libitum, compared to those fed restrictively. But there was no significant difference between males of the same weight.
- feed strategy (fasting before slaughter)	(Kjeldsen, 1993)	no	+	?	Restricted feeding with a fasting for 12 hours before delivery reduced skatole levels, compared to ad libitum feeding.
- feed composition (protein, amino acids, carbohydrates and others)	For an overview see (Zamaratskaia, 2004)	no	+/no	?	There have been numerous attempts to manipulate skatole levels using feed additives. The inclusion of a high amount of low-digestible protein in the diet increased skatole levels, and the use of casein as a source of protein decreased skatole levels. Addition of dietary carbohydrates, such as sugar beet pulp or raw potato starch, has been found to reduce skatole levels.
- special diet	(Hansen et al., 2000)	no	+	?	The use of growth promoting antibiotics prevents the risk of increase skatole levels.
Slaughtering (slaughterhouses)					
Live slaughter weight and age	(Aldal et al., 2005, Zamaratskaia, 2004)	+	+	+	Slaughter at a younger age and lower weight, before the onset of puberty, might reduce the risk of increased levels of boar taint compounds.

[1]A/S/I = androstenone, skatole, indole; no/(+)no/+/? = no effect observed/no significant effect observed/significant effect observed/no information yet available in the literature.

compounds were sometimes different. In this sense, research efforts could be strengthened by harmonization of knowledge from different studies in order to get insight into the factors' effects in similar conditions.

Based on the harmonized knowledge about the factors and their effects, different management measures can be designed and adopted to prevent boar taint. In this way, it might be possible to achieve the boar taint level acceptable to consumers, or at least to decrease this level to a certain extent. Implementation of these measures however assumes involvement of different chain participants. Also, the measures may differ significantly in terms of both cost and impact on boar taint reduction (measured in terms of androstenone, skatole and indole levels). So, economic feasibility of altering management strategies needs to be investigated.

In general, all these issues would also be important while bringing together altering management strategies with other alternatives to surgical castration such as genetic selection and slaughter at a younger age and lower weight. This implies that these issues need to be considered while choosing the best alternative to surgical castration for the whole chain. It is also important that the choice of such alternative (i) should be coherent with improvement of other aspects of animal production, such as food safety, animal health, animal welfare and environment, (ii) not to cause negative effects on meat qualities, and (iii) satisfy existing regulations . As can be seen from Table 1, some management strategies reduce levels of boar taint but at the same time have no practical application, at least in some countries. An example is the use of growth promoting antibiotics that is prohibited in many EU countries. Changing floor design is another example where slatted floor pens are better for reducing skatole and indole, compared to concrete floor pens. But wholly slatted floor is not acceptable in many countries due to its negative effect on pig welfare. In the light of animal welfare and health concerns, aggressive behavior and the resulting negative consequences, e.g. skin damage, should also be carefully considered while changing management strategies. As for meat quality, meat from entire males given fermented liquid diet was significantly worse in terms of the scores for flavor (Hansen et al., 2000). At the same time, there are also examples when altered strategies positively effect other aspects of animal production. For instance, "birth to slaughter" systems not only reduce boar taint (Aldal et al.; 2005, Fredriksen et al., 2006), but also improve pig health, resulting in lower costs for treatment (van der Peet-Schwering et al., 2008).

Economics of boar taint prevention along the chain

Implementation of any above-described alternative would have certain economic implications. Basically, it would involve additional costs that should be balanced against advantages and disadvantages associated with raising boars, compared to raising hogs, and expressed, if possible, in monetary terms.

Existing economic studies on boar taint prevention mainly deal with different scenarios of surgical castration under anesthesia and/or analgesia (Kluivers-Poodt et al., 2007). Presently it is the most practiced method in the EU-countries where surgical castration without pain relief is banned. Results show that additional costs differ among the considered scenarios, which were defined in terms of types of treatments available, person administered the treatment, i.e. farmer himself or with the support of veterinarian, and size of the farm. None of these scenarios however entails any advantages linked to raising boars. Furthermore, the current study primarily focuses on alternatives to surgical castration in any form.

