SCIENTIFIC OPINION

Scientific Opinion concerning a Multifactorial approach on the use of animal and non-animal-based measures to assess the welfare of pigs[1]

EFSA Panel on Animal Health and Welfare (AHAW)[2, 3]

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ABSTRACT

Pigs have a need for manipulable materials to satisfy a range of behavioural needs, which can be different in different classes of pig. When these needs are not met, a range of adverse welfare consequences result, one of these being an increased risk for tail-biting in weaners and rearing pigs. The ability to control the risk of tail-biting is essential when aiming to avoid tail-docking. Based on available scientific information this Opinion identifies the multiple interactions between risk factors, welfare consequences and animal and non-animal-based measures on the two subjects requested (i) the absence of functional manipulable materials, for pigs at different stages in life and (ii) tail-biting, for weaners and rearing pigs only. An attempt is made to quantify the relationships between the identified interactions by carrying out a statistical analysis of information from available databases, those being an international dataset collected using the Welfare Quality® protocol, which was not designed to evaluate risk factors for tail-biting and therefore, it had limitations in fitness for this analysis, and a large Finnish dataset with undocked pigs. Based on the current state of knowledge, the AHAW Panel proposes two simple tool-boxes for on farm use to assess (i) the functionality of the supplied manipulable material and (ii) the presence and strength of risk factors for tail biting. Both proposed tool-boxes include a combination of the most important resource-based and animal-based measures. Further development and validation of decision–support tools for customised farm assessment is strongly recommended and a proposal for harmonised data collection across the range of European farming circumstances is presented. A series of further recommendations are made by the AHAW Panel.

KEY WORDS

pig, welfare, tail-biting, tail-docking, enrichment, manipulable material

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SUMMARY

Following a request from the Commission, the EFSA Animal Health and Welfare Panel (AHAW) was asked to deliver a scientific opinion on a multifactorial approach on the use of both animal and non-animal-based measures to assess the welfare of pigs especially those welfare parameters regulated in Council Directive 2008/120/EC[4], Article 3(5) and Annex I Chapter I numbers 4 and 8 regulating the provision of manipulable material and avoidance of tail-docking.

In order to address the Terms of Reference (ToRs), the Opinion considers separately the issues of avoidance of tail-docking and provision of functional manipulable materials which meet the needs of the animals, although there is significant interaction between these two issues which is incorporated in the response. To promote the use of functional manipulable materials, consideration focuses on the identification of when such materials meet the behavioural needs of the animals at different stages in life, the suckling piglet, growing pig from weaning to slaughter and breeding sow and boar, and how this might be assessed in a farm situation. Since tail-docking of neonatal piglets is carried out to reduce the risk of tail-biting in later life, between weaning and slaughter, consideration focuses on the other risk factors for tail-biting in rearing and finishing pigs, and how these might be better managed and controlled in a farm situation to reduce the need for docking.

The first term of reference (ToR) is to identify the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures. A summary of available information in the scientific literature was made on two subjects (i) the absence of functional manipulable materials, for all life stages and (ii) tail-biting, for weaner and rearing pigs only.

The second ToR is to identify the strength and predictive capacity of the above identified interactions. To address this ToR, an attempt is made to quantify the relationships described in ToR 1 by carrying out a statistical analysis of information from available databases recording (i) multiple welfare outcome indicators in pigs and (ii) studies on the risk factors for tail-biting. Two datasets were used for this purpose: (i) a set of data from 242 farms in five countries [Spain, France, Finland, Netherlands, and Sweden] collected according to a common Welfare Quality® protocol, and (ii) a dataset from 1574 farms in Finland, collected by veterinarians during regular herd health visits during 2011 and 2012 providing information regarding the use of 8 different manipulable materials (straw, hay, peat, saw dust, paper, woodchips, wood, toy) together with the presence of tail-biting during the time of the visit to the farm.

The third ToR is to propose a model to evaluate how likely certain welfare consequences may happen given specific risk factors and which animal and/or non-animal-based measures would better fit for the assessment of those consequences. To address this ToR, consideration was given to the processes necessary to construct a 'diagnostic' tool-box of animal and non-animal-based measures which can be used to assess the level of risk from the contributing factors in the case of (i) lack of functional manipulable material, or (ii) tail-biting, and measures which can be used to describe the current extent of the welfare consequences.

The principal conclusions from the work are:

- Pigs have a need for manipulable materials to satisfy a range of behavioural needs, which can be different in different classes of pig. When these needs are not met, a range of adverse welfare consequences result, one of these being an increased risk for tail-biting in weaners and rearing pigs.

- Some manipulable materials, although good at meeting the behavioural needs of pigs, can also have adverse effects on other aspects of pig welfare. These adverse effects have not been adequately studied to ensure safe provision in all cases.

- The ability to control the risk of tail-biting through correct identification and alleviation of the predisposing animal, environmental and management factors on that farm is essential when aiming to avoid tail-docking. The presence of these risks can be indicated by a range of resource/management and animal-based measures.

- Analyses of an international dataset collected using the Welfare Quality® protocol did not show animal-based measures of behaviour which clearly distinguished between farms providing different types of manipulable material. Category of manipulable material was reflected in severe skin lesions, but not in bitten tails. This may reflect the fact that many farms had pigs with docked tails and there was a confounding between type of manipulable material and tail docking in this dataset.

- Analyses of an international dataset using the Welfare Quality® protocol suggested a number of animal and resource-based factors to be important risk factors for tail-biting, but a high degree of uncertainty in the model precludes strong conclusions. The dataset used was not designed to evaluate risk factors for tail-biting and therefore, it had limitations in fitness for this analysis.

- The Welfare Quality® dataset indicated the possibility for undocked pigs to be housed and managed in a way which does not imply an increased risk for tail-biting. However, this requires further investigation in more comprehensive datasets where the overall farm prevalence of bitten tails, including animals in hospital pens and euthanized/culled animals, is recorded.

- Analyses of a large Finnish dataset with undocked pigs showed that use of straw was associated with reduced tail-biting prevalence relative to the other types of manipulable material (including objects) present on Finnish farms. No other manipulable material gave consistent reduction in tail-biting across both weaner and rearing pigs compared to the population average.

- The adequacy of provision of manipulable material could be assessed under farm conditions by reference to a permitted list of materials, but this approach has major practical and biological limitations. A better resource-based approach would be to judge the functionality of the manipulable materials to meet the behavioural need of the pigs by the properties which that material possesses.

- Because the human view-point may not correctly interpret the pigs' perception of material suitability, it would be preferable in a tool-box to use animal-based measures for the assessment. The type of manipulable material supplied has an effect on the prevalence of severe skin lesions. It is also affects prevalence of bitten tails but this measure may be less sensitive if tails are docked. However, the specificity of both lesion measures to assess the functionality of manipulable material is limited. Therefore, a practical tool-box should contain direct behavioural measures.

- Animal-based behavioural measures of functionality of the supplied manipulable material need to be simple and robust under farm measurement conditions. The ratio between material-directed exploration and other redirected exploration to pen mates and pen fittings has been suggested for this purpose. However, no comprehensive measure has yet been scientifically validated for this purpose, although studies currently in progress are addressing this question.

- A simple tool-box for on-farm use to assess the functionality of the supplied manipulable material is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

- The presence of known risk factors for tail-biting can be assessed on farm using a tool-box containing both resource/management-based and animal-based measures. These outcome measures may not always be specific for a given risk factor, but the occurrence of a measure suggestive that a risk factor may be present indicates the need for further investigation.

- With present knowledge the relative importance of different risk factors as hazards for tail-biting and the interactions between these risk factors cannot be scientifically quantified. Further studies are needed for this purpose. These should provide the data necessary to weight different risk factors in decision-support tools which can provide customised risk assessment for individual farms.

- A simple tool-box for on farm use to assess the presence and strength of risk factors for tail-biting is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

The recommendations arising from the work are:

1 Any study on manipulable materials should consider possible adverse effects and their alleviation.

2 Further research should be carried out into the causal relationship between the general pig health and tail-biting risk.

3 There is a need for more comprehensive analyses of existing datasets collected for the purpose of evaluating risk factors for tail-biting in different farm typologies. This could better indicate the relative importance of different risk factors for the occurrence and severity of tail-biting outbreaks, and the way in which these factors interact.

4 In order to assess the true prevalence and importance of the risk factors for tail-biting and their interactions, further harmonised data collection across the range of European farming circumstances is needed. A proposal is made (Appendix J) for a data model which might be used in such a study

5 There is a need to investigate the farmers' acceptance level of tail-biting relation to their previous experiences of this problem and perceived ability to limit the level of injury.

6 There is a need for further studies to provide guidance on how to house and manage undocked pigs under different farm circumstances without uncontrollable tail-biting outbreaks.

7 Tail-biting and severe skin lesions should be included in a tool-box to assess the functionality of manipulable material, although it is recognised that these may be caused by many risk factors.

8 Validation of a practical on farm assessment protocol for functionality of manipulable material based on behavioural measures should be carried out, in order to provide a sensitive tool-box measure for use also in docked pigs.

9 The further development and validation, from robust epidemiological data, of decision-support tools for customised assessment of tail-biting risk factors on individual farms is strongly recommended. Such tools could assist farmers to identify, and prioritise correction of, the most important hazards for tail-biting on their own unit.

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BACKGROUND AS PROVIDED BY THE EUROPEAN COMMISSION

The European Union (EU) Animal Welfare Strategy 2011-2015 foresees the development of guidelines to facilitate the proper implementation of the requirements of Council Directive 2008/120/EC[4] laying down minimum standards for the protection of pigs[4]. The Commission would like to include welfare indicators in the guidelines so as to enable an assessment of degree of compliance with legislative requirements including those laid down in Council Directive 98/58/EC[5] concerning the protection of animals kept for farming purposes[6].

However, compliance with some requirements in one area may jeopardise the welfare of the animals in another area (e.g. the provision of straw to stimulate rooting behaviour may in a warm climate prove to have adverse effects due to humidity, attracting flies).

Welfare indicators (animal-based and non-animal-based measures) to be included in the guidelines should therefore be able to identify the actual well-being of the pigs, as a result of the interaction of the different factors and legal requirements.

The 2012 EFSA Scientific Opinion[7] identified a tool-box of potential animal-based and non-animal-based measures to address the main poor welfare outcomes caused by the risk factors identified in the previous EFSA Scientific Opinions on pig welfare[8]. However, this Opinion also highlighted that there is usually no simple one-to-one relationship between the observed outcomes and the possible causative risk factor. Some animal-based measures may be the result of a number of risk factors not only one and so contribute more to an overall welfare assessment than measures that are a consequence of a single factor. Hence, to identify the cause of a specific welfare outcome several animal-based measures need to be used.

Therefore, given the current on-going work on future EU guidelines on Council Directive 2008/120/EC[4] it would be opportune to identify which welfare indicators and interactions would be most appropriate to evaluate the well-being of pigs while also helping to assess the degree of compliance.

TERMS OF REFERENCE AS PROVIDED BY THE EUROPEAN COMMISSION

The Commission therefore considers it opportune to request EFSA to use a Multifactorial approach on the use of both animal and non-animal-based measures to assess the welfare of pigs especially those welfare parameters regulated in Directive 2008/120/EC[4], Article 3(5) and Annex I Chapter I numbers 4 and 8 regulating the provision of manipulable material and avoidance of tail-docking.

1. Identify the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures.

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[4] OJ L 47, 18.2.2009, p. 5.

[5] OJ L 221/23, 20.7.1998, p.5.

[6] OJ L 221, 8.8.1998, p. 23.

[7] Scientific Opinion on the use of animal based measures to assess welfare in pigs: http://www.efsa.europa.eu/en/efsajournal/pub/2512.htm

[8] Scientific Opinion on the welfare aspects of the castration of piglets: http://www.efsa.europa.eu/en/efsajournal/pub/91.htm
Scientific Opinion on the welfare of weaners and rearing pigs: effects of different space allowances and floor types: http://www.efsa.europa.eu/en/efsajournal/pub/268.htm
Scientific Opinion on animal health and welfare in fattening pigs in relation to housing and husbandry: http://www.efsa.europa.eu/en/efsajournal/doc/564.pdf
Scientific Opinion on the animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets: http://www.efsa.europa.eu/en/efsajournal/pub/572.htm
Scientific Opinion on the risks associated with tail biting in pigs and possible means to reduce the need for tail-docking considering the different housing and husbandry systems: http://www.efsa.europa.eu/en/efsajournal/pub/611.htm

2. Identify the strength and predictive capacity of the above identified interactions

3. Propose a model to evaluate how likely certain welfare consequences may happen given specific risk factors and which animal and/or non-animal-based measures would better fit for the assessment of those consequences.

The assessment should be based on and linked to the risk assessment of the previous EFSA Scientific Opinions on the welfare of pigs. In particular the Commission highlights the importance of the chosen indicators use in assessing compliance with legislative requirements as listed above.

ASSESSMENT

1. Introduction

1.1. Interpretation of the Terms of References (TORs)

In order to address the Terms of Reference (ToRs), the Opinion considers separately the issues of avoidance of tail-docking and provision of functional manipulable materials which meet the needs of the animals, although there is significant interaction between these two issues which will be incorporated in the response. To promote the use of functional manipulable materials, consideration focuses on the identification of when such materials meet the behavioural needs of the animals at different stages in life, the suckling piglet, growing pig from weaning to slaughter and breeding sow and boar, and how this might be assessed in a farm situation. Since tail-docking of neonatal piglets is carried out to reduce the risk of tail-biting in later life, between weaning and slaughter, consideration focuses on the other risk factors for tail-biting in rearing and finishing pigs, and how these might be better managed and controlled in a farm situation to reduce the need for docking.

To address the first ToR, regarding the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures, a summary of information is therefore provided on these two questions (i) the absence of functional manipulable materials, for all life stages and (ii) tail biting, for weaner and rearing pigs only. This will draw on the previous EFSA Scientific Opinions with particular relevance to these questions, where much of the necessary scientific literature was reviewed and expert opinion presented:

- Scientific Opinion of the Panel on Animal Health and Welfare on a request from the Commission on Animal health and welfare in fattening pigs in relation to housing and husbandry (EFSA, 2007a).

- Scientific Opinion of the Panel on Animal Health and Welfare on a request from the Commission on Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets. (EFSA, 2007b).

- Scientific Opinion of the Panel on Animal Health and Welfare on a request from Commission on the risks associated with tail-biting in pigs and possible means to reduce the need for tail-docking considering the different housing and husbandry systems. (EFSA, 2007c).

- EFSA Panel on Animal Health and Welfare (AHAW); Scientific Opinion on the use of animal-based measures to assess welfare in pigs. (EFSA, 2012a).

Information in these Opinions was subsequently updated in a technical report of EFSA[9]. This information, together with review of any new scientific information since the publication of these opinions and updates, will be used to construct a diagrammatic representation of the interactions between (i) the risk factors for poor welfare consequent on the failure to provide functional manipulable material at different stages in the pig's life, the welfare consequences of such lack of provision, and the indicators which can be used to identify and measure these welfare consequences; (ii) the risk factors for tail biting, the welfare consequences of being motivated to tail bite or being tail bitten and the indicators which can be used to identify and measure these welfare consequences. In addition, the animal-based measures which directly or indirectly indicate the presence and level of risk factors present in a given situation will also be considered.

[9] European Food Safety Authority, 2011. Technical report on Preparatory work for the future development of animal based measures for assessing the welfare of pigs, EN-18.
Available online: http://www.efsa.europa.eu/en/supporting/doc/181e.pdf

To address the second ToR, regarding the strength and predictive capacity of the above identified interactions, an attempt is made to quantify the relationships described in ToR 1 by carrying out a statistical analysis of information from available databases recording (i) multiple welfare outcome indicators in pigs and (ii) studies on the risk factors for tail biting. Where the available data prove to be inadequate for such assessment, expert opinion documented in the risk analyses presented in the previous EFSA Scientific Opinions is used to construct a qualitative assessment of the relative importance of the described interactions.

To address the third ToR, the information from the first two ToR is used to propose a practical model to evaluate (on a farm) how likely the adverse welfare consequences identified previously are to happen, given the specific risk factors which are present (on that farm). This includes considerations of the processes necessary to construct a “diagnostic” tool-box of animal and/or non-animal-based measures which can be used to assess the level of risk from the contributing factors in the case of (i) lack of functional manipulable material, or (ii) tail biting, and measures which can be used to describe the current extent of the welfare consequences.

1.2. General terminology

For the purpose of this Scientific Opinion, the following definitions have been applied to the different animal categories as set in the Council Directive 2008/120/EC[4]:

- Pig: means an animal of the porcine species, of any age, kept for breeding or fattening.
- Boar: means a male pig after puberty intended for breeding.
- Gilt: means a female pig after puberty and before farrowing.
- Sow: means a female pig after the first farrowing.
- Farrowing sow: means a female pig between the perinatal period and the weaning of the piglets.
- Dry pregnant sow: means a sow between weaning her piglets and the perinatal period.
- Piglet: means a pig from birth to weaning.
- Weaner: means a pig from weaning to the age of 10 weeks
- Rearing pig: means a pig from 10 weeks to slaughter or service.

Modified from the Scientific Opinion on the use of animal-based measures to assess welfare in pigs (EFSA, 2012a) and from the EFSA guidance on Risk Assessment for Animal Welfare (EFSA, 2012b):

- Risk factor: Any aspect of the environment of the animal in relation to housing and management, animal genetic selection, transport and slaughter, which may have the potential to impair or improve their welfare.
- Welfare consequence: the change in welfare that results from the effect of a factor or factors.
- Welfare indicator: an observed occurrence or trend in a measure indicative of welfare state.

- Welfare measure: a defined observation, recording or evaluation which can be used for the purpose of assessing an animal's welfare. These are in general animal-based but measures of housing and management may be predictors of changes in welfare.

- Animal-based measure: a response of an animal or an effect on an animal. It can be taken directly from the animal or indirectly and includes the use of animal records. The measure may, for example, be intended to: (i) assess the degree of impaired functioning associated with injury, disease, and malnutrition; (ii) provide information on animals' needs and affective states, such as hunger, pain and fear, often by measuring the strength of animals' preferences, motivations and aversions; or (iii) assess the physiological, behavioural and immunological changes or effects that animals show in response to various challenges.

- Non-animal-based (resources or management-based) measure: a measure of factors in the environment of the animal that may be linked to the likelihood of good or poor welfare.

1.3. Overview of previous EFSA Scientific Opinions

Following formal requests from the European Commission, the Animal Health and Welfare (AHAW) Panel of EFSA has issued a series of Scientific Opinions covering different aspects to the welfare of pigs. In 2007, three scientific opinions were adopted addressing (i) the animal health and welfare in fattening pigs in relation to housing and husbandry (EFSA, 2007a); (ii) the animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets (EFSA, 2007b); and (iii) the risks associated with tail-biting in pigs as possible means to reduce the need to tail-docking considering the different housing and husbandry systems (EFSA, 2007c). Management practices and environmental resources which are risk factors (or hazards) for poor pig welfare were identified in these three opinions but not linked to any welfare indicator or measure. In 2011, a technical report of EFSA[8] reviewed the pig welfare literature to identify gaps and potential areas to amend or strengthen the previous welfare Opinions as preparatory work for future development of animal-based measures for assessing the welfare of pigs. The technical report identified only a few additional conclusions. Among other things, it suggests that the use of group selection as a breeding strategy has the potential to reduce genetic predisposition to tail bite, and also draws attention to the predictive value of certain behavioural signs (e.g. tail posture).

In 2012, the AHAW Panel adopted a Scientific Opinion on the use of animal-based measures to assess welfare in pigs (EFSA, 2012a). The 2012 opinion integrated the previous EFSA welfare assessments with the animal-based measures proposed in the pig Welfare Quality® (2009) protocol with the full title 'Integration of animal welfare in the food quality chain: from public concern to improved welfare and transparent quality' and the focus was for the first time placed on the welfare consequences for the pigs when exposed to the factors which may have the potential to impair the welfare of the pig. It was concluded that 'in general the concepts of animal welfare used by the Welfare Quality® project and the EFSA Scientific Opinions overlap considerably. The main exception being that the Welfare Quality® protocol includes explicit signs of good welfare (i.e. positive emotional states), whereas the risk analyses presented in the EFSA opinions concentrate on the threats to poor welfare'. It was noted that there was difficulty in allocating reliable scales for scoring animal responses, as well as the need to identify robust and valid outcome based indicators of welfare. The opinion highlighted the insufficient animal-based measures to assess pain, frustration and the positive and negative emotional states of pigs and considered both animal-based and non-animal-based measures as useful predictors for assessing welfare of pigs. A full list of possible measures was compared to a tool-box from which the appropriate shortlist of measures are to be selected depending upon the specific objectives. However, setting thresholds between acceptable and unacceptable measures, and specifying how animal-based measures should be implemented, were not in the scope of the AHAW Panel (EFSA, 2012a).

2. Legislation

Council Directive 2008/120/EC[4] laying down minimum standards for the protection of pigs states that pigs should benefit from an environment corresponding to their needs for exercise and investigatory behaviour and that tail-docking is likely to cause immediate pain and some prolonged pain to pigs. Tail-docking practice is detrimental to the welfare of pigs, especially when carried out by incompetent and inexperienced persons. As consequence, rules should be laid down to ensure better practices.

Article 3 (5) of this Directive establishes that member states (MS) shall ensure that sows and gilts have permanent access to manipulable material at least complying with the relevant requirements laid down in Annex I. This Annex establishes that pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals.

In relation to tail docking, Annex I states that all procedures intended as an intervention carried out for other than therapeutic or diagnostic purposes, or for the identification of the pigs in accordance with relevant legislation, and resulting in damage to or the loss of a sensitive part of the body or the alteration of bone structure shall be prohibited, with some exceptions, tail-docking (docking of a part of the tail) being one of them. Nevertheless, tail-docking must not be carried out routinely but only where there is evidence that injuries to other pigs' tails have occurred. Before tail-docking is carried out, other measures shall be taken to prevent tail-biting and other vices, taking into account environment and stocking densities. For this reason inadequate environmental conditions or management systems must be changed.

The Directive also establishes that tail-docking shall only be carried out by a veterinarian, or a person trained and experienced in performing the applied techniques, with appropriate means and under hygienic conditions. If practised after the seventh day of life, tail-docking shall only be performed under anaesthetic and additional prolonged analgesia by a veterinarian.

Annex I, chapter II, section D3 of the Directive states for weaners and rearing pigs that 'when signs of severe fighting appear the causes shall be immediately investigated and appropriate measures taken, such as providing plentiful straw to the animals, if possible, or other materials for investigation. Animals at risk or particularly aggressive animals shall be kept separate from the group'.

3. ToR 1- Identification of the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures in relation to the provision of manipulable material and avoidance of tail-docking in pigs

3.1. Procedures to address this question

For the identification of the interactions between risk factors, welfare consequences and animal and non-animal-based measures, the methodology used in a recently published EFSA opinion on the welfare of broiler chickens was used (EFSA, 2012c). It involved the collection of these three aspects through a scan of the known literature and discussion in the working group. The interactions between them were identified and presented in a format similar to that of the broiler opinion, linking the three columns for the provision of functional manipulable materials by identifying risk factors, their associated welfare consequence(s) and finally the indicators associated with these consequences. This was done separately for weaners and rearing pigs, for piglets, for farrowing sows and for pregnant sows and boars because of the different behavioural needs that manipulable materials can satisfy at different life stages. Manipulable materials may be presented in a number of forms, including objects (sometimes called toys) which are suspended within the pen or loose on the floor, or substrates which are contained in troughs or racks or presented loose on the floor. In the latter case, these manipulable materials can sometimes take the form of bedding, which has functions over and above the satisfaction of behavioural needs referred to in this opinion. These may include the provision of non-slip flooring, cushioning for comfort around resting and thermal comfort. This Opinion considers only the role of the manipulable material to enable proper investigation and manipulation activities, in accordance with Annex I of Council Directive 2008/120/EC[4].

For the analysis of tail-biting risk, an additional procedure was the identification of a further set of animal-based measures which can be used as indicators to identify the presence of the major risk factors for tail biting.

For both sets of results, the scientific evidence of the strength of the relationship between risk factors, welfare consequences and animal-based indicators was assessed as being either a well-documented relationship, supported in a robust way by the available scientific evidence or other convincing evidence, or a weak or much less robust relationship, only supported by hypothetical or anecdotal evidence. This was then indicated on the diagrammatic representation of relationships.

3.2. Main findings

3.2.1. Provision of manipulable material

The need for manipulable materials is considered first for weaners and rearing pigs, where the role as a substrate for exploratory and foraging behaviour is common to all pig classes. Other classes are then considered, where additional roles specific to each of these classes are further discussed.

3.2.1.1. For weaners and rearing pigs

Weaner and rearing pigs need manipulable materials to satisfy intrinsically motivated exploratory and (possibly) foraging behaviour. This becomes apparent when these materials are absent or inadequate, and exploratory motivation is frustrated. Manipulation of other pigs and pen fittings will increase (e.g. Schouten, 1986; Fraser et al., 1991; Bolhuis et al., 2005; Peeters et al., 2006; Scott et al., 2006a,b), play behaviour will reduce (Chaloupkova et al., 2007), skin lesions and in particular tail-biting will increase (Schouten, 1986; Fraser et al., 1991; Beattie et al., 1995, 1996; De Jong et al., 1998; Sneddon et al., 2001; Van de Weerd et al., 2005). It has also been shown that the absence of manipulable material will affect the cognitive bias of young pigs: they will perceive ambiguous stimuli in a more pessimistic way (Douglas et al., 2012). A reduction in the accessibility of any materials provided, e.g. due to time restrictions, inadequate amount offered or suboptimal location of the material, will also result in negative welfare consequences and can be observed using the same indicators (e.g. Day et al., 2002; Van de Weerd et al., 2006). In addition, restricted access to a desired resource may increase competition and unrest (Hansen et al., 1982), as can be measured by increased levels of aggression, asynchrony of behaviour and less resting behaviour. The type and quality of the material offered also affects animal welfare. Materials which are of poor hygienic quality (e.g. through contamination) or which are injurious, may cause health problems and injuries (Tuyttens, 2005).

Figure 1 shows diagrammatically the relationships between the risk factors for inability to perform proper investigation and manipulation activities in weaned and rearing pigs, the welfare consequences of this inability and the animal-based indicators which can reflect the extent of these welfare consequences. For each risk factor, arrows and reference letters indicate which welfare consequence they might cause. For each welfare consequence, arrows and reference numbers indicate which animal-based measure may indicate their occurrence.

RISK FACTORS
(resources, environmental and management factors)

- Total lack of manipulable material (actual presence)
  ➔ a, g
  → b, c, h
- Unavailability of manipulable material during certain time periods
  ➔ a, e, g
  → b, c, h
- Inaccessibility of manipulable material
  ➔ a, d, e, g
  → b, c, h
- Low quantity of manipulable material (amount)
  ➔ a, e, g
  → b, h
- Low quality of manipulable material
  ➔ a, f, g.
  → b, c
- Inappropriate location of manipulable material in relation to the intended function of the material
  ➔ e, f, g, h.
- Lack of manipulable material for pigs who had previously experienced this (i.e. withdrawal of something expected)
  ➔ a, g
  → h
- Poor hygiene of manipulable material
  ➔ a, f
  → b
- Manipulable material which causes injury or pain to the animal
  ➔ g
  → a, b

WELFARE CONSEQUENCES

- a. Frustration of exploratory motivation
  ➔ 1, 2, 5, 6, 8, 9, 10, 12
  → 11
- b. Frustration of foraging motivation
  ➔ 8, 9
  → 1, 5, 6, 10
- c. Frustration of motivation to manipulate nesting material before lying down
  ➔ 6
  → 1,3,5,8,9, 10
- d. Frustration due to material being out of reach
  ➔1, 2, 5, 6, 8, 9, 10
- e. Competition for restricted amount of material
  ➔ 5, 6, 8, 9, 10
  → 12
- f. Health and thermoregulation problems arisen from poor hygiene
  ➔ 3, 4, 13
  → 7
- g. Injuries
  ➔ 4, 7, 8, 9
- h. Negative effect on resting behaviour, unrest
  ➔ 3, 5, 6, 10
  → 7, 8, 9, 13

ANIMAL-BASED INDICATORS
(direct and indirect)

1. Increased frequency of oral manipulation of other pigs
2. Changes in play behaviour with manipulable material
3. Soiling of pen, soiling of manipulable material
4. Increase of disease
5. Decreased manipulation of manipulable material
6. Increased manipulation of pen furniture
7. Increase of non-aggressive injuries
8. Increase of lesion score
9. Increase of tail; ear, flank biting
10. Increase in agonistic behaviour
11. Reduced diurnal cortisol rhythm
12. Negative affective state/ cognitive bias
13. Increased dirtiness of animals

Figure 1: Associations between risk factors and welfare consequences, and between welfare consequences and animal-based indicators in relation to provision of manipulable material for weaner and rearing pigs. Arrows in column 1 refer to the lettered boxes in column 2. Arrows in column 2 refer to the numbered boxes in column 3. A bold arrow (➔) relates to a well-documented relationship while a small arrow (→) suggests a weak or much less robust relationship.

3.2.1.2. For piglets

Piglets start showing rooting behaviour in their first week of life (Petersen, 1994). By adding manipulable materials to the environment of the piglets, redirected exploratory behaviour can be reduced. This has been shown for behaviour redirected towards littermates (Telkänranta et al., 2012), pen fittings (Lewis et al., 2006) and probably also the sow, resulting in fewer teat lesions in the dams (Lewis et al., 2006). There are indications that this affects the welfare of the sow indirectly, as sows with litters given extra manipulable objects showed a lower degree of tear staining (Telkänranta et al., 2014a), which is suggested as a novel indicator of chronic stress in pigs (DeBoer, 2012).

Giving access to appropriate manipulable material during the early stages of piglet life is especially important, as conditions during the early post-natal period have long-lasting effects on the development of the animals. Piglets benefit from the possibility to root and investigate at an early age, with effects on both their behavioural and physiological development. Early studies suggested that the pre-weaning manipulable material is important for reducing belly-nosing after weaning, and tail-biting in the weaner and rearing stages, but that these abnormal behaviours are more strongly influenced by the current environment (EFSA, 2007c). However, since then, many studies have highlighted the wide range of effects on behaviour of early access to manipulable material. Early access to manipulable material has been shown to decrease aggressive behaviour after weaning (Chaloupkova et al., 2007) and all the way through to the fattening stage (Munsterhjelm et al., 2009). Piglets given manipulable material have been shown to develop a more biologically normal cortisol rhythm (de Jong et al., 2000) and this effect seems to be long-lasting, depending on the early conditions (Munsterhjelm et al. 2010). In addition, level of manipulable material during the piglet stage can have an effect on tail-biting risk later on during the pigs´ life (Moinard et al., 2003; Telkänranta et al., 2014b) and the level of manipulable material in the pre-weaning environment might have a positive effect on the development of feeding behaviour (Oostindjer et al., 2011).

Figure 2 shows diagrammatically the relationships between the risk factors for inability to perform proper investigation and manipulation activities in piglets, the welfare consequences of this inability and the animal-based indicators which can reflect the extent of these welfare consequences. For each risk factor, arrows and reference letters indicate which welfare consequence they might cause. For each welfare consequence, arrows and reference numbers indicate which animal-based measure may indicate their occurrence. The welfare consequences and associated animal-based indictors printed in bold text highlight those which are class-specific for piglets.

RISK FACTORS
(resources, environmental and management factors)

- Total lack of manipulable material
  ➔ a, i, j
  → b, c, g, h
- Unavailability of manipulable material during certain time periods
  ➔ a, e, g
  → b, c, h
- Inaccessibility of manipulable material
  ➔ a, g
  → b, c, d, h
- Low quantity of manipulable material
  ➔ a, e, g
  → b, c, h
- Low quality of manipulable materia
  ➔ a, f, g
  → b, c, h
- Inappropriate location of manipulable material in relation to the intended function of the material
  ➔ a, d, e, f
  → b, c, g, h
- Poor hygiene of manipulable material
  ➔ a, f
  → b
- Manipulable material which causes injury or pain to the animal
  ➔ g
  → a, b

WELFARE CONSEQUENCES

- a. Frustration of exploratory motivation
  ➔ 1, 2, 5. 6, 7, 8, 9, 10, 11, 14, 15, 16
  → 12
- b. Frustration of foraging motivation
  → 1, 5, 6, 8, 9, 10, 14
- c. Frustration of motivation to manipulate nesting material before lying down
  ➔ 1, 5, 6
  → 3, 8, 9, 10
- d. Frustration due to material being out of reach
  → 1, 5, 6, 8, 9, 10
- e. Competition for restricted amount of material
  ➔ 10
  → 8, 9, 12
- f. Health and thermoregulation problems arisen from poor hygiene
  ➔ 3, 4
  → 7, 9 , 13
- g. Injuries
  ➔ 4,7, 8, 9
- h. Negative effect on resting behaviour, unrest
  → 3, 5, 6, 9, 10, 13
- **i. Unfavourable changes in behavioural development**
  ➔ 15, 16
  → 12
- **j. Unfavourable changes in development of stress resistance**
  ➔ 11
  → 16

ANIMAL-BASED INDICATORS
(direct and indirect)

- 1 Increased frequency of oral manipulation of other piglets
- 2. Changes in play behaviour with manipulable material
- 3. Soiling of pen, soiling of manipulable material
- 4.Increase of disease
- 5. Decreased manipulation of manipulable material
- 6. Increased manipulation of pen furniture
- 7. Increase of non-aggressive injuries
- 8. Increase of lesions score
- 9. Increase of tail; ear, flank biting
- 10. Increase in agonistic behaviour
- 11. Reduced diurnal cortisol rhythm (later in life)
- 12. Negative affective state/ cognitive bias
- 13 Increased dirtiness of animals
- **14. Increased number of udder and nipple lesions in sow**
- **15. Increased occurrence of fighting post-weaning**
- **16. Increased tail-biting frequency after weaning**

Figure 2: Associations between risk factors and welfare consequences, and between welfare consequences and animal-based indicators in relation to provision of manipulable material for piglets. Arrows in column 1 refer to the lettered boxes in column 2. Arrows in column 2 refer to the numbered boxes in column 3. A bold arrow (➔) relates to a well-documented relationship while a small arrow

(→) suggests a weak or much less robust relationship. The welfare consequences and associated animal-based indictors printed in **bold** text highlight those which are class-specific for piglets.

3.2.1.3. For farrowing sows

Sows in the farrowing unit, like pigs in other stages, also have a need for manipulable materials as substrates for foraging and exploratory behaviour and, in sows, lack of material can cause an increase in stereotypic behaviour (EFSA, 2007b).

In farrowing sows, manipulable material has a specific, and very important, function in addition to those reported for pigs of other ages. Sows have a strong, hormonally determined need to build a farrowing nest (EFSA, 2007b). In semi-natural conditions, sows use a variety of materials to form a bedded and often covered nest. The restriction of the possibilities to fulfil this need by crating the sow, and by not providing material for nesting, is stressful for the sow (Lawrence et al., 1994), and the stress level stays high after farrowing (Oliviero et al., 2008). During the nest building phase, the frustration caused by inability to fulfil the need to nest build can be seen as sham nest building and stereotypic manipulation of pen structures (Lawrence et al, 1994). A restrictive farrowing environment reduces the oxytocin level of sows (Oliviero et al., 2008), and further addition of nesting materials can increase the oxytocin level (Yun et al. 2013). The stress, and parallel endocrinological changes, cause several negative effects on sow and piglet welfare, as well as on production. Farrowing duration increases, followed by an increase in stillbirth numbers (Oliviero et al., 2008, 2010), early milk production and colostrum transfer decreases (resulting in lower immunity in piglets), causing lower piglet weight gain (Yun et al., 2014), and maternal reactiveness and good mothering characteristics are reduced (Herskin et al,. 1998; Yun et al., 2013).

When considering farrowing and lactating sows, a specific challenge is to find ways to provide appropriate nest building and manipulable material within the constraints of the crates, in which most sows are kept during this period. In addition to the crate being restricted in space allowance, thus making it difficult to use solid objects for manipulable material, the restriction of the sows´ movements, as well as the typical pawing and rooting behaviour, during the nest-building period cause any bedding-type or loose material to easily end up out of reach of the sows. Most farrowing pens are also, to a great extent, fitted with slatted floors, which makes the addition of bedding-type material, such as straw, saw-dust or shredded paper difficult and only providing short-term benefit for the sow. A recent study has demonstrated the feasibility of providing substantial amounts of straw in partly slatted pens, and that the straw throughput is enough to avoid hygienic problems if the chop length is adjusted for the slat flooring used (Westin et al., 2013). An alternative solution proposed by Dutch researchers is to use a jute cloth (approximately 1 x 1.5 m) suspended from the side of the crate, with which the sow can make rooting movements on the floor. Unpublished data suggests that the availability of jute during the nest building phase results in fewer sow posture changes and fewer piglets crushed during parturition (Anita Hoofs, 14 Feb 2014, personal communication at stakeholder symposium on "The Prodromi Farrowing system" in Arnhem, the Netherlands).

When considering studies on nest-building behaviour of sows, and the welfare of the sows during this phase, it is important to note that it is not possible to fully separate the effect of lack of nest building material from confining the sow in a crate in all the mentioned studies. It is probable that the confinement is a greater welfare issue than the lack of nest building substrate (Jarvis et al., 2004). In the figure below, connections that might be a result of a combined effect of crating and the lack of nest-building material are therefore mentioned as weak links (as indicated by thin arrows). The term 'manipulable' material in figure 3 includes also material provided to the sow to use for nest-building behaviour.

Figure 3 shows diagrammatically the relationships between the risk factors for inability to perform proper investigation and manipulation activities in farrowing sows, the welfare consequences of this inability and the animal-based indicators which can reflect the extent of these welfare consequences. For each risk factor, arrows and reference letters indicate which welfare consequence they might cause. For each welfare consequence, arrows and reference numbers indicate which animal-based measure may indicate their occurrence. The welfare consequences and associated animal-based indictors printed in bold text highlight those which are class-specific for farrowing sows.

RISK FACTORS (resources, environmental and management factors)	**WELFARE CONSEQUENCES**	**ANIMAL-BASED INDICATORS** (direct and indirect)
Total lack of manipulable material ➔ a, h → b, c, g	a. Frustration of exploratory motivation ➔ 5. 6, 14 → 11, 12	1. Increased frequency of oral manipulation of other pigs*
Unavailability of manipulable material during certain time periods ➔ a, g → b, c, g	b. Frustration of foraging motivation → 5, 6, 11, 12, 14	2. Changes in play behaviour with manipulable material
Inaccessibility of manipulable material ➔ a, d, g → b, c, g	c. Frustration of motivation to manipulate nesting material before lying down → 3, 5, 6, 11,12, 14	3. Soiling of pen, soiling of manipulable material
Low quantity of manipulable material ➔ a, g → b, c, g	d. Frustration due to material being out of reach → 5, 6, 11, 12, 14	4. Increase of disease
Low quality of manipulable material ➔ a, g → b, c, e, f. g	e. Health and thermoregulation problems arisen from poor hygiene ➔ 4 → 3, 12	5. Decreased manipulation manipulable material
Inappropriate location of manipulable material in relation to the intended function of the material ➔ a, g → b, c, e, g	f. Injuries ➔4, 7, 12	6. Increased manipulation of pen furniture
Poor hygiene of manipulable material ➔ a, e, g → b, c, g	g. Negative effect on resting behaviour, unrest → 4, 12,14	7. Increase of non-aggressive injuries
Manipulable material which causes injury or pain to the animal ➔f	**h. Frustration of motivation to build a farrowing nest** ➔ 5, 6, 14 → 11, 12, 15, 16, 17, 18, 19	8. Increase of lesion score
		9. Increase of tail, ear, flank biting*
		10. Increase in agonistic behaviour *
		11. Reduced diurnal cortisol level
		12. Negative affective state / cognitive bias.
		13. Increased dirtiness of the animals.
		14. Occurrence of sham nest building
		15. Increased piglet mortality during farrowing
		16. Reduced milk production causing low piglet growth
		17. Reduced colostrum intake by piglets, potentially causing increased disease occurrence
		18. Low reactivity towards piglets
		19. Restlessness during farrowing

* not applicable for individually housed sows

Figure 3: Associations between risk factors and welfare consequences, and between welfare consequences and animal-based indicators in relation to provision of manipulable material for farrowing sows. Arrows in column 1 refer to the lettered boxes in column 2. Arrows in column 2 refer

to the numbered boxes in column 3. A bold arrow (➔) relates to a well-documented relationship while a small arrow (→) suggests a weak or much less robust relationship. The welfare consequences and associated animal-based indictors printed in bold text highlight those which are class-specific for farrowing sows.

3.2.1.4. For pregnant sows and boars

Pregnant sows and boars are fed restrictively with a high energy food, which takes them a very short time to eat. Therefore, the time spent exploring and foraging in relation to feed ingestion is very limited and animals remain unsatisfied after consuming their feed because of low gutfill. This gives rise to a state of high foraging motivation which, in the absence of suitable manipulable material, gives rise to abnormal behaviours. In sows (and, though less well documented, in boars) this may primarily be seen as stereotypies, restlessness and aggression (Fraser, 1975; Rushen, 1984, 1985; van Putten and van de Burgwal, 1990; Terlouw et al., 1991; Terlouw and Lawrence, 1993; Spoolder et al., 1995; Durrell et al., 1997; Whittaker et al., 1998). However, in some situations, the presence of straw has been associated with an increase in the incidence of vulva biting (Rizvi et al., 1998) or aggression (Whittaker et al., 1999), possibly due to a confounding with feeding system or to impaired access to feed spread on the floor. The welfare consequences of lack of, or restricted access to, suitable substrate for foraging and exploration are considered to be higher in breeding animals than in slaughter pigs because of their chronic hunger arising from feed restriction and hence higher motivation to forage and explore.

Insufficient access to foraging/exploration materials may arise due to 1) lack of any substrate, 2) sufficient access to an inappropriate material or 3) an appropriate substrate is given but not in sufficient quantities. Materials that reduce the occurrence of harmful redirected behaviours are less well studied in sows than in rearing pigs, but include straw (Whittaker et al., 1999) and peat (Durrell et al., 1997). Since pregnant sows and boars are feed restricted and the motivation to explore is thus predominantly appetitive foraging, materials that contain edible parts are probably the most appropriate to satisfy the motivation to explore in sows and boars and prevent abnormal behaviours (van Putten and van de Burgwal, 1990; Gjein and Larssen, 1995; Edge et al., 2005). There is not enough scientific evidence to state the minimum amount of rooting materials that is needed to satisfy the behavioural needs of sows. If given access to a large amount of straw, sows consume around 500 gram per day (Cole, 1990). Pedersen et al. (2005) showed that large pigs were willing to work by pressing an operant panel in order to obtain up to 1 kg of straw per day during a test period of 50 minutes.

Lack of bulky or high-fibre food for restrictedly fed sows, gilts and boars is associated with prolonged frustration, and pain due to stomach ulcers is likely to occur (Meunier-Salaun et al., 2001). Therefore, appropriate provision of fibre, which may be in the form of the manipulable substrate, is essential to avoid reduced welfare.

Figure 4 shows diagrammatically the relationships between the risk factors for inability to perform proper investigation and manipulation activities in pregnant sows and boars, the welfare consequences of this inability and the animal-based indicators which can reflect the extent of these welfare consequences. For each risk factor, arrows and reference letters indicate which welfare consequence they might cause. For each welfare consequence, arrows and reference numbers indicate which animal-based measure may indicate their occurrence. The welfare consequences and associated animal-based indictors printed in bold text highlight those which are class-specific for pregnant sows and boars. Since breeding boars are generally housed singly, animal-based indicators which involve interaction with others (marked ¤ in the below figure) may not be seen on most farms.