In general, not much research into economics of alternatives to surgical castration of boars is available in the literature. Few studies have been conducted to examine economic consequences of immunocastration (Novoselova, 2007) and slaughter at a younger age and lower weight (Baltussen et al., 2008). For immunocastration, comparison of savings on labor cost of surgical castration, higher daily weight gain and better feed conversion with additional labor cost of vaccination and vaccine price involved indicated a decrease in the hog cost price (farm level). Baltussen et al. (2008) opposed the same benefits of boar production with losses related to slaughtering boars at a younger age and lower weight, assuming that the whole country raised only boars; whereas in the rest of the EU castration was carried out, and that the risk of boar taint was totally eliminated. This study showed significant decline in the gross added value for the pig sector (farm and slaughterhouse levels) as a result of slaughtering boars at a younger age and lower weight. As mentioned above, depending on the vaccination time in case of immunocastration and knowing that slaughter at a younger age and lower weight in reality does not entirely eliminate boar taint, it might be necessary to perform on-line detection at the slaughter line in addition to any of these two alternatives to assure absence of boar taint. So far, such alternative and the corresponding costs and benefits are not considered in literature; perhaps, due to insufficient knowledge about detection techniques applicable in the slaughter setting. Likewise, little information is available on economic consequences of other alternatives to surgical castration. So, basic questions such as what alternative or combination of alternatives is the best and at what cost, remain unanswered.

The existing studies on alternatives to surgical castration do not take into account all the identified pros and cons of raising boars (Table 2). And although many of pros and cons have been widely discussed in the literature, economic studies on boar production is usually limited to exploring benefits resulting from better feed conversion, better growth rate and higher carcass leanness. For a review of studies to quantify such benefits, see Xue et al. (1997). In this sense, a more complete cost-benefit analysis, with all pros and cons considered, is lacking. It should however be noted that monetary value is not to be easily assigned to all of the presented advantages and disadvantages. For example, more complicated economic methods would be needed to value improved animal welfare.

Also, Table 2 shows that potential advantages and disadvantages often relate to different levels of the pig production chain. This logically suggests that cost and benefits resulting from implementation of a particular alternative to surgical castration will also be somehow distributed among chain participants. To the authors' knowledge, no research is available to investigate this issue and, therefore, to indicate how total effort is to be best allocated among the chain participants. Both chain participants and the government would be interested in such knowledge to optimize their decisions on boar taint prevention. So, a chain perspective on economics of prevention of boar taint need to be further elaborated.

Table 2. Potential advantages "+" and disadvantages "–" associated with raising boars, compared to hogs.