RISK FACTORS
(resources, environmental and management factors)

- Total lack of manipulable material
  ➔a, g.
  → b, h.
- Unavailability of manipulable material during certain time periods
  ➔a, e, g
  → b, h
- Inaccessibility of manipulable material
  ➔a, b, d, e, g
  → h
- Low quantity of manipulable material
  ➔a, e, f, g
  → b, h
- Low quality of manipulable material
  ➔f, g
  →a, b, h
- Inappropriate location of manipulable material in relation to the intended function of the material
  ➔a, d, e, f, g, h.
  →b
- Lack of manipulable material for pigs who had previously experienced this (i.e. withdrawal of something expected)
  ➔a, d, g
  → b, h
- Poor hygiene of manipulable material
  ➔ f
  → a, b
- Manipulable material which causes injury or pain to the animal
  ➔ g
  → a, b

WELFARE CONSEQUENCES

a. Frustration of exploratory motivation
  ➔ 1, 5, 6,7, 8, 9, , 12, 14
  → 11

b. Frustration of foraging motivation
  ➔8 , 9, 14
  → 1, 5, 6, 12

c. Frustration of motivation to manipulate nesting material before lying down

d. Frustration due to material being out of reach
  ➔ 1, 5, 6, 7, 8, 9, 14
  → 11

e. Competition for restricted amount of material¶
  ➔ 5, 6, 7, 8, 9, 10, 14
  → 11

f. Health and thermoregulation problems arising from poor hygiene
  ➔ 3,4, 13
  → 11

g. Injuries
  ➔7, 8, 9, 10

h. Negative effect on resting behaviour, unrest
  ➔ 3, 10
  → 7, 8, 13

ANIMAL-BASED INDICATORS
(direct and indirect)

1. Increased frequency of oral manipulation of other pigs¤
2. Changes in play behaviour with manipulable material
3. Soiling of pen, soiling of manipulable material
4. Increase of disease
5. Decreased manipulation of manipulable material
6. Increased manipulation of pen furniture
7. Increase of non-aggressive injuries
8. Increase of lesion score
9. Increase of tail; ear, flank biting¤
10. Increase in agonistic behaviour¤
11. Decreased diurnal cortisol rhythm
12. Negative affective state/ cognitive bias
13. Increased dirtiness of animals
14. **Increase of stereotypes/ vacuum behaviour**

Figure 4: Associations between risk factors and welfare consequences, and between welfare consequences and animal-based indicators in relation to provision of manipulable material for pregnant sows and boars. Arrows in column 1 refer to the lettered boxes in column 2. Arrows in column 2 refer to the numbered boxes in column 3. A bold arrow (➔) relates to a well-documented relationship while a small arrow (→) suggests a weak or much less robust relationship. The welfare consequences and associated animal-based indictors printed in bold text highlight those which are

class-specific for pregnant sows and boars. Since breeding boars are generally housed singly; these may not be seen on most farms.

3.2.1.5. Assessment of the possible welfare risks from providing manipulable material

In the paragraphs above, the risks associated with the absence of manipulable material, restrictions on availability when present and risks associated with the quality of the materials are presented. Risks associated with the presence of materials as such were not discussed, as the mandate of this opinion is based on the assumption that manipulable materials are generally beneficial to animal welfare. This may not always be the case, as has been documented in particular in relation to the use of straw. The provision of straw is almost always associated with the use of solid floors in the lying area. Even though pigs tend to keep their lying area free from excrement, the use of solid floors may increase the likelihood of pigs coming in contact with manure, when compared with the use of slatted floors. The risk of coming into contact with pathogens may be further increased when ambient temperatures in the pen reach a level where pigs start avoiding the bedding and seek thermal comfort in the dunging area (e.g. Ducreux et al., 2002; Spoolder et al., 2012). Pigs prefer to lie down for resting on a straw bedded floor at 18-21 °C, while at 25-27 °C, i.e. above the thermo-neutral zone, they select a bare concrete floor (Fraser, 1985). Above the thermal neutrality value, straw bedding might increase the risk of heat stress, as fermentation within the bedding in deep litter systems is a source of additional heat (Correa et al., 2000). However, straw provided in small amounts for manipulation rather than as bedding, or provided in racks, should not give rise to any thermal problems. Tuyttens (2005) reviewed the possible risk factors associated with hygiene from the available scientific literature. He refers to work by Davies et al. (1997), who show that the prevalence of *Salmonella* in manure from fattening pigs was lower with than without slatted floors. Finally he suggests that straw was identified as a risk factor for infections with *Yersinia enterocolitica* (Skjerve and Lium, 1998) and with the helminth Oesophagostomum (Roepstorff and Jorsal, 1990).

While the AHAW Panel has not carried out a full systematic review of the biological and chemical hazards that may be associated with manipulable material, it is possible that infectious agents and/or chemical contaminants may be brought into contact with pigs by provision of manipulable material which has been contaminated during its production or storage. For example, provision of straw of poor quality may increase the risk of health problems associated with ingestion of mycotoxins (Bryden, 2012), and there is some evidence that bedding material can increase the risk for mycobacteria infections in pigs (Matlova et al., 2004). There is also some evidence that straw can contain residues of chemical compounds such as chloramphenicol which may be synthesised by natural occurring soil bacterial or by contamination with manure from pigs illegally treated with the substance (Berendset et al., 2013; Nordkvist et al., 2014).

However, in his review Tuyttens (2005) also lists several beneficial effects for health of straw, in comparison with the absence of straw. He identifies literature sources that suggest beneficial effects of straw compared to slats for the prevalence of movement disorders, claw damage and other leg injuries (Brennan and Aherne, 1987; Andersen and Bøe, 1999), influenza A infections (Ewald et al., 1994), stomach and intestine disorders (Christensen et al., 1995; Smith and McOrist, 1998) and the mortality of pigs (Hoogerbrugge, 1987) and piglets (van Veen et al., 1985). Tuyttens (2005) concludes that ‘the relation between the use of straw and pig health is equivocal: some diseases/injuries are more prevalent in strawed housing systems while the opposite is the case for other diseases/injuries’.

With respect to other bedding-type manipulable materials the AHAW Panel could not identify additional risks on top of those associated with level, location and quality as discussed in the preceding paragraphs. When using artificial materials, such as used newspaper, cardboard and empty plastic bottles and canisters it is important to make sure the materials are hygienic and safe both from a toxicological and physical point-of-view. Examples of risks are digestion of great amounts of ink used for printing on paper, staples and sharp edges of plastic containers. Used tyres may contain wire which can cause mouth injury. Also, when using natural material, such as wood, some risks might occur. Especially dry wood, such as old planks, might risk splinters injuring the pigs´ mouth, while this risk appears to be smaller with fresh wood. Chains, ropes and similar objects can cause injuries if the pigs or one of their extremities, get entangled in them, although the risk is usually very minor. Using easily destructible materials, such as ropes, branches, or plenty of long straw, increases the risk of problems with the manure system, which might, indirectly, decrease animal welfare by decreasing hygiene and air quality. This, however, is a risk that can be avoided by proper and adequate management. Finally, if long-lasting manipulable materials are used during several pig batches, it is important to ensure that the materials are easily cleaned to avoid disease transmission between batches. Information on these risks comes largely from anecdotal reports from farmers and veterinarians and has been subjected to limited scientific study. However, recent work on the development of diagnostic tests using oral fluids extracted from pig chewing ropes demonstrates the presence of a variety of viable pathogenic agents on such manipulable materials (Prickett et al., 2008).

3.2.2. Avoidance of tail docking

Avoidance of tail-docking depends on the ability to control the risk of tail-biting through correct identification and alleviation of other predisposing environmental and management factors. The risk factors associated with the occurrence of tail-biting were described in an earlier EFSA opinion (EFSA, 2007c) and an update given in the technical report of EFSA[10]. The main findings of the opinion and update are presented in the diagram below (Figure 5).

The figure presents these aspects in relation to weaner and rearing pigs only, as tail-biting in other categories of pigs is rare. To focus the discussion, as well as the development of recommendations on reducing the need to dock tails, only one welfare consequence is considered: tail biting. However, it is acknowledged that there are several related or resulting welfare consequences associated with being tail bitten, such as pain, fear, infections, disturbed resting behaviour etc.

The risk factors for tail-biting to occur in weaners and rearing pigs, which are identified in the previous EFSA opinion and a number of other comprehensive scientific reviews (Schrøder-Petersen and Simonsen, 2001; EFSA, 2007c; Taylor et al., 2010; Edwards, 2011), are listed in the first column of the figure below. Whilst, at a detailed level, a great number of individual risk factors have been proposed (Taylor et al., 2012), these tend to fall within the broader categories listed for simplicity in this column.

As discussed in detail and comprehensively referenced in the reviews cited in the previous paragraph, the main risk factor is the lack of sufficient manipulable material. In previous paragraphs of this Scientific Opinion, this risk factor has been addressed in detail. A second important category of risk factors relates to the climate in the building, including extremes of temperature and draughts. Poor air quality, with high levels of dust and noxious gases consequent on inadequate ventilation is another risk factor category. Evidence has been increasing for the importance of other health problems in the animals as a predisposing factor, with reduced tail-biting associated with good vaccination programmes.

Nutritional deficiencies have been widely implicated, in particular deficiencies in sodium, total protein or specific amino acids such as tryptophan. Competition for resources, social instability and high stocking densities are all known risk factors associated with the management of the social environment. Castrated male pigs have been shown to be at greater risk of being tail bitten than females, although there has been no direct comparison between castrates and entire males. It is therefore not possible to be certain that castration per se is a risk factor. There are also identified risk factors related to genotype and ontogeny. An unfavourable genetic correlation between tail-biting predisposition and both lean tissue growth rate and body fatness exists. It has also been demonstrated that developmental changes due to modification of the fetal environment resulting from maternal

[10] European Food Safety Authority, 2011. Technical report on Preparatory work for the future development of animal based measures for assessing the welfare of pigs, EN-18. Available online: http://www.efsa.europa.eu/en/supporting/doc/181e.pdf

stress can adversely affect subsequent behaviour (Kranendonk et al., 2006), and suggested that this might be a risk factor for tail biting. However, scientific validation of this possibility is still lacking.

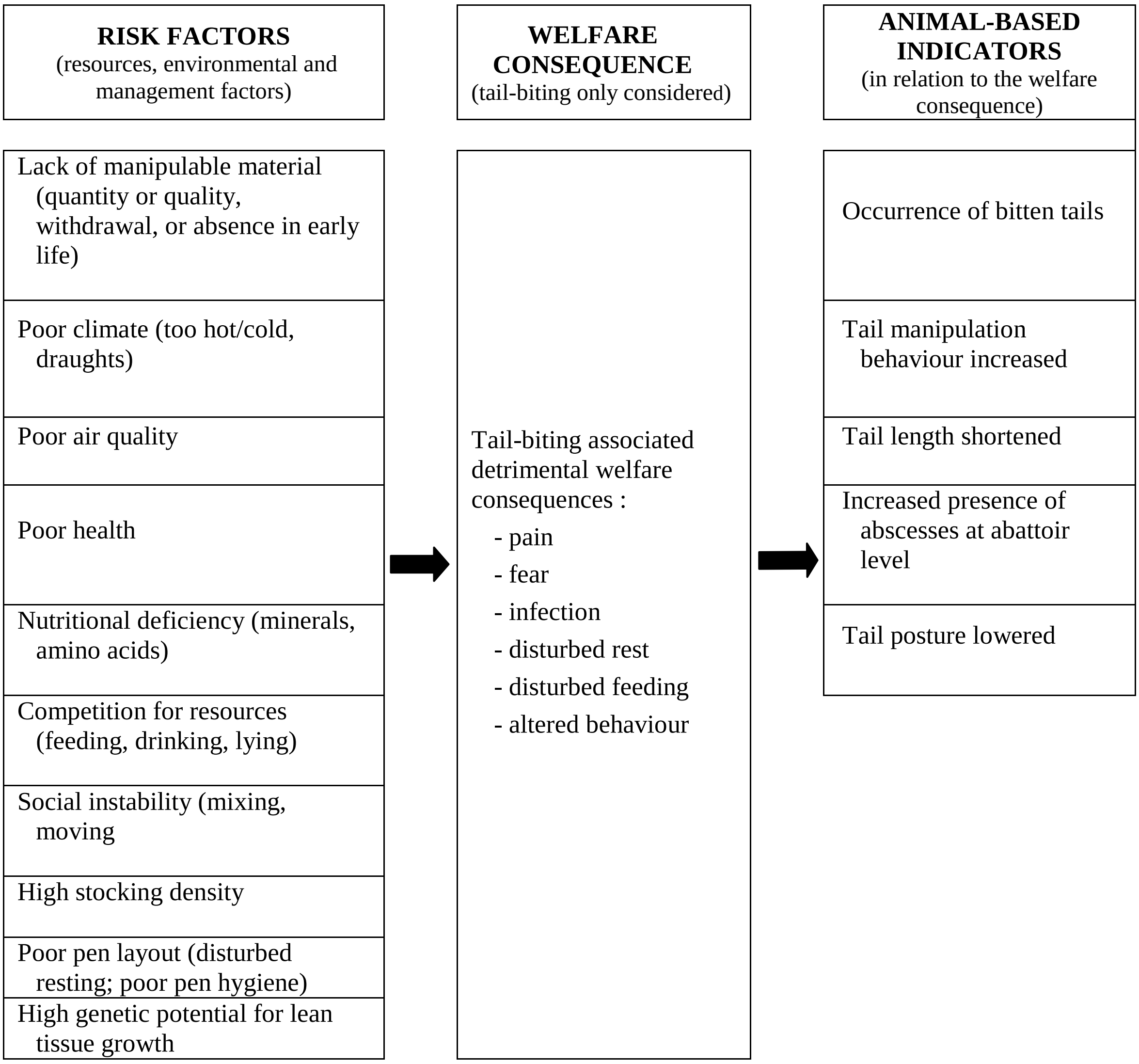

Figure 5: Associations between risk factors and the welfare consequence of tail biting, and the animal-based indicators of this consequence. In order to avoid the need for tail-docking these other risk factors need to be controlled.

This information was combined with the outcomes of EFSA expert discussions on animal-based indicators associated with the risk factors for tail biting. The reason for this is that early identification and mitigation of risk factors, and especially of their actual importance on specific farms, may help to reduce the occurrence of tail biting, and thus reduce the need to tail dock.

Temperature and draughts may affect tail-biting incidence, and may result in altered lying behaviour, panting (too hot) or shivering (too cold) (e.g. Scott et al., 2009). Poor air quality, such as increased levels of ammonia and dust, results in respiratory problems like coughing and sneezing (Scott et al., 2007). Health problems and nutritional deficiencies can be identified through veterinary diagnostics, including aspects of behaviour such as lying behaviour and restlessness (Scott et al., 2007). Competition for resources, social instability and high stocking densities may all be identified by unrest in the group, including increased levels of aggression and skin lesions (Velarde, 2007). Less clear indicators are available for risk factors related to genotype and ontogeny. Where the risk factors are associated with intensive selection for leanness (Moinard et al., 2003; Breuer et al., 2005) the level of backfat thickness, measured ultrasonically on the live animal or on the carcass at slaughter, may be an indicator. Genetic risk factors can be related to subsequent aggression (and associated skin lesions) (Turner, 2011).

Figure 6 shows diagrammatically the relationships between the risk factors for tail-biting and the animal-based measures which can be used to identify the presence of these factors. For each risk factor, in column 2, arrows and reference numbers indicate which animal-based measures might be used for their identification.

ANIMAL-BASED INDICATOR (in relation to the risk factors)	**RISK FACTORS** (resources, environmental and management factors)
1 *See previous Section (3.2.1) on manipulable materials for a list of indicators.*	Lack of manipulable material (quantity or quality, withdrawal) ⬅ 1, 6, 9
2 Panting, shivering, lying behaviour.	Poor climate (too hot/cold, draughts) ⬅ 2, 5, 9 ; ← 3
3 Coughing, sneezing, red eyes.	Poor air quality ⬅ 3.
4 Poor body condition, diarrhoea, coughing, sneezing.	Poor health ⬅ 2, 3, 4, 5, 7, 8, 9.
5 Poor body condition, poor coat condition, foraging.	Nutritional deficiency (minerals, amino acids) ⬅ 4, 5, 8.
6 Skin lesions, aggression.	Competition for resources (feeding, drinking, lying) ⬅ 6, 9. ← 7
7 Gastric ulcers.	Social instability (mixing, moving) ⬅ 6, 9. ← 7
8 Low backfat thickness.	High stocking density ⬅ 6, 9
9 Restlessness.	Poor pen layout (disturbed resting; poor pen hygiene) ⬅ 6, 9, 10 ← 2, 3, 5.
10. Dirty pigs.	

Figure 6: Associations between risk factors for tail-biting and the animal-based measures which might be used to identify their presence. Arrows in column 2 refer to the numbered boxes in column 1. A bold arrow (⬅) relates to a well-documented relationship while a small arrow (←) suggests a weak or much less robust relationship.

3.3. Concluding remarks related to ToR1

Pigs have a need for manipulable materials to satisfy a range of behavioural needs, which can be different in different classes of pig. When these needs are not met, a range of adverse welfare consequences result, one of these being an increased risk for tail-biting in weaners and rearing pigs.

The above sections, and especially the Figures (1-6), illustrate the complexity of the function of manipulable material and the background for tail biting. In addition, the figures illustrate the multifaceted interactions between the different risk factors, welfare considerations and animal-based indicators of these.

Some manipulable materials, although good at meeting the behavioural needs of pigs, can also have adverse effects on other aspects of pig welfare. These adverse effects have not been adequately studied to ensure safe provision. There should be further studies on manipulable materials which consider possible adverse effects and their alleviation.

Avoidance of tail-docking depends on the ability to control the risk of tail-biting through correct identification and alleviation of other predisposing environmental and management factors. The presence of these risks can be indicated by a range of resource and animal-based measures.

Although there is an abundance of new scientific evidence supporting the conclusions in previous EFSA opinions, all adding important details to the understanding of the multifactorial function of manipulable materials for pigs, there have not been any major new insights. One of the areas where perhaps most new evidence has been produced is the effect of the provision of additional manipulable material to piglets at the pre-weaning stage, and their long-lasting effects on development (see Section 3.2.1.2), including their propensity to tail bite later in life. The same absence of major new insights is true for the general understanding of tail biting, it´s risk factors and consequences. One area that has, however, been receiving more attention lately, but where the evidence is still scarce is the interaction between poor general health and tail-biting (Niemi et al., 2012; Munsterhjelm et al., 2013a). This topic deserves further research focus. There have also been several recent studies looking into individual differences of tail biters and their victims, as compared to control pigs (see e.g. Brunberg et al., 2011; Brunberg et al., 2013; Munsterhjelm et al., 2013b; Palander et al., 2013; Valros et al., 2013), which might aid in solving the problem in the long term, and which indicate the need for further investigations of risk factors such as genetic background, feeding, behavioural development and stress susceptibility of the animals.

4. ToR 2- Identification of the strength and predictive capacity of the above identified interactions relating to the provision of manipulable material and avoidance of tail-docking in pigs

4.1. Procedures to address this question

In an attempt to derive quantitative estimates of the strength of the most important relationships between the risk factors, welfare consequences and outcome measures identified above, a collaborative exercise with the Assessment and Methodological Support (AMU) unit of EFSA was initiated.

The objective was:

(a) To assess the strength of relationship between animal-based measures and the functionality of a manipulable material to meet behavioural needs.

(b) To assess the strength of relationship between risk factors for tail biting, including the type of manipulable material, and animal-based measures of this welfare outcome.

An email circular was sent to scientists known to be active in research into provision of manipulable material (also referred as environmental enrichment) and tail biting, enquiring about the availability of datasets which might be suitable for combination and large scale statistical analysis necessary to evaluate interactive effects. If they held such datasets which they were willing to make available to EFSA, they were asked to provide information on:

1. The type of dataset (experiment, survey).
2. The animal-based outcome measure (e.g. % of pigs with damaged tails).

3. The risk factors included in the dataset.
4. The approximate size of dataset (number of animals, pens, farms).

These datasets were then considered for suitability for the tasks specified.

4.1.2. Description of data

Seventeen scientists responded with willingness to make datasets available. These comprised datasets of 3 types:

a) Controlled experiments which provide a quantitative relationship between specific risk factors and tail biting. Seven datasets were received from five countries [the Netherlands, Germany, Finland, Ireland, and Belgium]. These generally explored a single specific treatment in controlled experimental conditions with a limited number of animals. It was found that the diversity of treatments and methodologies made it impossible to combine these for meta-analysis in the time available.

b) Epidemiological studies relating farm risk factors to tail-biting outcome. Six datasets were received from four countries [the United Kingdom, Ireland, France, and Finland]. These individually included a significant number of farms, but their limited geographical representation, different data collection location (farm or abattoir) and different outcome measures made it impossible to combine these for meta-analysis in the time available. Further important datasets were identified in Germany and Belgium which might have permitted a meaningful combined analysis, but neither was available for sharing in time for use in this opinion, although they were offered for use at a later date. Finally, only the Finnish dataset was of sufficient size to merit further detailed analysis on its own.

c) Datasets with multiple outcome measures (including tail biting) such as the Welfare Quality® studies. Six datasets were received from six countries [Spain, France, Finland, the Netherlands, the United Kingdom, and Sweden]. These included data collected according to a common protocol, making it possible to combine them for exploratory analyses as detailed in the following sections. This conducted analysis did not incorporate the UK dataset due to its late receipt and the small number of farms involved.

4.1.3. Description of the statistical procedures

4.1.3.1. Combined Welfare Quality® Dataset

Information regarding welfare in pig farms, collected using the standard protocol arising from the EU Welfare Quality® project (2009) as part of research projects in several MS, has been collated[11]. Data include a number of measures such as: number of animals in the farm, their average initial weight, the average slaughtered weight, size of the pen, age of the animals at the visit to the farm, space per pig(m^2), space per 100 kg, temperature, flooring type, the use or not of straw in the farm, type of feeder, feed formulation, type of drinkers, number of water supplies per animal, functionality of the drinkers and their condition in terms of cleanliness, cleanliness of the pen, the type of manipulable material used in the farm, access to outdoor, body condition score for the animals, if docking of the pig tails is performed in the farm, and the presence of any animal with tail lesions of severity level 2 as specified in the Welfare Quality® protocol as fresh blood visible on the tail and/or evidence of some swelling and infection, and or/ part of the tail tissue missing and presence of crust

In order to investigate the strength of relationship between provision of different types of manipulable materials and possible animal-based measures of their functionality, simple descriptive statistics for

[11] With thanks to Valerie Courboulay (Institut du Porc, France), Stefan Gunnarsson (Sveriges Lantbruksuniversitet, Sweeden), Camilla Munsterhjelm (University of Helsinki, Finland), Déborah Temple and Eva Mainau (IRTA and University of Barcelona, Spain), Alison Bond (University of Bristol, the United Kingdom) and Herman Vermeer (Wageningen UR Livestock Research, the Netherlands).

various behavioural measures and injury scores in the Welfare Quality® protocol were related to manipulable material type, which was a simplified classification of the manipulable material provided, to see if clear differences between extremes were apparent.

Due to the nature of the data to be analysed and the aim of ToR 2 (to search for a predictive model able to classify farms or pens according to their status related to tail-biting lesions of severity level 2 observed during the visits to the farm), machine learning algorithms (classification and regression tress, random forest, boosting methods and support vector machine) were used to identify potential interactions between the previously listed risk factors impacting on the presence of animals in a farm or in a pen with lesion of severity level 2. A brief description of these methods is presented in Appendix A.

To find a classification rule that is able to identify farms or pens with animals presenting tail lesions (severity level 2), classification trees and extensions of this method such as: random forest and boosting techniques are specifically developed. Classification trees (CART) is a technique that identifies risk factors (from the list of risk factors available) that could be used to split the data into subgroups which are more homogeneous in terms of farms or pens having animals with tail lesions (aiming at forming pure groups of farms or pens in which their status in relation to tail lesions is the same as much as possible, i.e. ideally farms or pens in group 1 having no tail lesion issues and group 2 farms or pens with tail lesions observed, which will imply that with a single split you will be able to classify all farms or pens correctly). Once this has been done, each of the subgroups (if they are not pure) is further divided into two groups with a similar purpose, up to the point in which groups are not needed to be split because they are pure. The Random forest technique takes into consideration the fact that the prediction tool that is built is simply based on a single database, and that if the data were to be collected again the outcome would not be identical due to variability in the population. When using random forest, in order to identify risk factors for tail lesion an initial analysis was done including all Welfare Quality® data received and in addition a sub group analysis was conducted to compare the influence of risk factors in different subpopulations. Random forest was then applied for the following three subpopulations: (1) farms or pens from Finland, which provided the largest dataset and has banned tail docking, (2) farms or pens with tail-docking and (3) farms or pens without tail docking. This was to examine the possibility that important effects were masked because of probable confounding between country, housing system and tail-docking practice. Boosting techniques aim at reducing, as much as possible, potential misclassification due to particularities observed in the data. Support vector machine techniques use mathematical methodology of a potential hypothetical space in which the classes are linearly separable (meaning that you could find a line that is able to separate the tail-biting farms from those that do not present tail-biting issues).

In all methods used for classification the imbalanced number of observation in the classes were taken into account; specifically, for random forest when drawing the bootstrap samples a weighing scheme was used to ensure inclusion of samples from each country as well as from the two classes (tail-biting and no tail biting). For the methods dealing with recursive partitioning, different loss functions were used and selection of the best loss function was based on the trade-off between overall error and classification error of the tail-biting class, trying to maximize the sum of both errors. Details and references on the machine learning algorithms used here can be found in Appendix A. Also descriptive tables and graphs are presented in Appendixes B to G in order to explore the data provided.

4.1.3.2. Finnish Farm Survey Data

Data from 1574 farms (1655 holdings) in Finland,[12] where tail-docking is banned, have been collected by veterinarians during regular herd health visits during 2011 and 2012. Information regarding the use of 8 different manipulable materials (straw, hay, peat, saw dust, paper, woodchips, wood, toy) together with the presence of tail-biting during the time of the visit to the farm was reported.

[12] With thanks to Sanna Nikunen (Association for Animal Disease Prevention ETT ra, Sikava, Finland) for providing the data from the Sikava National Health and Welfare Program.

In order to study the impact of the use of a particular manipulable material on the presence of tail-biting in a farm, a generalized linear mixed effect model (GLMM) has been used. The GLMM model contains an overall intercept, fixed effects associated to the presence of each of the 8 manipulable materials and two random intercepts associated to the farm and holding levels, to account for potential correlation between the observations taken from the same holding within a particular farm and correlation between holdings within a farm.

The model could be written as follow:

$$g(y_{ijk}) = \beta_0 + b_{0i} + b_{0ij} + \beta_1 \mathrm{EnrMt}_{ijk}^{1} + \beta_2 \mathrm{EnrMt}_{ijk}^{2} \ldots + \beta_8 \mathrm{EnrMt}_{ijk}^{8} \qquad \text{(I)}$$

$$b_{0ij} \sim N(0, \sigma_H^2)$$

$$b_{0i} \sim N(0, \sigma_F^2)$$

Where $g(\cdot)$ is the link function used (in this case the logit link function was used), y_{ijk} represents the probability of having tail-biting in visit (k) for holding j and farm i, β_0 and β_s, $s = 1, \ldots, 8$ are the so called fixed effects, b_{0i} and b_{0ij} are the random effects, which are assumed to be normally distributed with mean 0 and variances σ_F^2 and σ_H^2 respectively. The model was used to test the effect of each of the manipulable materials on the probability of having tail-biting issues in the farm.

Backward selection procedure was followed in order to find the most parsimonious model that is able to fit the data well. The selected models contain only the manipulable material types that are statistically significant and the fit is assessed. The plot with the observed proportion of tail-biting reported in the different visits for each of the holdings (ratio between the numbers of times tail-biting was reported out of the total number of visits to the holding) together with the prediction and confidence intervals is shown. Also population proportions for each of the combination of manipulable materials from the final model are reported in order to show potential differences. The model was used separately for weaner pigs and rearing pigs (called finishers in the dataset provided). Goodness of fit measure for regression models other than the linear type has been previously studied by Cragg and Uhler (1970) and Cameron and Windmeijer (1997), among others, a number of different Pseudo-R^2 measures to summarize goodness of fit of the model are presented, as well as graphical representation to visually evaluate the fit of the final model. Descriptive tables and graphs are presented in Appendixes H and I in order to explore the data provided.

4.2. Main findings

4.2.1. Welfare indicators for lack of functional manipulable material

4.2.1.1. Farm level analysis of Welfare Quality® datasets

The Welfare Quality® dataset divided manipulable material description into six classes of manipulable materials: straw, object (including things sometimes called toys), chain, mixed (both straw and object/chain), none or unknown. Possible animal-based measures of the functionality of the provided manipulable materials which were recorded included:

- Positive indicators of function: exploring manipulable material.
- Negative indicators of lack of function: exploring pen fittings, negative social behaviour, skin lesions and tail biting.
- Ratios of exploring manipulable material to other redirected exploratory behaviours were also calculated from the raw data.

Descriptive statistics for each of these possible welfare indicators are shown in Appendix B. These showed the range of values for different behavioural measures within manipulable material category to be very large and far greater than the differences between even extreme categories of ‘straw’ or ‘no manipulable material’, suggesting that none of these measures taken according to the Welfare Quality®

protocol (2009) provided a useful outcome-based assessment of functionality of manipulable material. The prevalence of pigs with severe skin lesions (referred to as 'wounds') was, however, significantly reduced on farms where straw or mixed manipulable materials (straw plus objects) were provided, although no difference in mild skin lesions or tail-biting prevalence was demonstrated (see Tables 1 to 3, with raw data shown in Appendix B).).

Table 1: Confidence interval of the probability of mild skin wounds (skin lesions) for each manipulable material category according to the Welfare Quality® definition.

Manipulable material type	2.5 %	97.5 %
Chain	0.7305	Inf
Combined substrates	0.4543	0.6832
None	0.5976	0.8383
At least a substrate material plus an object	0.9335	Inf
Straw	0.6377	0.8818
Unknown	0.1607	0.9773

Table 2: Confidence interval of the probability of severe skin wounds (skin lesions) for each manipulable material category according to the Welfare Quality® definition.

Manipulable material type	2.5 %	97.5 %
Chain	0.1456	0.7000
Combined substrates	0.0849	0.2540
None	0.4970	0.7502
At least a substrate material plus an object	0.4422	0.7158
Straw	0.1754	0.4053
Unknown	0.1608	0.9773

Table 3: Confidence interval for the probability of tail lesions for each manipulable material category according to the Welfare Quality® definition.

Manipulable material type	2.5 %	97.5 %
Chain	0.0060	0.3715
Combined substrates	0.2387	0.4583
None	0.2016	0.4453
At least a substrate material plus an object	0.1935	0.451
Straw	0.1326	0.3475
Unknown	0.0227	0.8392

4.2.2. Risk factors for tail-biting

4.2.2.1. Combined Welfare Quality® Dataset

a) Farm level analysis

Data from 242 intensive farms in 5 countries [Finland (97), France (30), the Netherlands (63), Spain (40) and Sweden (12)] were collated regarding potential risk factors for tail biting. The total number of farms reporting tail lesions was 71, while 171 did not report tail lesions of severity score 2. A full analysis of the data is presented in Appendix C, D and E, with only the major findings summarised below, since in general the explanatory power achieved by the models explored in the analysis was too weak to reliably ascribe relative predictive power to different factors. However, figures in the appendix show best estimates of the relative importance of the different factors highlighted below, and the directionality of their effect. Table 4 summarises the significant risk factors indicated by each statistical approach, with more important factors given in bold text, and less important ones in normal text. In general, there was good agreement between the different methodologies.

Table 4: Summary of the findings from the different methods applied to farm level data.

Method	Overall error	Most important risk factors
Classification and Regression Trees	38.02 %	**Age**, **space per pig**, **number of water supplies**, **slaughter weight**, **pen size**, **number of pigs in the farm**, **initial weight**, **space per 100 kg**, **temperature**, **manipulable material type** and body condition score.
Random Forest	41.74 %	**Age**, **space per 100 kg, number of water supplies**, **space per pig**, **number of pigs in the farm**, **pen size**, **temperature**, **slaughter weight**, **initial weight**, **manipulable material type**, flooring used, drinker type, feeder type and body condition score
Boosting	36.12 %	**Temperature**, **space per pig**, **pen size**, **number of water supplies**, **age**, **slaughter weight**, **initial weight**, **number of pigs in the farm**, **space per 100 kg**, **manipulable material type**, drinker type, feeder type, flooring used, cleanliness of the pen and feed formulation used.

The prevalence of bitten tails did not differ in the available dataset between farms which did, or did not, practice tail docking. However, there was significant confounding between country, straw provision and tail-docking practice because of different national legislation and the natural tendency of farmers to only refrain from docking when they perceive risk of biting to be low.

The farms in the dataset which did not practice docking were located in Finland and Sweden (as opposed to the docked pigs which were in the Netherlands and Spain). They were more likely to have solid flooring and provide deep bedding. Straw was present in all farms which do not dock, and absent in all farms that dock. The most frequently used feeding system is a hopper in docked pig farms providing predominantly dry feed, and a trough on farms that do not practice docking (which provide mainly liquid feeding). It appears that undocked pigs are cleaner than docked pigs, and have fewer mild and severe body lesions. See Appendix E.

Controlled experiments clearly demonstrate the protective effects of tail-docking and straw provision as individual factors which can reduce the prevalence of bitten tails (EFSA, 2007c). However, with the lack in the available dataset of farms which both provided minimal manipulable material and also left tails undocked, the true interactive consequences of these factors could not be adequately assessed.

When different subpopulations were considered (Finland only, undocked pigs only or docked pigs only) the set of important variables found was the same, indicating consistency across different subpopulations. However, the overall prediction error for all subpopulations considered is relatively high: 42 % considering all available data, 49 % when analyzing only Finland, 44 % in the farms with tail-docking and 51 % in farms without tail docking. The large overall error obtained implies the need for additional data to improve the predictive capacity of the model, and results obtained based on these data provide limited evidence on definitively influential risk factors regarding tail lesions.

This somewhat inconclusive result probably reflects the limitations of the available dataset for the purpose for which it was used. An important drawback of the analyses is the limited and unbalanced overall data available: 84 tail-biting farms *versus* 199 no tail-biting farms, 41 extensive farms *versus* 242 intensive farms. Moreover, as medicated pigs as well as severe tail bitten pigs removed to hospital accommodation were excluded from the data collection under the Welfare Quality® protocol, the absolute prevalence of tail-biting which is recorded, and possibly the sensitivity of the analysis, will be reduced.

The analysis was initially carried out with farm as the statistical unit. However, since many of the risk factors may vary within farm, it is apparent that pen (rather than farm) level data will be much informative and probably will improve the analysis outcomes. The analysis was therefore repeated within pen-level data.

b) Pen level analysis

Data from 2748 pens in 5 countries [Finland (1127), France (304), the Netherlands (839), Spain (358) and Sweden (120)] were collated regarding potential risk factors for tail biting. The proportion of pens presenting tail lesions (severity level 2) ranged from 1 -6 % (total number of pens reporting tail lesions was 139, while 2609 did not report tail lesions of severity score 2).

A full analysis of the data is presented in Appendix F and G, with only the major findings summarised below. It should be noted that farm identity was not included in this analysis, so that every pen was considered to be independent. Table 5 summarises the significant risk factors indicated by each statistical approach resulting from the pen level analysis, with more important factors given in bold text, and less important ones in normal text. In general, there was good agreement between the different methodologies.

Table 5: Summary of the findings from the different methods applied to pen level data.

Method	Overall error	Most important risk factors
Classification and Regression Trees	20 %	**Age**, **number of pigs in the farm, space allowance, manipulable material type**, **number of water supplies**, **initial weight, flooring used, slaughter weight**, **drinkers type**, **body condition score**, **temperature, feed formulation, tail-docking** and **cleanliness of the pen**.
Random Forest	26 %	**Age**, **space allowance**, **number of pigs in the farm, number of water supplies**, **temperature**, **initial weight**, **slaughter weight, manipulable material type**, **feed formulation, drinkers type**, **flooring used, body condition score**, bedding, **cleanliness of the pen**, feeder type, cleaning drinkers (yes/no), outside access, **tail-docking** and functioning of drinkers (yes/no)
Boosting	26 %	**Manipulable material type**, **number of water supplies, space allowance, drinkers type, flooring used, age, feed formulation, tail docking,** bedding, **number of pigs per farm,** functioning of drinkers (yes/no), **body condition score slaughter weight**, feeder type, **temperature**, cleaning drinkers (yes/no), **cleanliness of pen**, outside access and **initial weight**.

In first place it should be noted that the data collated provide a representation of pig pens in Europe but cannot be considered a representative sample of pig pens in Europe. Furthermore, results obtained from these analyses should be interpreted only for hypothesis generation since they are not by any means conclusive.

An important drawback of the analyses is the limited and unbalanced data (139 tail-biting pens *versus* 2609 no tail-biting pens). Moreover, it must be borne in mind that there may be under-representation of tail biting, as medicated pigs as well as severe tail bitten pigs removed to hospital accommodation are excluded from the data collection under the WQ® protocol.

The overall prediction error for all subpopulations considered is relatively high: 26 % considering all available data, 29 % when analyzing only Finland, 25 % in the pens with tail-docking and 23 % in pens without tail docking. However, the predictive performance of the model for tail-biting alone is only between 47-53 %. It should be highlighted that for all subpopulation analyses the set of important variables found are similar, indicating consistency across different subpopulations. The large overall error obtained implies the need for additional data, specifically to ensure EU population representativeness to improve the predictive capacity of the model.

c) Farm versus Pen –level analysis

In order to compare the risk factors which came up from the two analyses, farm *versus* pen level, a compilation of the findings is presented in Table 6. The risk factors which were common to the three methods but which differed between the farm and pen level analyses appear in bold.

Table 6: Overview of the risk factors from the different methods applied at farm and pen level

Risk factors	Farm level analysis	Pen level analysis
Common to the three statistical methods used	Age Space per pig Number of water supplies Slaughter weight **Pen size** Number of pigs in the farm Initial weight **Space per 100 kg** Temperature Manipulable material type	Age Number of pigs in the farm Space allowance Manipulable material type Number of water supplies Initial weight **Flooring used** Slaughter weight **Drinkers type** **Body condition score** Temperature **Feed formulation** **Tail docking** **Cleanliness of the pen**
Common to two of the three statistical methods used	Body condition score Flooring used Drinkers type Feeders type Cleanliness of the pen Feed formulation*	Bedding Feeder type Cleanliness of drinkers Outside access Functioning of drinkers

The three methods used for data analysis were: Classification and Regression Trees (CRT); Random Forest and Boosting methods. The order of the listed risk factors indicates their relative importance when using the CRT method in decreasing order. The risk factors which were common to the three methods but that differed between the farm and pen level analyses appear in bold letters.
*Feed formulation appeared only in one, rather than in two, of the three statistical methods used at farm level.

In general, the same factors were revealed as being important in the farm and pen level analyses. These related to age/weight, pen space allowance and flooring, feed and water provision, temperature and manipulable material type. Since the pen level analyses gave greater replication, and more precision in individual circumstances, some factors were revealed more clearly, showing in output from all three statistical methods rather than just one or two. In addition tail-docking practice, which did not appear in the farm level analyses, was revealed as a risk factor of moderate importance in the pen level analyses although pseudo-replication of this within farm was not taken into account.

Of the factors indicated to be important some, such as pig weight or age, cannot be readily changed in a production system but might help to identify periods where close monitoring is merited. Other factors such as farm size, pen size, or flooring material, can only be changed with significant infrastructure cost and consequently need to be planned over time. Finally, some factors like manipulable material type may be changed on a relatively short timescale provided that compatibility with manure management is possible.

The Welfare Quality® protocol is focussed on animal-based measures of welfare, and many of the known resource-based risk factors were not recorded to give the possibility of quantitatively assessing their predictive value. These limitations highlight the need for a large, comprehensive and harmonised dataset to adequately allow true analysis of the strength of interactive relationships between risk factors for tail-biting and this animal-based welfare outcome. Suggestions for such a data model are given in Appendix J.

4.2.2.2. Finnish Farm Survey Data

Finnish farm data collected by veterinarians during 2011 and 2012 cover the use of eight different manipulable materials (provided for enrichment) together with the presence of tail-biting at the time of the visit (see Section 4.1.2.2 for further details). The combinations of manipulable materials used in the different holdings are shown in Appendix H. The total number of combinations of manipulable materials used in the different holdings is 157, with frequencies of usage of any particular combination between 1 and 1521.

Full details of the results of the analyses are shown in Appendix I, with a summary presented below from the separate analyses of rearing pigs and weaners.

Weaners

The final model obtained after the model building process contains the following manipulable material indicators: Straw, Peat, Sawdust and Toys (Table 7). The main finding of the analysis is that using straw, as manipulable material for weaners, reduces significantly the relative probability of having tail biting, conditionally on the holding, while peat and toys increase significantly the relative probability of having tail-biting in a specific holding. The pseudo R^2 obtained for the final model using Cragg and Uhler (1970) formula was 0.483, indicating an acceptable fit.

Table 7: Estimated parameters from final model.

Fixed effects	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.3410	0.1727	-7.767	8.05e-15 ***
Straw	-0.5494	0.1338	-4.105	4.05e-05 ***
Peat	0.3713	0.1352	2.746	0.006024 **
Sawdust	0.2006	0.1100	1.824	0.068176
Toy	0.3383	0.1002	3.377	0.000732 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Rearing pigs

The final model obtained after the model building process contains the following manipulable material categories: Straw, Hay, Peat, Paper, Wood and Objects (referred to in this data set as Toys) (Table 8). The main finding of the analysis is that using straw, hay and peat as manipulable material reduces the relative probability of having tail biting, conditionally on the holding, while paper, wood and toys increase the probability of having tail-biting in a specific holding relative to the overall probability of having tail-biting in these holdings [n.b. there was no negative control without any manipulable material or with just a chain in this population, so we are only able to measure relative functionality of different materials rather than whether they are able to confer any benefit relative to no, or only basic, provision].The pseudo R^2 obtained for the final model using Cragg and Uhler (1970) formula was 0.476, indicating an acceptable fit.

Table 8: Estimated parameters from final model.

Fixed effects	Estimate	Std. Error	Z value	Pr(>|z|)
Intercept	1.31399	0.12688	10.356	< 2e-16 ***
Straw	-0.32597	0.10342	-3.152	0.00162 **
Hay	-0.24956	0.10374	-2.406	0.01615 *
Peat	-0.34048	0.12093	-2.816	0.00487 **
Paper	0.27929	0.08888	3.142	0.00168 **
Wood	0.31813	0.13306	2.391	0.01681 *
Toy	0.33875	0.08097	4.184	2.87e-05 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

4.3. Concluding remarks regarding ToR 2

Analyses of an international dataset using the Welfare Quality® protocol failed to show animal-based measures of behaviour which clearly distinguished between farms providing different types of manipulable material. However, the prevalence of pigs with severe skin lesions, generally indicative of increased aggression, was reduced when straw, alone or in combination with objects, was provided in comparison with other types of manipulable material or a lack of manipulable material.

Analyses of a large Finnish dataset with undocked pigs showed that use of straw was associated, in both age groups of pigs, with reduced tail-biting prevalence in comparison with provision of objects (referred to as toys). Within this population of undocked pigs, all receiving some form of manipulable material, there was a clear reduction in tail-biting risk when the manipulable material provided was straw and increased relative risk when it was a toy. This supports findings from individual controlled scientific experiments (EFSA, 2007c). Straw in this survey did probably not refer to bedding in the majority of the cases, but to lesser quantities of straw provided only as manipulable material once or twice a day. Results for some other materials were inconclusive, with different indications coming from analyses of data on weaned or rearing pigs. Since the dataset had no farms without any manipulable material or with just a chain, it cannot be said that the materials which were assessed as increasing relative risk provided no benefit to the pigs, but only that they provided less benefit than the other materials used in the Finnish situation. There was no analysis at pen level, which would have been more informative, and no record of the quantity or quality of the manipulable material provided, or of other known risk factors which would permit a more integrated analysis.

Analyses of an international dataset using the Welfare Quality® protocol suggested a number of animal and resource-based factors to be important risk factors for tail biting, but a high degree of uncertainty in the model precludes strong conclusions. The dataset used was not designed to evaluate risk factors for tail-biting and therefore, it had limitations in fitness for this analysis.