	References		Principal results
Animal breeding			
Unplanned breeding	(Zamaratskaia, 2004)	"–"	Castration prevents unplanned breeding
Animal growing (fattening farms)			
Feed conversion	(Walstra, 1974) (Xue et al., 1997a) (Patterson and Lightfoot, 1984) (Andersson et al., 1997)	"+"	More efficient feed conversion
Growth rate	(Bonneau, 1998, Walstra, 1974) (Xue et al., 1997a) (Patterson and Lightfoot, 1984) (Andersson et al., 1997)	"±"	Faster growth sometimes, data are inconsistent due to variability among other factors (diets and the difference in weight and age of maximum growth) Superior live weight under restricted feeding for a given amount of food, although under truly ad libitum feeding hogs may eat more than boars and gain faster in the later fattening stages but to the detriment of carcass quality
Environmental benefit	(Xue et al., 1997a)	"+"	Reduced faecal waste and reduced environmental impact
	(Bonneau, 1998)	"+"	Better efficiency for nitrogen retention
Animal health	(Bonneau, 1998)	"+"	The markedly lower number of chronic inflammations
	(Patterson and Lightfoot, 1984)	"+"	No risk of infection involved in castration
Animal welfare	(Bonneau, 1998) (Zamaratskaia, 2004)	"+"	No pain and discomfort of castration for animals
Behavior control	(Bonneau, 1998) (Zamaratskaia, 2004)	"–"	More aggressive behavior
Costs related to castration:	(Bonneau, 1998)	"+"	No labor costs involved in castration
		"+"	No possible animal losses and temporary decrease in performance following castration
	(Bañón et al., 2004)	"+"	Decrease in production costs related to feeding
Slaughtering (slaughterhouses)			
Carcass quality and characteristics:			
- backfat thickness and leanness	(Bonneau, 1998, Walstra, 1974) (Xue et al., 1997a) (Patterson and Lightfoot, 1984) (Andersson et al., 1997)	"+" "–"	Thinner backfat, leaner carcasses Sometimes, too lean carcasses may also be a problem, the industry need a minimum quantity of good quality fat. Extreme leanness can result in a lack of cohersion between backfat and the underlying muscle
- percentage primal cuts	(Walstra, 1974)	"+"	
- classification score	(Walstra, 1974)	"+"	
- dressing percentage	(Walstra, 1974) (Andersson et al., 1997)	"–"	Dressing percentage reduction
- percentage offal	(Walstra, 1974)	"–"	Lower percentage offal

Table 2. (continued)

	References	Principal results	
- fat quality	(Bonneau, 1998)	“–“	Softer and less resistant to oxidation (especially in lean pigs genotypes)
	(Xue et al., 1997a)	“–“	The higher degree of unsaturation and higher water content of leaner animals can result in carcasses with unacceptably soft fat
- carcass length	(Xue et al., 1997a)	“+“	Longer carcass length
- longissimus muscle area	(Xue et al., 1997a)	“+“	Larger longissimus muscle area
- bone proportion	(Xue et al., 1997a)	“–“	Higher bone proportion, heavier bones at the same slaughter weight
- attractiveness of chops & joints	(Patterson and Lightfoot, 1984)	“+”	More attractive chops and joints
- skin proportion	(Patterson and Lightfoot, 1984)	“–“	Higher skin proportion, thicker and not that fine skin
- pH value (pH_u)	(Xue et al., 1997a)	“–“	Higher pH_u, no difference when less than 4 hours elapse from farm to slaughter
Consumption			
Meat quality:			
- boar taint	EFSA report (2004)	“–“	Presence of boar taint, the most important limitation
- appealing to consumer	(Bonneau, 1998)	“+”	Smaller development of intermuscular
- meat tenderness	(Bonneau, 1998)	“–“	Less tender
Nutritional advantages			
- development of adipose tissue	(Bonneau, 1998)	“+”	
- dietetic point of view	(Bonneau, 1998)	“+”	Lower lipid content and more unsaturated fatty acids in adipose tissues
- protein content	(Zamaratskaia, 2004)	“+”	Higher protein content

Conclusions and future outlook

This paper examines the key technical (alternatives to surgical castration, factors influencing boar taint development) and economic considerations associated with the presently feasible alternatives to surgical castration. In particular, it reviews the state of the art of these issues from a chain perspective.

The paper concludes that prevention of boar taint is a challenge and task for the entire pig production chain and an integrating approach would be useful to deal with this. The study suggests genetic selection in the animal breeding stage, altering management strategy in the animal growing stage and slaughter at a younger age and lower weight in the slaughtering stage as primary alternatives to be considered in development of such an approach. When sufficient knowledge is available, the approach can be elaborated by including on-line detection of carcasses with (possibly) high levels of boar taint and/or other alternatives.

In the first place, such an approach would require to fill the identified gaps in the knowledge about technical and economical aspects of boar taint prevention in the broader chain context and provide more insights into consumer acceptance of boar taint. In the next step, integrated chain models should be developed. These models should account for costs and benefits at the individual level of each chain participant as well as at the entire chain level. Thus, such models may help prioritize opportunities for allocating resources to preventing boar taint within 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 totally determined.

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