In this dataset, no difference in the prevalence of bitten tails was found between farms or pens with docked tails and those leaving tails intact. However, it cannot be concluded that docking has no effect, due to the confounding in the dataset of intact tails and provision of straw as a manipulable material. Other studies (reviewed in EFSA, 2007c) have demonstrated that leaving tails intact results in increased damage when compared to pigs with docked tails kept under the same conditions.

The dataset does, however, indicate the possibility for undocked pigs to be housed and managed in a way which does not imply an increased risk for tail biting. However, this requires further investigation in more comprehensive datasets, since the Welfare Quality® dataset had limitations for this purpose. In particular, the sampling protocol excluded hospitalised pigs or those receiving veterinary treatment and hence the prevalence of tail-biting will have been underestimated. Furthermore, mild tail lesions were not considered but only those serious enough to cause bleeding or tissue removal.

The circumstances in which farmers are willing to accept, and manage, a low prevalence of tail-biting if tails are left entire requires more investigation. It is likely that this will be influenced by their previous experience of tail-biting outbreaks and their perception of how well they are able to control such outbreaks and limit the level of injury which results.

There is a need to obtain better information on the relative importance of different risk factors for the occurrence and severity of tail-biting outbreaks, and the way in which these factors interact. The ability to obtain quantitative estimates of such relationships is currently limited by a lack of available data detailing the consequences for tail-biting of the simultaneous, or historic, presence or absence of the wide spectrum of known potential risk factors across a range of different production systems. Such datasets are beginning to accumulate from different countries and a number of these were identified during the preparation of this opinion as currently, or soon to be, available for use. Even though they are not being collected according to standardised protocols, they have sufficient commonality to offer the potential for valuable insights if collated and subject to combined statistical analyses. They would allow greater clarification of the interaction between different risk factors and the relative importance of these in relation to farm typology. Such data could then be used to improve the predictive strength of the farm specific risk assessment tools, described in Sections 5.1.3 and 5.2.3 which assist farmers to identify, and prioritise correction of, the most important hazards for tail-biting on their own unit.

5. ToR 3- Proposed model to evaluate how likely certain welfare consequences may happen given specific risk factors for lack of functional manipulable material or for tail biting, and which animal and/or non-animal-based measures would better fit for the assessment of those risks and consequences

5.1. Provision of manipulable material

5.1.1. Procedures to address this question

The analyses of the available literature have not resulted in new insights into the suitability of different manipulable materials to improve pig welfare. Much of what was written in earlier opinions regarding the qualitative relationships between risk factors, welfare consequences and animal-based indicators is still valid, and at the same time information to quantify the associations between risk factors and their welfare consequences is still largely lacking.

The AHAW Panel has therefore set out to address the question of what a relevant route would be to assess the appropriateness of materials on farms where welfare problems are experienced, or can be expected. This approach can be divided into three main questions: 1) what can be said about the material which is being offered in terms of e.g. material nature, accessibility, quantity, safety, etc.; 2) what can be said about the properties of the materials from the point of view of the pig, such as the possibility to smell, chew, root, share, destroy or eat the material, etc.; 3) what animal-based indicators are present which relate to the use of manipulable materials and their ability to adequately satisfy the behavioural needs of the animals.

For each of these questions the observations from the previous paragraphs and the relevant literature were combined to indicate possibilities for use in 'tool-boxes' for on farm assessment. This document deals first with manipulable materials as a substrate for exploratory and foraging motivation, and secondly, the special cases found in only certain classes of pig are considered separately.

5.1.2. Main findings

5.1.2.1. The potential tool box measures for describing the manipulable material

There are relatively few controlled studies in which manipulable materials have been ranked according to their likely benefit to animal welfare. Bracke et al. (2006) reviewed 54 experiments, reporting 200 statistically significant welfare outcomes, and compared the number of times that different materials gave positive, negative or no difference in welfare outcome measures when compared to a negative control of a barren pen. These data, summarised in Table 9, show that roughages and floor based substrates have more frequently given positive experimental outcomes.

Table 9: The number of experiments reporting positive (+), negative (-) or no difference (0) in welfare outcome measures when compared to a negative control of a barren pen for different categories of manipulable material. The ratio of positive to negative results is indicated as +/- (Bracke et al., 2006). A new column giving the odds of odds of improvement (+) vs non-improvement (- & 0) has been calculated and added to the original table as providing a ranking which is less biased by the unbalanced number of the studied elements.

Material	+	-	0	+/-	Odds
Metal (chains)	6	4	8	1.5	0,50
Mineral blocks	3	1	3	3.0	0,75
Rubber / plastic (hoses, belts)	19	4	9	4.7	1,46
Rope / cloth	6	1	5	6.0	1,00
Wood (beams, blocks, branches)	7	1	3	7.0	1,75
Straw (loose, rack, basket)	28	3	8	9.3	2,55
Roughage (beet, hay, silage)	10	1	5	10.0	1,67
Mixtures (compound enrichment)	28	2	4	14.0	4,67
Substrates (compost, earth, sawdust)	17	1	7	17.0	2,13

In the only large comparison of different materials within the same experiment, Van de Weerd et al. (2003) used the extent of manipulation time as a criterion for ranking a large number of varied substrates and objects in order of preference for weaned and growing pigs, at the same time classifying each material by various property definitions (see later). The intensity of interactions of 222 groups of three weaner and 222 groups of three grower pigs with 74 different objects were studied during 5 days after presentation. Table 10 shows the most utilised materials, with a wide range of different materials and presentation methods featuring in this favoured list.

Table 10: The top 25 of most popular objects for day 1 of presentation, ranked according to total object interaction time (seconds in 12 hours[(a)]), with scores for the presence (1) of absence (0) of properties of these objects which subsequent analysis suggest to be important (van de Weerd et al., 2003)

No	Objects	Odorous	Deformable	Not rootable	Not attached	Chewable	TOI time[(b)]
1	Lavender straw with whole peanuts in box	1	1	0	1	1	11.9
2	Maize waste paper basket	1	1	0	1	1	10.6
3	Hessian sack in box	1	1	0	1	1	10.4
4	Coconut halves hanging	1	0	1	0	1	10.1
5	Cloth strip hanging	0	1	1	0	1	9.7
6	String hanging	0	1	1	0	1	9.1
7	Carrots hanging on string	1	0	1	0	1	9.1
8	Sisal rope with knots	1	1	1	0	1	8.4
9	Swedes in box	1	0	0	1	1	8.3
10	Cardboard box	0	1	0	1	1	8.3
11	Paper (shredded) in box	0	1	0	1	1	8.1
12	Astroturf in box	0	1	0	1	1	7.7

No	Objects	Odorous	Deformable	Not rootable	Not attached	Chewable	TOI time(b)
13	Compost in box	1	1	0	1	1	7.1
14	Straw (long) in box	1	1	0	1	1	7.0
15	Webbing (hanging)	0	1	1	0	1	6.6
16	Mobile (hanging)	0	1	1	0	1	6.3
17	Cabbage (loose)	1	1	0	1	1	6.2
18	Hessian sack (hanging)	1	1	1	0	1	6.1
19	Mushroom compost in box	1	1	0	1	1	6.1
20	Lavender straw in box	1	1	0	1	1	5.6
21	Sisal rope (hanging)	1	1	0	0	1	5.6
22	Wheel (loose)	1	0	0	1	1	5.2
23	Cat litter in box	1	1	0	1	1	5.0
24	Straw (chopped) in box	1	1	0	1	1	5.0
25	Bark chips in box	1	1	0	1	1	4.9

a) whilst this is what is indicated in the paper, the value would appear to be more likely to be minutes per 12 h.
b) TOI time: Total Object Interaction time recorded as second in 12 hours.

The materials named in the current Council Directive 2008/120/EC[4] (straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such) feature to some extent amongst these, but were not exclusively favoured. This suggests that a tool-box which defines suitable manipulable materials only by name is unlikely to be the best approach, since such a list would need to be large and continually updated as new materials are proposed and validated. It also fails to take into account the large variation in functionality which can occur within a named material, dependent on many other factors such as size, presentation method, hygienic quality etc.

An alternative approach, considers a tool-box of measures based on the desirable properties which a material should exhibit in order to meet the behavioural needs of pigs. By reanalysing the dataset described above, categorising each material according to 28 property descriptors, van de Weerd et al. (2003) investigated the characteristics which played a major role in determining the level of object-directed behaviour. The main characteristics emerging on day 1 (odorous, deformable, not rootable, not attached, chewable) reflected the initial attractiveness of an object. The main characteristics emerging on day 5 (ingestible, destructible, contained, not particulate, not rootable) reflected sustained attention towards an object. The appearance of 'not rootable' in these lists, whilst perhaps counter-intuitive, reflects the fact that many suspended objects were intensively used in comparison to objects presented at floor level. This may, in part, reflect the importance of another characteristic – hygienic quality or 'not soiled' - not tested in this experiment but demonstrated in other studies (Grandin et al., 1983; Munsterhjelm et al., 2014). A further property known to be very important is novelty (van de Weerd et al., 2003; Gifford et al., 2007; Trickett et al., 2009).

Using such data from literature, Bracke (2008) developed a computer-based model to assess manipulable materials (EMats) for intensively-farmed weaned, and rearing pigs on a scale from 0 to 10. This model, called RICHPIG, uses a (parsimonious) weighted average calculation rule to calculate enrichment (referring to manipulable material) scores from assessment criteria scores (which specify welfare relevant material properties of EMats) and weighting factors (WFs), which specify the relative importance of the assessment criteria). In total, 30 assessment criteria were identified and classified as object design criteria (e.g. novelty and accessibility), behavioural elements (e.g. nose, root, chew), biological functions (explore and forage), manipulations (i.e. object-directed behaviours), other (non-manipulative) consequences (e.g. aggression and stress) and object performance criteria (e.g. changeability/ destructibility and hygiene) (see examples in Table 11). WFs were calculated from a systematic analysis of 573 scientific statements collected in the database, using 11 so-called weighting categories (Wcat, i.e. scientific paradigms to assess welfare such as the study of natural behaviour, consumer demand studies and stress-physiology) to assign Wcat level scores (which indicate the intensity, duration and incidence of a welfare impact) to the assessment criteria. Table 11 shows examples of a range of materials and the scores given to them by the model.

Table 11: Example descriptions and enrichment scores calculated by the RICHPIG model for several enrichment materials (Bracke, 2008)

Enrichment material	RICHPIG functionality score[(a)]	Description
Reference pen (no enrichment)	1.46	Pen without enrichment material, otherwise (just) meeting minimum legal requirements for animal welfare. Typical/standard pen for weaners (as of 25 kg), growers and fatteners (up to 100 kg), respectively. Pen surface for fatteners 0.7–1 m–2 pig. Pigs typically fed *ad libitum* pellets, partly slatted concrete floor, stable group of approximately 10 pigs per pen.
Metal chain	2.24	A metal chain, hung vertically, at shoulder height, some 20 cm off the back of the pen.
Plastic ball	2.32	Heavy plastic ball (35 cm diameter) free on the pen floor.
Rubber hose cross	3.04	Two rubber hoses, fixed in the form of a cross, suspended on a chain, slightly above shoulder height.
Rope	3.29	Straight sash cord (cotton 1 cm diameter, 40 cm long) suspended from the pen gate at shoulder height (daily) adjusted according to consumption.
Pinewood beam	4.25	Pinewood beam (13 cm diameter, 1.5 m long) suspended by chains to the wall, at 'knee' (carpus) height.
Earth	4.71	Earth in a small trough (dimensions: 15 × 20 cm).
Foodball	5.20	The Edinburgh Foodball®, containing food pellets that drop out when the ball is rooted upon (refilled once daily).
Mushroom compost	6.53	Spent mushroom compost on a horizontal metal rack (1 m^2 above the pigs' heads), grid size 30 mm^2, compost refreshed daily, approximately 1/3 kg pig–1 day–1.
Strawrack device	6.54	Coarse chopped straw from a rack with a trough, a chain (to facilitate sliding of the straw) and a soft-wood beam (8 cm diameter, 50 cm long) hung horizontally above the trough on two chains (straw use: 10–20 g pig–1 day–1; straw length: 11 cm).
Straw twice daily	7.08	A handful of long straw provided twice daily (approximately 20 g pig–1 day–1).
Fodderbeets	7.09	Roughage, chopped fodderbeets (low DM) in a trough, provided *ad libitum* once daily.
Long straw and branches	8.34	Long straw provided once daily in a pen with two fir branches (which are renewed every month or when destroyed).
Straw and beet roots	8.54	When whole straw mixed with chopped beet roots provided *ad libitum* on the pen floor once daily.

(a): RICHPIG functionality score derived by a (parsimonious) weighted average calculation rule to calculate enrichment scores from assessment criteria scores and weighting factors (Bracke, 2008)

5.1.2.2. The potential tool box measures for evaluation of the properties of the available manipulable material

Construction of a tool-box for the evaluation of manipulable materials based on resource-based measures should therefore score the enrichment provided according to the number of desirable properties that it exhibits. Using an e-mail questionnaire Bracke et al. (2007) elicited expert opinion from 8 senior pig welfare experts on the importance of 33 assessment criteria. Kendall's coefficient of concordance of the experts was 0.41 ($P < 0.001$), which is only moderate, but this still constitutes the best current basis for such a tool. The scores given for each property are shown in Table 12. With better definition of the exact meaning of each property, these could provide the framework for an overall score which could be used to decide on the extent to which the manipulable material provided is adequate to conform to the intention of the Council Directive 2008/120/EC[4]. However, such an approach requires further validation through analysis of larger datasets linking properties to welfare outcomes or, failing this, consensus opinion from a wider range of experts.

Table 12: The median scores given by pig welfare experts for the importance of different properties of manipulable materials in meeting the welfare needs of the pig (Bracke et al., 2007). Properties listed are defined in more detail in the paper cited.

Assessment criterion	Median expert score (0-10 scale)
Object design criteria ('causes'):	
Novel/renewed	8
Accessibility	7.5
Multifunctional	7
Smelling, odorous	7
Palatability, flavour, taste	6.5
Nutritiousness	5
Visually appealing	3.5
Behavioural elements of positive AMI*:	
Rooting	8.5
Nosing	8
Biting	8
Pushing	6.5
Chewing	6.5
Pulling	5.5
Shaking	4.5
Carrying	3
Biologically functional objectives of AMI*:	
Explore/learn	9.5
Animal–material interaction	9.5
Tail and ear biting	9
Foraging	7.5
Pen-directed behaviour	5
Other (positive and negative) consequences:	
Stress	8
(Other) harmful social behaviour	8
Aggression	8
Health	8
Fear	7
Activity	6.5
Disturbance of other pigs	6
Production	1.5
Object performance consequences:	
Changed	8
Moveability	7
Ingestion	7
Hygiene/soiling	7
Sound producing	4

*AMI: Animal material interactions

5.1.2.3. The potential tool box measures for animal-based indicators which reflect the functionality of the manipulable material

The use of a tool-box based on resource-based measures of material properties is still problematic, as it relies on the subjective human interpretation of these properties. It would therefore be better if a reliable animal-based measure could be found which could be applied in a practical farm situation. Bracke et al. (2006) reviewed the different measures which have been used to assess the value of manipulable materials (referred as environmental enrichment) for pigs. These include positive measures such as object-directed behaviour (occupation) and negative measures such as aggression and tail-biting which indicate inadequacy of the material provided. Table 13 shows the number of times that different measures have been used, and how often an improvement in that measure was related to improved enrichment in the expected way, or showed an aberrant or non-significant change.

Table 13: The number of times that different welfare outcome measures have shown an improvement in that measure related to improved enrichment (+), or shown an aberrant (-) or non-significant change (No difference) (Bracke et al., 2006)

Welfare outcome measure	Response to increased enrichment			
	+	-	No difference	P-value (2-tailed sign test)
Object-directed behaviour	44	1	8	<0.001
Tail and ear biting	18	1	8	<0.001
Aggression	13	3	7	<0.05
(Other) harmful social behaviour	13	0	8	<0.01
Pen-directed behaviour	6	2	3	Not significant
Activity	19	8	15	0.05
Fear (of humans)	3	1	3	Not significant
Production	3	0	15	Not significant
Health and hygiene	3	2	2	Not significant

Results of this analysis suggest that the most reliable welfare outcome measures distinguishing suitability of manipulable materials would fall into two classes. Firstly, the absence of wounds reflecting increased injurious and aggressive behaviours, such as bitten tails, ears, flanks or (for pregnant sows) vulvas, or skin lesions. Secondly the presence of desirable behaviours such as exploratory and manipulatory behaviour directed to the material provided and the absence of exploratory behaviours redirected to pen mates (negative social behaviours) or pen fittings (which might also develop over time into stereotyped behaviours). However, there does not appear to be clear-cut relationship between these two sets of measures, as studies have shown differences in tail damage, but not object-directed explorative behaviour (Telkänranta et al., 2014b,c) or piglet-directed explorative behaviour (Telkänranta et al., 2014b) between treatments with different levels of manipulable material.

The wounds are relatively easy to score and methods for this are defined in the Welfare Quality® protocol. They will reflect the situation over a period of time, since the injuries will take time to heal and sometimes leave long term scars, and are hence not sensitive to the exact timing of measurement. The analysis in Section 4.2.1 did demonstrate that farms providing manipulable material in the form of straw, often considered to best meet the needs of pigs, had a lower prevalence of pigs with severe skin lesions. Furthermore, the analysis described in Section 4.2.2.2 also linked provision of straw with reduced prevalence of bitten tails. These measures of injury are, however, possibly limited in specificity, as indicated by the multiple causal factors for tail-biting summarised in Section 3.2.2, and in sensitivity as shown in the analysis of tail lesions in Section 4.2.1.This will particularly be the case when tail-docking is practiced on the farm.

These considerations would suggest that the behavioural measures might provide a more specific and more sensitive animal-based indicator of manipulable material adequacy. However, these pose a greater measurement challenge under practical farm conditions, since they will be sensitive to the timing and measurement methodology. The absolute level of exploratory behaviour shows variation linked to circadian rhythms of activity, will be related to feeding time and level, and will be sensitive to disturbances such as the presence of an observer. For these reasons, an assessment based on a short observation period at a non-standardised time of day is likely to yield little insight, and this is supported by the analysis of these behaviours from the Welfare Quality® dataset shown in Section 4.2.1. To overcome these problems, it has been suggested that a measure which takes into account only pigs which are active and showing exploratory behaviour, and which then calculates the ratio of pigs performing manipulable material-directed behaviour to pigs performing other redirected behaviours might be more robust (Mullan et al., 2009). Such a measure has been shown, to have reasonable inter-observer reliability (Mullan et al., 2011a) and, in a small sample of farms, to relate well to a resource-based score of manipulable material (referred as enrichment) quality (Mullan et al., 2011b).

However, whilst such a measure should be theoretically more robust to time of day and disturbance factors, and therefore readily applicable on farm and in a limited time, it requires further validation. The analysis carried out in Section 4.2.1, failed to show the clear utility of this ratio measure, but this may be partly a result of the relatively general categorisation of the manipulable materials available in this dataset. Further validation of such a measure is therefore required before it can be unconditionally recommended for practical use. This work is ongoing in a current EU project (FareWellDock project, www.farewelldock.eu) with results from this part of the project anticipated by end of 2015.

Whilst the discussion here has focussed on weaners and rearing pigs, it must be bourne in mind, as indicated in Section 3.2, that manipulable materials serve some additional specific functions in particular classes of pigs. It would be predicted that a similar animal-based measure of the functional use of the material (e.g. for foraging behaviour in pregnant sows or nest building in farrowing sows) in relation to redirected behaviours (such as stereotyped bar biting or vacuum chewing) should provide a useful indicator, although the actual on-farm measurement methodology again requires validation.

A number of different resources to improve understanding of the needs of pigs for manipulable materials, the suitability of different materials for this purpose and the form in which these can be provided and assessed in practice have recently been developed to assist farmers, advisors and assessors. These include an e-learning tool produced under the EU WelNet project[13] and a website on practically applicable enrichment objects developed in a Finnish project[14].

5.1.3. Proposed tool-box for the assessment of adequacy of manipulable material on a farm

The current Council Directive 2008/120/EC[4] requires that pigs must have 'permanent access to a **sufficient quantity** of material to enable **proper investigation and manipulation** activities'. These terms are not explicitly defined. In the tool proposed below the AHAW Panel suggests measures by which sufficiency and efficacy (enabling proper activities) can be assessed.

The proposed tool-box has two components as shown in Figure 7. The first relates to the properties of the material suggested to be important to meet the behavioural needs of the pigs. The second relates to animal-based measures which reflect adequacy of the material provided. The components suggested here are those indicated by existing literature or expert opinion but have not all yet been scientifically validated.

[13] Available at: https://www.euwelnetpigtraining.org/
[14] Available at: http://kotisivu.surffi.net/~heltel1/research_on_enrichment.html

1 Resource-based measures (properties of the manipulable material provided)
1A- Material characteristics: what is presented • Safe (free of biological and chemical hazards free and non injurious) • Deformable and moveable by pig manipulation (able to be changed in location, appearance or structure as a result of the activity of the pig) • Multi- functional (able to be manipulated by the pig in a variety of ways including rooting chewing, ingesting) • Feed-related properties (odorous ,palatable flavour and nutritious) 1B - Managerial characteristics: how it is presented: • Novel/renewed (regularly replaced or replenished such that the interest of the pig is sustained) • Accessible (available for oral manipulation to all pigs at all times) • Hygienic (not soiled with excreta)
2 Animal-based measures (combination of physical and behavioural measures)
2A - Absence of bitten tails (indicative of, but not specific to, manipulable material properties) 2B - Absence of skin lesions (indicative of, but not specific to, manipulable material properties) 2C - Appropriate exploratory behaviour (the ratio of exploration directed to manipulable material in comparison to that directed to pen fittings and other pigs or vacuum oral behaviour). In the case of farrowing sows the ratio should be between nest building behaviour and redirected behaviour.

Figure 7: Proposed tool-box for the assessment of adequacy of manipulable material based on existing literature or expert opinion.

5.2. Avoidance of tail-docking

5.2.1. Procedures to address this question

Since the analyses of available data carried out under ToR2 did not yield a clear and comprehensive prioritisation of risk factors, a potential tool box for identifying hazards associated with the occurrence or the risk of tail-biting has been derived from the hazards quantified in the EFSA Scientific Opinion on tail-biting (EFSA, 2007c), in combination with the measures identified in ToR 1. In the 2007 Scientific Opinion, experts were asked to score the quantitative assessment of likelihood that tail-biting can occur for a given exposure to a hazard (defined in terms of intensity and duration). This was done for the docked as well as the undocked populations, and resulted in likelihoods that were generally three times higher in the undocked population compared to docked population of pigs. This was based on available evidence and expert opinion of the protective effect of tail docking.

5.2.2. Main findings

Table 14 categorises the hazards, and then ranks the categories in order of likelihood of causing tail biting. Ongoing tail-biting is the highest likelihood hazard, followed by (in descending order) aspects related to manipulable materials, health, genotype (including gender), competition, the environment, diet and herd size. Animal-based and resource-based measures were then allocated to each of these categories of hazards. This categorisation considers only single hazards as the data did not allow consideration of interactions or multifactorial relationships. The EFSA expert opinion considered an undocked population of pigs to be more at risk of tail biting. This was not evident in the Welfare

Quality® data analyses in the current Opinion, but the confounding of docking and straw provision, as discussed in Section 4.2.2.1, may account for this different result.

The table thus suggests an order in the use of measures which farmers can apply to address tail-biting risk. Firstly, farmers should check for signs of existing biting problems (tail biting, tail lesions, tail posture and restlessness), and then check the availability and quality of the manipulable materials, based on the properties reviewed in section 5.1. The latter should be done not just by looking at the materials themselves (see guidelines described in previous paragraphs), but also by checking for aggression, skin lesions and restlessness in the pen, as well as use of the manipulable material provided. The third most important category includes measures related to animal health, most of which can be identified and interpreted by non-veterinarians.

Table 14: Animal and resource-based indicators for the hazards for tail-biting listed in the EFSA Scientific Opinion on tail-biting (EFSA, 2007c). The hazards are categorised and presented in order of highest likelihood of occurrence, as judged by the experts in this previous EFSA Opinion.

Hazard /Risk Factors	**Likelihood of tail-biting (expressed as %)**		**Resource /management-based indicators of hazard**	**Animal-based indicators of hazard**
	Docked population	Undocked population		
1. **Presence of biting**				
Presence (no removal) of tail bitten and biting animals	30	70		Increased tail lesions; Lowered tail posture; Increased tail-biting behaviour; Increased restlessness
2. **Manipulable materials**				
Absence of bedding having previously had bedding since weaning	5	15	Measures related to functionality of the manipulable material*: 1A. Material characteristics: • Safe • Deformable and moveable by pig manipulation • Multi- functional • Feed-related properties 1B. Managerial characteristics : • Novel/renewed • Accessible • Hygienic	Increased severe skin lesions; Increased tail lesions Increased aggression; Increased restlessness; Reduced interaction with manipulable material Increased redirected exploration to pen mates Increased redirected exploration to pen furniture
Lack of straw and absence of adequate enrichment	5	15		
Lack of straw and 100% slatted floor	3.5	10.5		
Lack of long straw	3	9		
Lack of farrowing house bedding	0.2	0.6		
Fully slatted flooring during suckling	0.2	0.6		
3. **Health**				
Being in a group with growth retarded pigs	2	6	Biosecurity programme; SPF[(a)] status, vaccination programme	Increase of the following indicators: Panting, shivering; Lying behaviour ; Coughing, sneezing; red eyes; Poor body condition; Diarrhoea; Variation in pig size within group
Poor herd health status	1	3		
Presence of clinical disease in the individual	1	3		
4. **Genotype and gender**				
Castration in males[(b)]	1	6	Genetic merit for lean tissue growth rate and low fat deposition	Presence of castrated males High carcass leanness;
Genetic selection for high lean tissue growth	1	3		
5. **Competition**				
High stocking density	1	3	Number of animals per m^2; Number of animals per feeder; Mixing management	Increase of the following indicators: Skin lesions;
High feeding competition	1	3		

Hazard /Risk Factors	Likelihood of tail-biting (expressed as %)		Resource /management-based indicators of hazard	Animal-based indicators of hazard
	Docked population	Undocked population		
Delay of feed supply	1	3		Aggression; Restlessness Poor body condition
Mixing of animals excluding at weaning time	0.5	1.5		
6. **Environment**				
High air speed (draughts)	1	3	Air temperature; Air speed; Light level; level of noxious gases (e.g. CO_2, NH_3)	Increase of the following indicators: Panting, shivering, Poor body condition, poor coat condition; Restlessness; Red eyes; Modified lying behaviour showing thermal discomfort;
Heat stress	0.5	1.5		
Cold stress	0.5	1.5		
Poor air quality	0.2	0.6		
Absence of natural light	0.2	0.6		
1. **Diet**				
Inadequate dietary sodium	0.5	1.5	Diet composition	Increase of the following indicators: Poor body condition, diarrhoea; Poor coat condition, restlessness, foraging behaviour; Gastric ulcers; Variation in pig size within group
Amino acid deficiency	0.5	1.5		
Abrupt change of feed composition	0.2	0.6		
2. **Herd size**				
Large herd size	0.1	0.3	Herd size	

*see Section 5.1.3 for further detailed information
(a): SPF: specific pathogen free
(b): The literature clearly shows that being a castrate gives significantly greater risk of being bitten than being a gilt. Being an entire male may give slightly more risk than a gilt, but data are not conclusive. Whilst this therefore suggests castration may increase risk, there is no direct comparison between castrates and entire males. We cannot therefore be certain that castration per se is a risk (EFSA, 2007c)

The analyses carried out as part of this Scientific Opinion highlighted the significance of a number of risk factors suggested in Table 14. Although the error in these analyses was high, of the factors which can be influenced by management (i.e. excluding pig age/weight and herd/group size) they suggest space allowance and manipulable material type to be very influential, and method of water provision, feed formulation, flooring type, temperature, cleanliness of the pen and tail-docking to be of lesser importance. However, because of the degree of error and the fact that not all suggested risk factors were present in the dataset, it is not possible to revise the estimates of relative importance given in Table 14.

The prioritization of the list of factors presented in Table 14 may be difficult, as most important risk factors vary among farms. A better approach is therefore to assess the risk factors according to the farm specific situation. Since the EFSA (2007c) report was published, a number of tools for farm specific assessment of risk factors for tail-biting have been published. These include: (i) the Husbandry Advisory Tool (Taylor et al., 2012)[15]; and (ii) a subsequent German version (SchwIP) derived from this Schwanzbeiß-Interventions-Programm[16]. These tools for the farm-specific assessment of tail-biting risk are complemented by other tools for management of a tail-biting outbreak once it has occurred, such as the *Danish 10* steps[17] action plan.

[15] Available at: http://www.bris.ac.uk/vetscience/webhat
[16] Available at: http://www.fli.bund.de/no_cache/en/startseite/institutes/institute-of-animal-welfare-and-animal-husbandry/labs-working-groups/haltung/schweine/project-schwip.html#h3_2_2.
[17] Available at: http://vsp.lf.dk/~/media/Files/Folier/Halebid_10pkt_plan_uk.ashx

5.2.3. Proposed tool-box for the assessment of the risk of tail-biting on a farm

If a customized tool such as described in the preceding paragraph is not available, a simplified tool-box to assess the risk of tail-biting on a farm is presented in Figure 8. This suggests both resource based and animal-based indicators of the presence and strength of the major risk factors.

Hazard /Risk Factors	Resource /management-based indicators of hazard	Animal-based indicators of hazard
1 Presence of biting		• Increased tail lesions; • Lowered tail posture; • Increased tail-biting behaviour; • Increased restlessness
2 Manipulable materials	• Absence of manipulable material with properties related to functionality for the pig: 1A Material characteristics: • Safe • Deformable and moveable by pig manipulation • Multi- functional • Feed-related properties 1B Managerial characteristics : • Novel/renewed • Accessible • Hygienic	• Presence of bitten tails (indicative of, but not specific to, manipulable material properties) • Presence of skin lesions (indicative of, but not specific to, manipulable material properties) • Inappropriate exploratory behaviour (a low ratio of exploration directed to manipulable material in comparison to that directed to pen fittings and other pigs or vacuum oral behaviour).
3 Health	• Poor biosecurity programme; • Lack of specific pathogen free status • Inadequate vaccination programme.	Increase of the following indicators: • Panting, shivering; • Lying behaviour ; • Coughing, sneezing; red eyes; • Poor body condition; • Diarrhoea; • Variation in pig size within group
4 Genotype	• High genetic merit for lean tissue growth rate and low fat deposition	• High carcass leanness
5 Competition	• High number of animals per m^2; • High number of animals per feeder; • Poor mixing management	Increase of the following indicators: • Skin lesions; • Aggression; • Restlessness • Poor body condition
6 Environment	• Extreme or variable air temperature; • High air speed; • Intense light level; • High level of noxious gases (e.g. CO_2, NH_3)	Increase of the following indicators: • Panting, shivering, • Poor body condition, poor coat condition • Restlessness; • Red eyes; • Modified lying behaviour showing thermal discomfort;
7 Diet	• Diet composition: • Lack of sodium • Lack of amino acids • Lack of energy	Increase of the following indicators: • Poor body condition, diarrhoea; • Poor coat condition, • Restlessness, • Foraging behaviour; • Gastric ulcers; • Variation in pig size within group

Figure 8: Proposed tool-box for the assessment of the presence and strength of risk of tail-biting based on existing literature or expert opinion.

5.3. Concluding remarks (ToR3)

The adequacy of provision of manipulable material could be assessed under farm conditions by reference to a permitted list of materials, but this approach has major practical and biological limitations. A better resource-based approach would be to judge the functionality of the manipulable materials to meet the behavioural need of the pigs by their properties. Scientific literature has defined which properties make them suitable to meet animal needs (Section 5.1.2.1).

Because the human view point may not correctly interpret the pigs' perception of material suitability, it would be preferable to use animal-based measures for the assessment. The functionality of the supplied manipulable material is reflected in severe skin lesions, as indicated by the Welfare Quality® dataset (see Tables 1-3). It is also reflected in bitten tails, as shown in the Finnish farm dataset (see Tables 7 and 8), but this measure may be less sensitive if tails are docked since it was not significant in the Welfare Quality® dataset (see Section 4.2.1). However, other aspects of housing and management also affect both these measures, meaning that their specificity to assess the functionality of manipulable material is limited. Therefore, a practical tool-box should contain a measure which is more specific than these lesions such as direct behavioural measures.

Behavioural measures of manipulable material functionality include material-directed behaviour, measures of redirected behaviour, and injurious abnormal behaviour and aggression. Animal-based behavioural measures of material functionality need to be simple and robust under farm measurement conditions. No comprehensive measure has yet been scientifically validated for this purpose but studies currently in progress are addressing this question. A measure which shows the ratio of behavioural directed towards manipulable material to re-directed exploratory behaviour has the potential to show functionality of that manipulable material, without introducing bias from time of day when assessment are made or from general activity levels of the pigs, but requires scientific validation.

A simple tool-box for on farm use to assess the functionality of the supplied manipulable material is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

The presence of known risk factors for tail-biting can be assessed on farm by both resource/management-based and animal-based indicators. These are not always specific for a given risk factor, but their presence indicates the need for further investigation. With present knowledge the relative importance of different risk factors as hazards for tail-biting and the interactions between these risk factors cannot be scientifically quantified. Further studies are needed for this purpose. These should provide the data necessary to weight different risk factors in decision-support tools which can provide customised risk assessment for individual farms. The further development and validation of such tools is strongly recommended. A simple tool-box for on farm use to assess the presence and strength of risk factors for tail-biting is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

Conclusions and Recommendations

Conclusions

ToR 1- Identification of the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures in relation to the provision of manipulable material and avoidance of tail-docking in pigs

- Pigs have a need for manipulable materials to satisfy a range of behavioural needs, which can be different in different classes of pig. When these needs are not met, a range of adverse welfare consequences result, one of these being an increased risk for tail-biting in weaners and rearing pigs.

- Some manipulable materials, although good at meeting the behavioural needs of pigs, can also have adverse effects on other aspects of pig welfare. These adverse effects have not been adequately studied to ensure safe provision in all cases.

- The ability to control the risk of tail-biting through correct identification and alleviation of the predisposing animal, environmental and management factors on that farm is essential when aiming to avoid tail-docking. The presence of these risks can be indicated by a range of resource/management and animal-based measures.

ToR 2- Identification of the strength and predictive capacity of the above identified interactions relating to the provision of manipulable material and avoidance of tail-docking in pigs.

- Analyses of an international dataset collected using the Welfare Quality® protocol did not show animal-based measures of behaviour which clearly distinguished between farms providing different types of manipulable material. Category of manipulable material was reflected in severe skin lesions, but not in bitten tails. This may reflect the fact that many farms had pigs with docked tails and there was a confounding between type of manipulable material and tail docking in this dataset.

- Analyses of an international dataset using the Welfare Quality® protocol suggested a number of animals and resource-based factors to be important risk factors for tail biting, but a high degree of uncertainty in the model precludes strong conclusions. The dataset used was not designed to evaluate risk factors for tail-biting and therefore, it had limitations in fitness for this analysis.

- The Welfare Quality® dataset indicated the possibility for undocked pigs to be housed and managed in a way which does not imply an increased risk for tail biting. However, this requires further investigation in more comprehensive datasets where the overall farm prevalence of bitten tails, including animals in hospital pens and euthanized/culled animals, is recorded.

- Analyses of a large Finnish dataset with undocked pigs showed that use of straw was associated with reduced tail-biting prevalence relative to the other types of manipulable material (including objects) present on Finnish farms. No other manipulable material gave consistent reduction in tail-biting across both weaner and rearing pigs compared to the population average.

ToR 3- Proposed model to evaluate how likely certain welfare consequences may happen given specific risk factors for lack of functional manipulable material or for tail biting, and which animal and/or non-animal-based measures would better fit for the assessment of those risks and consequences

- The adequacy of provision of manipulable material could be assessed under farm conditions by reference to a permitted list of materials, but this approach has major practical and biological limitations. A better resource-based approach would be to judge the functionality of the manipulable materials to meet the behavioural need of the pigs by the properties which that material possesses.

- Because the human view-point may not correctly interpret the pigs' perception of material suitability, it would be preferable in a tool-box to use animal-based measures for the assessment. The type of manipulable material supplied has an effect on the prevalence of severe skin lesions. It is also affects prevalence of bitten tails but this measure may be less sensitive if tails are docked. However, the specificity of both lesion measures to assess the functionality of manipulable material is limited. Therefore, a practical tool-box should contain direct behavioural measures.

- Animal-based behavioural measures of functionality of the supplied manipulable material need to be simple and robust under farm measurement conditions. The ratio between material-directed exploration and other redirected exploration to pen mates and pen fittings has been suggested for this purpose. However, no comprehensive measure has yet been scientifically validated for this purpose, although studies currently in progress are addressing this question.

- A simple tool-box for on farm use to assess the functionality of the supplied manipulable material is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

- The presence of known risk factors for tail-biting can be assessed on farm using a tool-box containing both resource/management-based and animal-based measures. These outcome measures may not always be specific for a given risk factor, but the occurrence of a measure suggestive that a risk factor may be present indicates the need for further investigation.

- With present knowledge the relative importance of different risk factors as hazards for tail-biting and the interactions between these risk factors cannot be scientifically quantified. Further studies are needed for this purpose. These should provide the data necessary to weight different risk factors in decision-support tools which can provide customised risk assessment for individual farms.

- A simple tool-box for on farm use to assess the presence and strength of risk factors for tail-biting is proposed, which includes a combination of the most important resource-based and animal-based measures based on the current state of knowledge.

RECOMMENDATIONS

ToR 1- Identification of the multiple interactions between risk factors, welfare consequences and animal-based and non-animal-based measures in relation to the provision of manipulable material and avoidance of tail-docking in pigs

1 Any study on manipulable materials should consider possible adverse effects and their alleviation.

2 Further research should be carried out into the causal relationship between the general pig health and tail-biting risk.

ToR 2- Identification of the strength and predictive capacity of the above identified interactions relating to the provision of manipulable material and avoidance of tail-docking in pigs

3 There is a need for more comprehensive analyses of existing datasets collected for the purpose of evaluating risk factors for tail-biting in different farm typologies. This could better indicate the relative importance of different risk factors for the occurrence and severity of tail-biting outbreaks, and the way in which these factors interact.

4 In order to assess the true prevalence and importance of the risk factors for tail-biting and their interactions, further harmonised data collection across the range of European farming circumstances is needed. A proposal is made (Appendix J) for a data model which might be used in such a study.

5 There is a need to investigate the farmers' acceptance level of tail-biting relation to their previous experiences of this problem and perceived ability to limit the level of injury.

6 There is a need for further studies to provide guidance on how to house and manage undocked pigs under different farm circumstances without uncontrollable tail-biting outbreaks.

ToR 3- Proposed model to evaluate how likely certain welfare consequences may happen given specific risk factors for lack of functional manipulable material or for tail biting, and which animal and/or non-animal-based measures would better fit for the assessment of those risks and consequences

7 Tail-biting and severe skin lesions should be included in a tool-box to assess the functionality of manipulable material, although it is recognised that these may be caused by many risk factors.

8 Validation of a practical on farm assessment protocol for functionality of manipulable material based on behavioural measures should be carried out, in order to provide a sensitive tool-box measure for use also in docked pigs.

9 The further development and validation, from robust epidemiological data, of decision-support tools for customised assessment of tail-biting risk factors on individual farms is strongly recommended. Such tools could assist farmers to identify, and prioritise correction of, the most important hazards for tail-biting on their own unit.

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APPENDICES

Appendix A. Classification methods used for modelling the Welfare Quality® data

Classification can serve two different purposes. One may be, in a situation in which we have a set of observations and we want to establish the existence of cluster or classes present in the data at hand. The second one, in which we know the number of classes and our goal is to establish a rule whereby we can classify a new observation into one of the existing classes. The former is commonly known as Clustering or Unsupervised Learning, the latter is usually referred in the statistical literature as discrimination (also called Supervised Learning), which means the establishment of the classification rule from given correctly classified data (often called training data). If we are using correctly classified data then we are presupposing that someone is able to classify without error. Hence, a logical question arises: why is it necessary to replace this exact classification by some approximation? Several can be the reasons, for example: in the medical field we may wish to avoid the surgery that would be the only sure way of making an exact diagnosis, or in our case we wish to avoid tail-biting injury, so we ask if a reliable diagnosis can be made based on other symptoms.

In this section we will focus on discrimination techniques to classify farms having tail-biting issues from those that don't based on several statistical approaches. Classification and Regression Trees (Breiman et al., 1984), Boosting methods (Freund and Schapire, 1996), Random Forest (Breiman, 2001) and Support Vector Machines are briefly reviewed.

1. Classification and Regression Trees (CART)

Classification and regression trees (CART) is the most well-known tree model or algorithm in the statistics community. The idea behind this is very simple; it is a method where, following specific splitting rules, disjoint subsets of the data are constructed. These subsets are called nodes. Further splitting is repeated several times within these nodes. We focus on binary classification trees, where splitting occurs into exactly two child nodes. This partitioning process results in a saturated tree. The saturated binary tree is then pruned to an optimal size tree. This is the so-called pruning process. The final step is the selection process, which determines the final tree. In the following subsections a brief overview of the different processes is given.

1.1 The Partitioning Process

The partitioning process is based on splitting rules, which involve conditioning on predictor variables. The best possible variable to split the root node is the one that results in the most homogeneous and purest child nodes. A measure for the goodness of split is defined as the reduction in impurity. This partitioning process results in a saturated tree with the characteristic that if no limit is placed on the number of splits, eventually `pure' classification will be achieved. In that case the saturated tree is usually too large to be useful. Therefore it is typically to set a minimum size of a node a priori or a maximum number of levels for the tree to reach (Breiman et al., 1984).

1.2 The Pruning Process

The point is to find the subtree of the saturated tree that is most predictive of the outcome and least vulnerable to noise in the data. Breiman et al. (1984) proposed to let the partitioning continue until the tree is saturated or nearly so, and this generally large tree is pruned from the bottom up using cost-complexity method. Cost-complexity pruning is defined as the cost (a measure for total impurity in the final nodes) for the tree plus a complexity parameter times the tree size.

1.3 The Selection Process

For the original dataset, the cost decreases monotonically with increasing number of nodes. For the test data, the cost decreases with increasing number of nodes, but reaches a minimum and then increases as complexity increases. The optimal tree is that in which we obtain a minimum cost for the new data. Often there are several trees with costs close to the minimum, then the smallest-sized tree whose cost does not exceed the minimum cost plus the standard error of the cost will be chosen. When no test sample is available, k-fold cross-validation is useful, in which k random subsamples, as equal in size as possible are formed from the learning sample. The classification tree of the specified size is computed k times, each time leaving out one of the subsamples from the computations, and using that subsample as a test sample for cross-validation. The CV costs computed for each of the k test samples are then averaged to give the k-fold estimate of the CV costs.

1.4 Handling Missing Data

One attractive feature of tree-based methods is the ease with which missing values can be handled. There are several methods to deal with missing values. One of the most common used methods uses the approach of surrogate splits, which attempt to utilize information in the other predictors to assist in making the decision to send an observation to the left or to the right daughter node. They look for the predictor that is most similar to the original predictor in classifying the observations. Similarity is measured by a measure of association. It is not unlikely that the predictor that yields the best surrogate split may also be missing. Then there will be looked for the second best, and so on. In this way all available information is used.

2. Boosting Methods

Boosting methods have been very popular in the late 90’s in the machine learning and statistical communities. From a statistical perspective, they can be viewed as a nonparametric optimization algorithm in function space, as first pointed out by Breiman (Breiman, 1998, 1999). This view turns out to be very fruitful to adapt boosting for other problems than classification, including regression and survival analysis. Maybe it is worth mentioning here that boosting algorithms have often better predictive power than bagging (Breiman, 1998); of course, such a statement has to be read with caution, and methods should be tried out on individual datasets, including e.g. cross-validation, before selecting one among a few methods. Boosting has proved to be an effective method to improve the performance of base classifiers, both theoretically and empirically. The underlying idea is to combine simple classification ‘rules’ (base classifiers) to form an ensemble, whose performance is significantly improved.

Freund and Schapire (1996) collaborated to produce the well-known AdaBoost.M1 (also known as Discrete AdaBoost) algorithm (given above). A number of ensemble methods have appeared in the literature over the last decade such as arcing (Breiman, 1999), bagging (Breiman, 1996), random forests (Breiman, 2001), and boosting. A provably polynomial complexity boosting algorithm was derived in Schapire (1999), whereas the Adaptive Boosting (AdaBoost) algorithm in various varieties developed by Freund and Schapire (1996, 1997) proved to be a practical implementation of the boosting ensemble method. In Friedman, Hastie and Tibshirani (2000), it was shown that boosting can be thought of as a stage-wise gradient descent procedure that minimizes an exponential cost function and provided a statistical view of the technique.

3. Random Forest (RF)

The random forest method (Breiman, 2001) is a supervised learning algorithm that has previously been successfully applied to many different type of studies. A random forest is an ensemble of many identically distributed trees generated from bootstrap samples of the original data. Each tree is constructed via a tree classification algorithm. The simplest random forest with random features is formed by selecting randomly, at each node, a small group of input variables to split on. The size of the group is fixed throughout the process of growing the forest. Each tree is grown by using the CART methodology without pruning. After the forest is formed, drop a case with input x into the forest for each tree to classify x. Several methods can be used to classify a particular observation. For example, the forest chooses the class for x having the majority vote. Specifically, for each case, the proportion of votes for each class is recorded. For each member of a test set (with or without class labels), these proportions are also computed. They contain useful information about the case. The margin of a case is the proportion of votes for the true class minus the maximum proportion of votes for the other classes. The size of the margin gives a measure of how confident the classification is. In our case we will use different prior weight for the tail-biting class.

Some features of random forest that can be highlighted:

- It generates an internal unbiased estimate of the generalization error as the forest building progresses.
- It gives estimates of what variables are important in the classification and generates information about the relation between the variables and the classification.
- It computes proximities between pairs of cases that can be used in clustering, locating outliers, or by scaling, give useful views of the data.
- It is well known that random forests avoid over fitting and usually have better classification accuracy than classification trees.

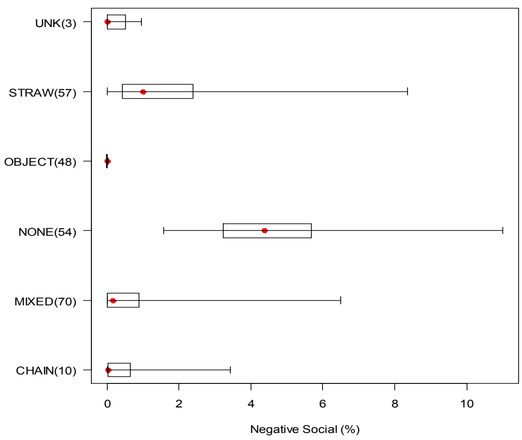
4. Support Vector Machine (SVM)

Support vector machine (SVM) is a family of learning algorithms which is nowadays considered as one of the most efficient methods in many applications. SVM is a supervised learning technique for classification and regression. The theory was developed in the late sixties and seventies by Vapnik and Chervonenkis, but the first practical implementation was only published in the early nineties (Vapnik, 2000). Since then the popularity of the method has grown tremendously among the machine learning and statistical communities. The key to the success of SVM is the kernel function which maps the data from the original space into a high dimensional (possibly infinite dimensional) feature space. By constructing a linear boundary in the feature space, the SVM produces nonlinear boundaries in the original space. When the kernel function is linear, the resulting SVM is a maximum-margin hyperplane. Given a training sample, a maximum-margin hyperplane splits a given training sample in such a way that the distance from the closest cases (support vectors) to the hyperplane is maximized. Typically, the number of support vectors is much less than the number of the training sample. Nonlinear kernel functions such as the polynomial kernel and the Gaussian (radial basis function) kernel are also commonly used in SVM. The computational complexity of the SVM depends on the training sample, thus it avoids the traditional problem of ‘Curse of dimensionality’. More detailed discussion of SVM and kernel methods can be found in Scholkopf and Smola (2002).

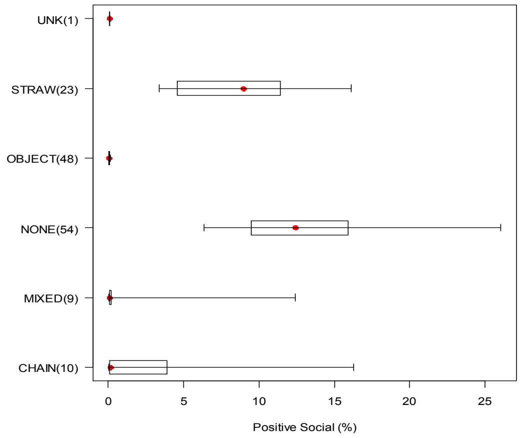
Appendix B. The distribution of different possible animal-based measures of the functionality of manipulable material according to the Welfare Quality® classification of environmental enrichment

Diagrams show the median, inter-quartile range and 95th confidence intervals for various behavioural measures as defined in the Welfare Quality® protocol for farms within each manipulable material category. Description of the manipulable categories is as follows: Unknown (unk); Straw (straw); None (none); Combined substrates (mixed), Chain (chain only); At least a substrate material plus an object (object). The number of farms in the analysis is shown in the title and their distribution indicated in the y-axis labels. Not all datasets included information on all behaviours, hence ratios are sometimes only from a more limited subset of farms.

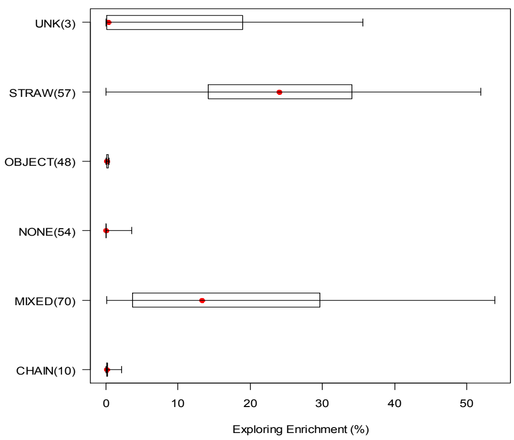
Negative Social Percentage (242 observations)



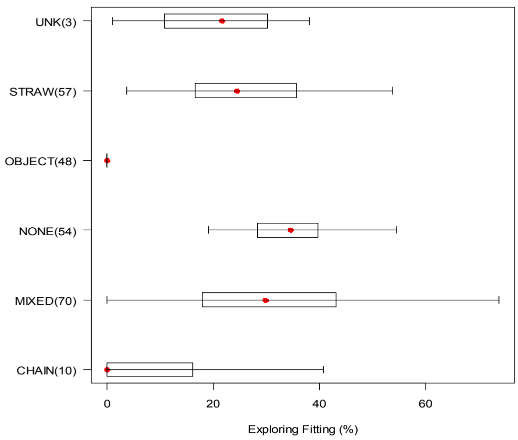
Positive Social Percentage (145)



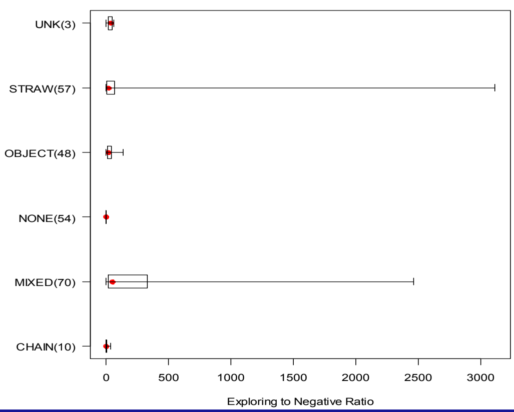
Exploring Enrichment Percentage (242)



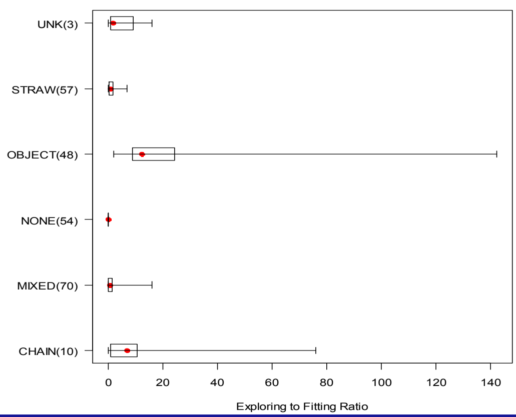
Exploring Fitting Percentage (242)



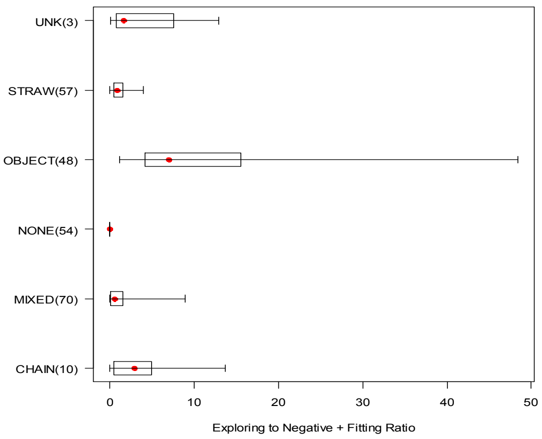
Exploring to Negative Ratio (242)



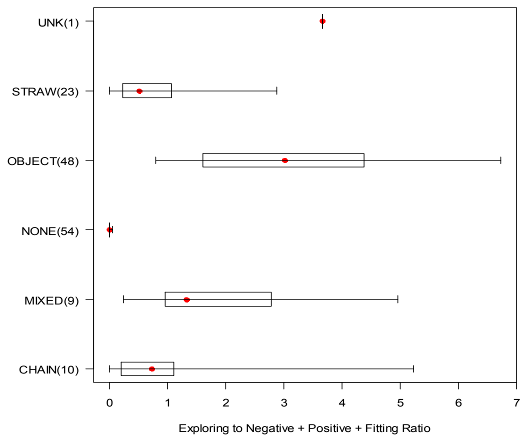
Exploring to Fitting Ratio (242)



Exploring to (Negative + Fitting) Ratio (242)



Exploring to (Negative + Positive + Fitting) Ratio (145)



The following tables (B1-B6) show the extent to which different outcome measures are dependent on the type of manipulable material provided on a farm

Table B1: Number of farms reporting animals with mild wounds (skin lesions) for each manipulable material category.

Mild Wound Presence	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	0	30	33	0	10	1	27.8
Yes	10	49	40	52	37	4	72.8

Table B2: Number of farms reporting animals with severe wounds (skin lesions) for each manipulable material category.

Sever Wound Presence	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	6	60	36	21	45	3	60.4
Yes	4	19	39	31	17	2	39.6

Table B3: Number of farms reporting tail lesions for each manipulable material category.

Tail lesions	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	9	46	37	33	44	2	70.7
Yes	1	24	17	15	13	1	29.3

Table B4: Number of farms reporting negative social behaviour in animals for each manipulable material category.

Negative social behaviour	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	0	27	4	3	11	1	16.3
Yes	10	52	71	49	51	4	83.7

Table B5: Number of farms reporting positive social behaviour in animals for each manipulable material category.

Positive social behaviour	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	0	0	1	0	0	0	0.5
Yes	10	18	74	52	28	3	99.5

Table B6: Number of farms reporting animals exploring enrichment for each manipulable material category.

Exploring enrichment	Chain only	Combined substrates	None	A substrate material plus an object	Straw	Unknown	%
No	1	0	67	0	3	1	25.4
Yes	9	79	8	52	59	4	74.6

Appendix C. Summary tail lesion tables at farm level from the Welfare Quality® data

The following tables (C1-C12) classify farms where tail lesions were present or absent in relation to different environmental factors. Data from 242 intensive farms in 5 countries [Finland (97), France (30), the Netherlands (63), Spain (40) and Sweden (12)] were collated regarding potential risk factors for tail biting. The total number of farms reporting tail lesions was 71, while 171 did not report tail lesions of severity score 2.

Table C1: Presence of tail lesions in relation to flooring type

	Presence of tail lesions		% tail lesions
	no	yes	
Bedding	11	2	15
Fully slatted	16	10	38
Ground [(a)]	0	0	0
Mixed	0	1	100
Partially slatted	116	51	31
Solid	12	2	14
Unknown	16	5	24

(a): natural flooring mud or grass

Table C2: Presence of tail lesions in relation to straw provision

	Presence of tail lesions		% tail lesions
	no	yes	
Presence of straw	85	36	30
Absence of straw	81	33	29
Unknown	5	2	29

Table C3: Presence of tail lesions in relation to feeder type

	Presence of tail lesions		% tail lesions
	no	yes	
Ground	0	0	0
Hopper	62	29	32
Mixed	22	10	31
Trough	86	32	27
Unknown	1	0	0

Table C4: Presence of tail lesions in relation to water supply (drinkers) type

	Presence of tail lesions		% tail lesions
	no	yes	
Bowl	14	4	22
Mixed	23	10	30
Nipples	62	25	29
None	1	0	0
Others	0	0	0
Trough	4	2	33
Unknown	67	30	31

Table C5: Presence of tail lesions in relation to feed formulation

	Presence of tail lesions		% tail lesions
	no	yes	
Dry	76	30	28
Wet/ Liquid	95	41	30

Table C6: Presence of tail lesions in relation to functionality of water supply (drinkers)

	Presence of tail lesions		% tail lesions
	no	yes	
Functional drinkers	42	20	32
No functional drinkers	62	21	25

Table C7: Presence of tail lesions in relation to cleanliness of water supply (drinkers)

	Presence of tail lesions		% tail lesions
	no	yes	
Clean drinkers	42	20	32
Dirty drinkers	62	21	25

Table C10: Presence of tail lesions in relation to outside access

	Presence of tail lesions		% tail lesions
	no	yes	
No outside access	144	59	29
Outside access	9	1	10

Table C8: Presence of tail lesions in relation to pen cleanliness

	Presence of tail lesions		% tail lesions
	no	yes	
Dirty pen	32	11	26
Clean pen	72	30	29

Table C11: Presence of tail lesions in relation to body condition score

	Presence of tail lesions		% tail lesions
	no	yes	
0	127	49	28
1	44	22	33

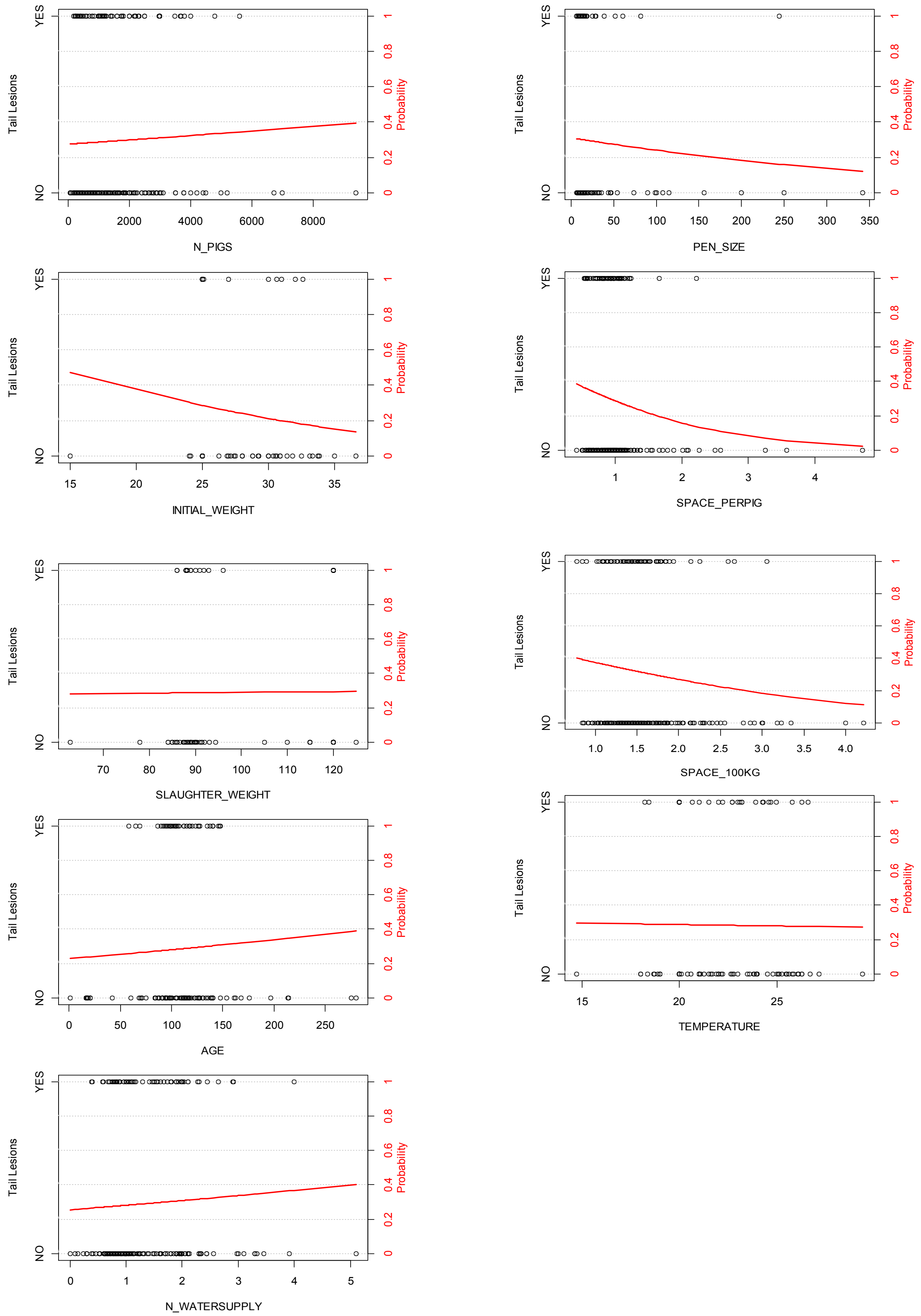
Table C9: Presence of tail lesions in relation to type of manipulable material

	Presence of tail lesions		% tail lesions
	no	yes	
Chain	9	1	10
Combined substrates	46	24	34
None	37	17	31
At least a substrate plus an object	33	15	31
Straw	44	13	23
Unknown	2	1	33

Table C12: Presence of tail lesions in docked and undocked pigs

	Presence of tail lesions		% tail lesions
	no	yes	
Undocked	78	31	28
Docked	76	35	32
Unknown	17	5	23

Graphical representation of the continuous factors collected in the Welfare Quality® database and their ranges, together with the potential impact on the probability of having tail-biting in a farm (red line).



Appendix D. Detailed results of analyses of the combined Welfare Quality® datasets at farm level to assess the interactive relationships between different factors and the animal-based welfare outcome of tail biting

The proportion of farms presenting tail lesions (severity level 2) per country is shown in Figure D1. It is clear that no big differences in proportion of farms with tail lesions between countries are observed. The total number of farms reporting tail lesions was 71, while 171 did not report tail lesions of severity score 2. Also, it is important to note that Finland and Sweden do not perform tail docking, while in the Netherlands, all farms visited had pigs with docked tails. For the case of Spain and France some farms were reported as unknown regarding whether tail-docking was in place (Figure D2), but most of the farms have reported tail-docking in place. Despite this difference in docking prevalence, tail-biting proportion is very similar between countries.

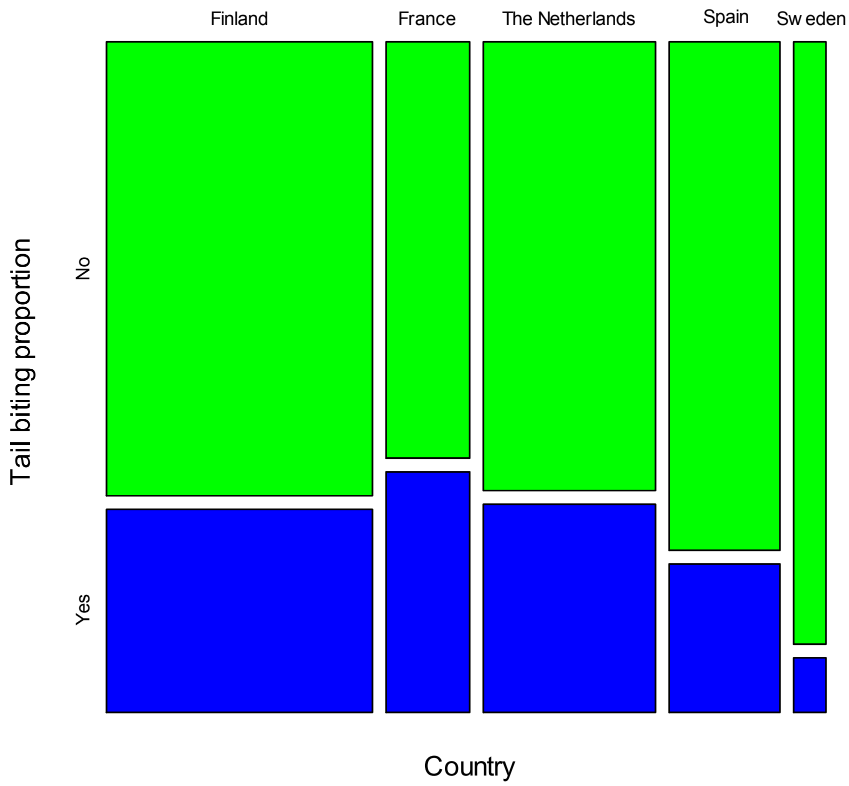


Figure D1. Proportion of farms with tail lesions reported by Country (bar width is related to the number of farms of each country).

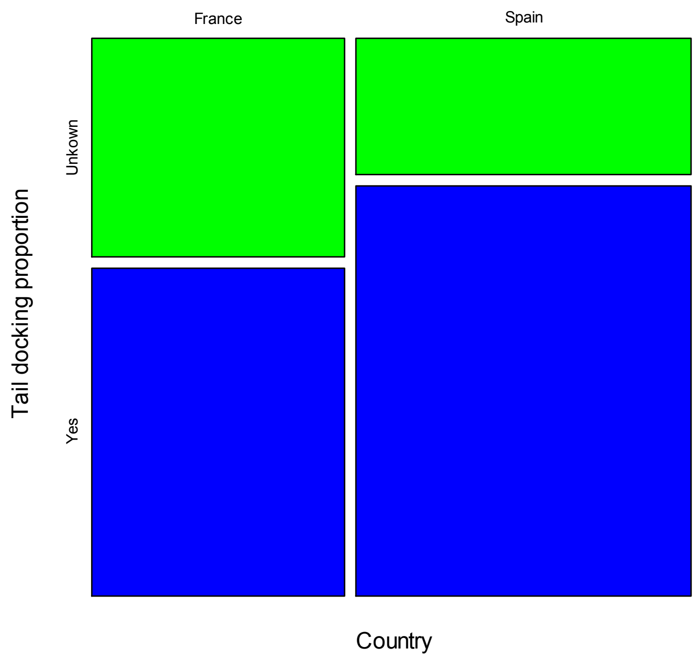


Figure D2. Proportion of farms with tail-docking reported by France and Spain (bar width is related to the number of farms of each country).

In order to explore potential differences between farms that performed tail-docking with those that did not perform tail-docking with respect to tail lesion (severity level 2) occurrence, the proportion of farms reporting tail lesions in the two groups (tail docked or not) was calculated. Figure D3 shows that no clear difference is observed in terms of the proportion of farms reporting tail lesions if the farm applied tail-docking or not, but a confounding of this factor with straw provision makes interpretation difficult. Other summary tables as well as exploratory graphs are presented Appendix C.

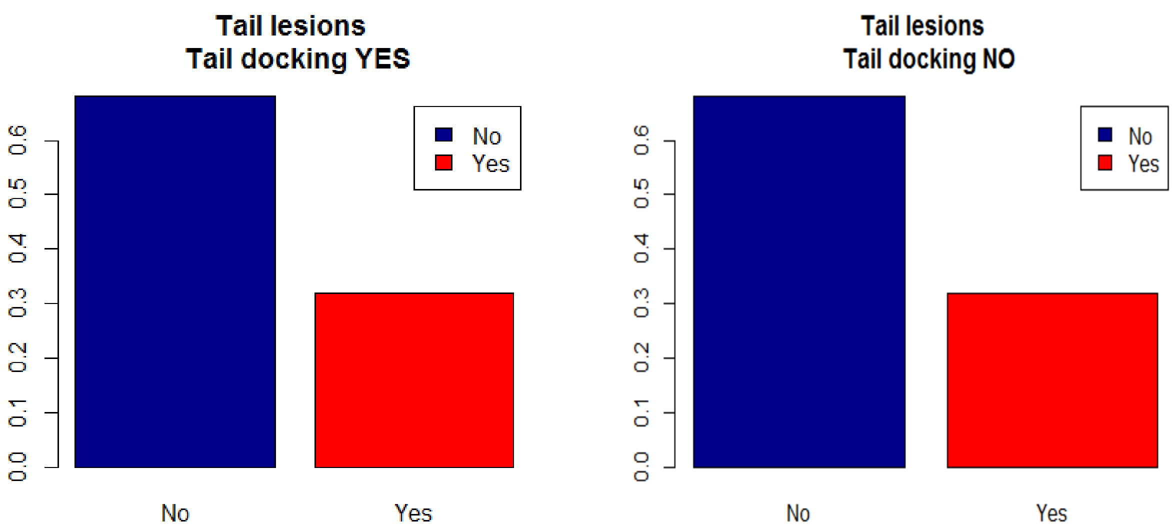


Figure D3. Proportion of farms with tail lesions when tail-docking is or not used in the farm.

In order to identify the relevant interactions between risk factors to establish a classification rule able to predict farms having tail lesion (severity level 2) CART is applied. The final tree obtained is shown in Figure D4.

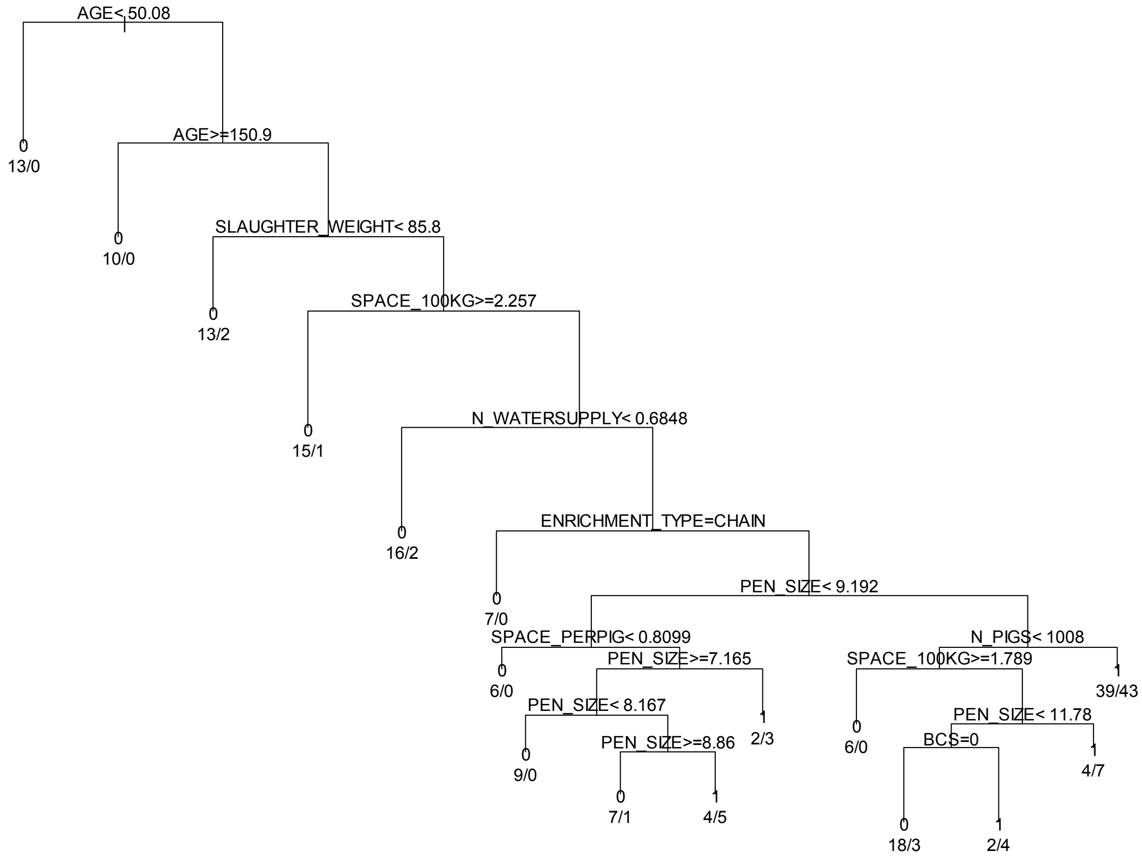
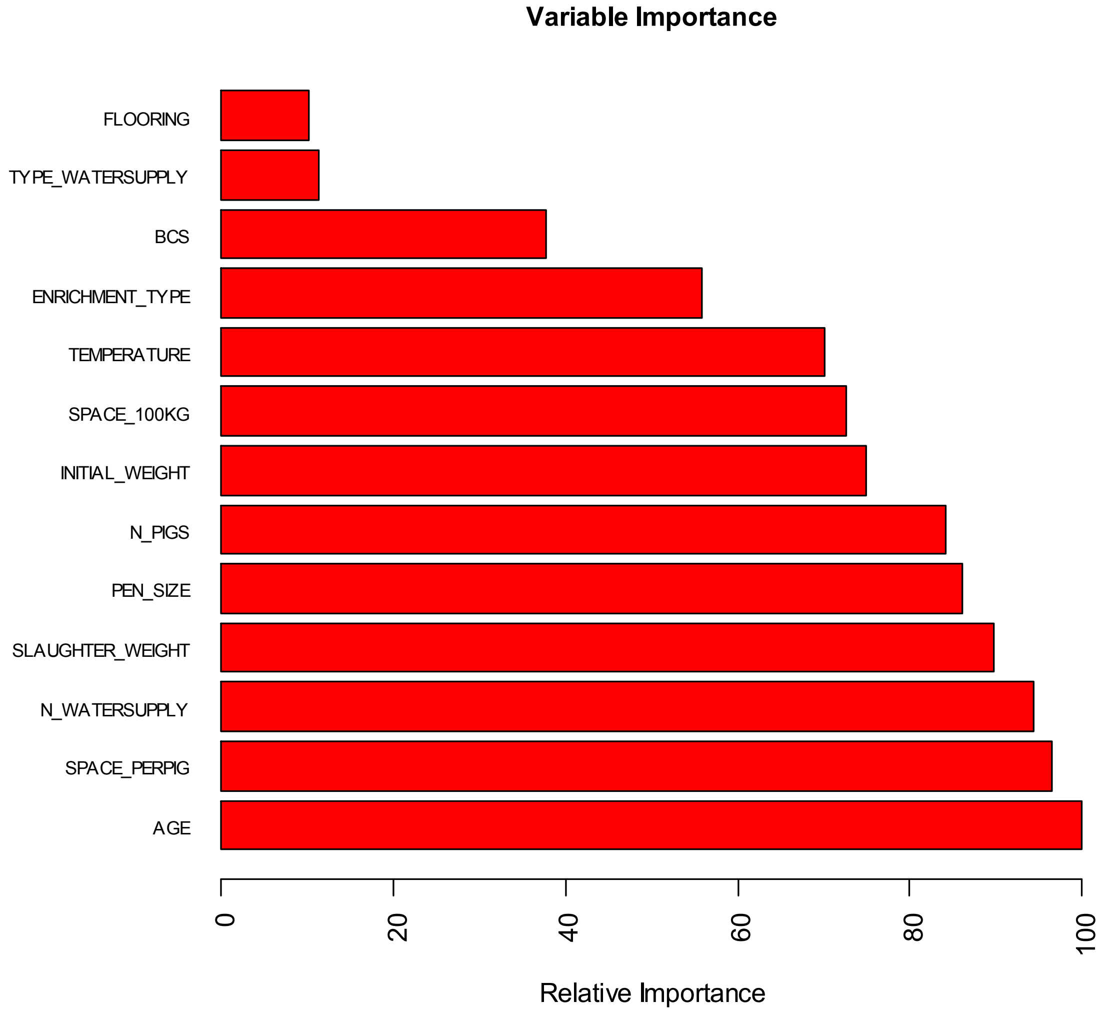


Figure D4. Classification tree (CART) obtained after pruning. The numbers presented in the final nodes represent the farms without tail biting issues and the number of farms with tail biting issues (e.g. 13/0, meaning 13 farms without tail biting issues and 0 farms with tail biting issues classified in that node).

It is clear that farms with younger animals (age below 50 days) do not present tail lesions, but also for those farms having animals of age above 150.9 days. If the age of the animal is between 50 and 150 days, but the slaughter weight is below 85.8kg, most of the farms (13 out of 15) are not reporting tail lesions. If the animals in the farms are between 50 and 150 days old and the slaughter weight is above 85.8 kg, but the space per 100kg is above 2.257 m^2, farms are classified as not tail-biting farms (15 out of 16). The interpretation of the rest of the branch could be done in a similar manner to that previously explained. It should be highlighted the importance of the interactions identified by the technique, including age with slaughter weight, a triple interaction between age, slaughter weight and space per 100 kg, a four way interaction between age, slaughter weight, space per 100 kg and number of water supplies, a five way interaction between age, slaughter weight, space per 100 kg, number of water supplies and enrichment (referring to manipulable material) type, a six way interaction between age, slaughter weight, space per 100 kg, number of water supplies, enrichment type and pen size, two seven way interaction between age, slaughter weight, space per 100 kg, number of water supplies, enrichment type, pen size and space per pig and age, slaughter weight, space per 100 kg, number of water supplies, enrichment type, pen size and number of pigs in the farm.

In terms of variable importance to predict the farms with potential tail-biting issues, it should be mentioned that the most important variables are the age of the animal, space per animal, number of drinkers (water supply points) per animal, average slaughter weight (which could be interpreted as a proxy variable for the time animals remain in the farm), pen size and farm size (Figure D5). In order to evaluate the classification rule performance the overall error as well as the error for each of the classes of farms is calculated using cross validation methods in order to obtain an unbiased estimate of the different misclassification errors. The number of farms well classified as a farm reporting no tail lesions are 104 out of 171 (error of 39 %), from the farms reporting tail lesions (severity level 2) 46 out of 71 resulted well classified (error of 35 %), producing an overall error of 38 %.

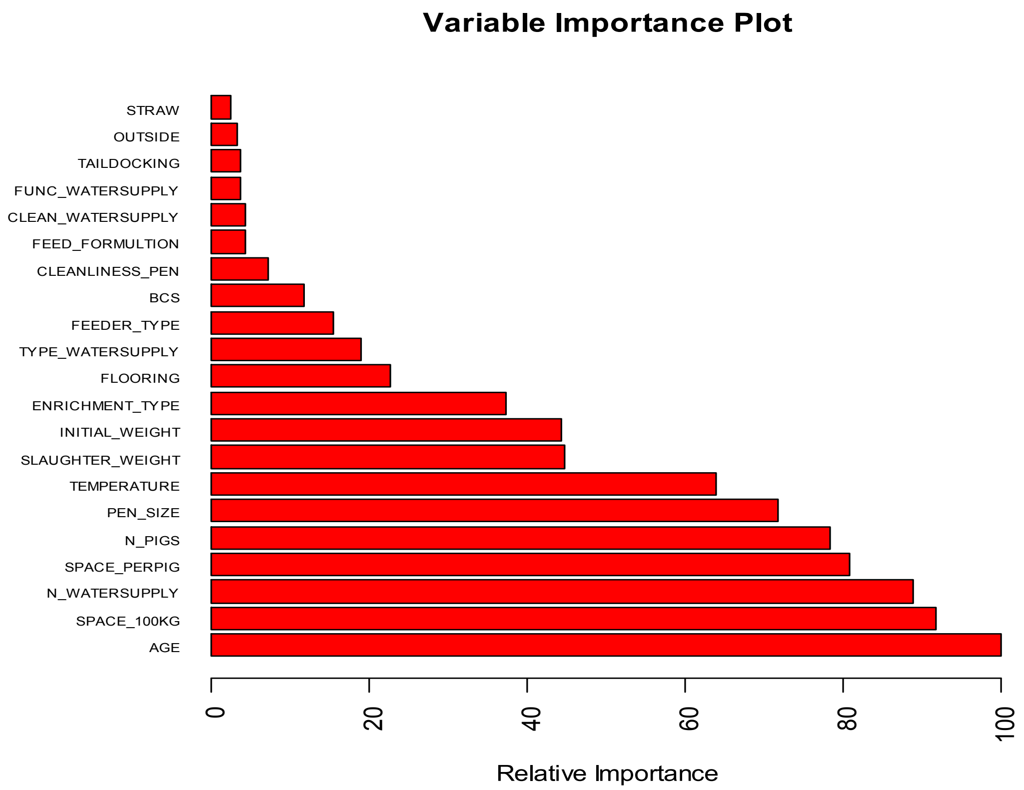


Flooring: type of flooring, Type_WaterSupply: type of drinkers; BCS: Body Condition Score; Enrichment type: type of supplied manipulable material; Temperature: room temperature; Space_100 kg: space allowance in m^2/ 100 kg animal; Initial_weight: starting weight for fattening in kg; N_Pigs: number of pigs on farm; Pen_Size: pen area in m^2; Slaughter_Weight: final weigh at slaughter in kg; N_Watersupply: number of drinkers; Space per pig: space allowance in m^2 per pig; Age: age of pigs in days at visit.

Figure D5. Relative measure of variable importance using the prune tree.

If instead random forest is used to build a predictive model to classify farms according to their status related to tail biting, the results of the tuning process indicate that an overall error of 42 % is obtained, having incorrectly classified 56 % (40 out of 71) of the farms reporting tail lesions (severity level score 2). In term of variable importance, results show (Figure D6) that similar variables appear to be the most important to predict the presence of tails lesions of severity level score 2 in a farm.

It is important to note that the overall prediction error for all subpopulations considered is relatively high: 42 % considering all available data, 49 % when analyzing only Finland, 44 % in the farms with tail-docking and 51 % in farms without tail docking. It should be highlighted that for all subpopulation analyses the set of important variables found was the same, indicating consistency across different subpopulations. The large overall error obtained implies the need for additional data to improve the predictive capacity of the model, and results obtained based on this data provide limited evidence on definitively influential risk factors regarding tail lesion.

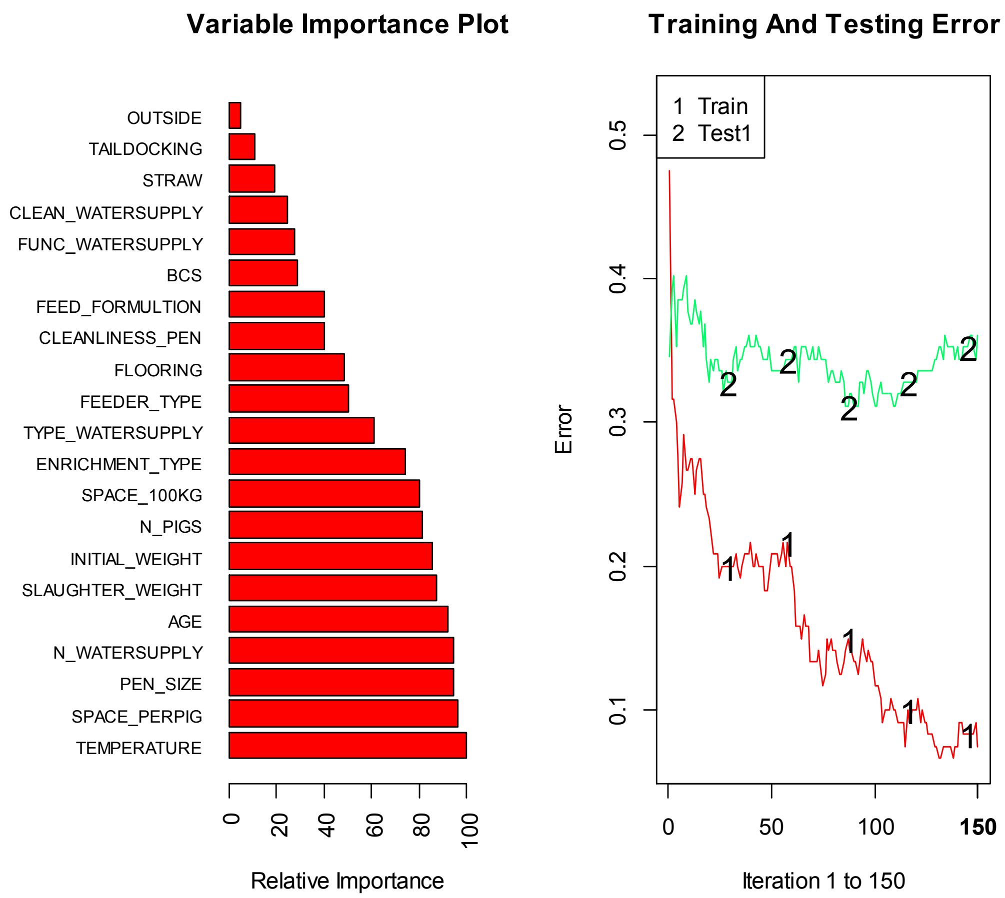


Straw: straw provided as manipulable material; Outside: access to outside area; Func_Watersupply: number of drinkers functioning properly; Clean_watersupply: cleanliness of drinkers; Feed formulation: feed form; Cleanliness_pen: cleanliness of pen; BCS: Body Condition Score; Feeder_Type: type of feeder; Type_WaterSupply: type of drinkers; Flooring: type of flooring; Enrichment type: type of supplied manipulable material; Initial_weight: starting weight for fattening in kg; Slaughter_Weight: final weigh at slaughter in kg; Temperature: room temperature; Pen_Size: pen area in m^2; N_Pigs: number of pigs on farm; Space per pig: space allowance in m^2 per pig; N_Watersupply: number of drinkers; Space_100 kg: space allowance in m^2/ 100 kg animal; Age: age of pigs in days at visit.

Figure D6. Relative measure of variable importance using the Gini measure from random forest.

When boosting methods are used, considering the data split into training and test sets, the overall error is reduced below 10 % for the training set, but the final overall error obtained for the testing set was around 36 % (Figure D7), but classifying correctly only 32 % of the farms having tail lesions with severity score 2. Here also, similar risks factors are found as having an impact on the classification of farms in terms of presence of tail lesions with severity score 2.

Finally, the result obtained by applying support vector machine method also indicates an overall error of 41 %, classifying only 47 % of farms having tail lesions correctly (results not shown).



Outside: access to outside area; Straw: straw provided as manipulable material; Clean_watersupply: cleanliness of drinkers; Func_Watersupply: number of drinkers functioning properly; BCS: Body Condition Score; Feed formulation: feed form; Cleanliness_pen: cleanliness of pen; Flooring : type of flooring; Feeder_Type: type of feeder; Type_WaterSupply: type of drinkers; Enrichment type: type of supplied manipulable material; Space_100 kg: space allowance in m^2/ 100 kg animal; N_Pigs: number of pigs on farm; Initial_weight: starting weight for fattening in kg; Slaughter_Weight: final weigh at slaughter in kg; Age: age of pigs in days at visit; N_Watersupply: number of drinkers; Pen_Size: pen area in m^2; Space per pig: space allowance in m^2 per pig; Temperature: room temperature.

Figure D7. Results obtained when using boosting methods.

Appendix E. Characteristics of farms in the Welfare Quality® (WQ®) datasets at farm level in relation to whether or not tail-docking is practised

Table E1: Number of farms reporting tail-docking per country.

Country	No tail docking	Unknown	Tail docking
Finland	97	0	0
France	0	12	18
Netherlands	0	0	63
Spain	0	10	30
Sweden	12	0	0

Table E2: Number of farms reporting tail-docking in relation to flooring type.

Flooring	No tail docking	Unknown	Tail docking
Bedding	4	9	0
Fully slatted	2	0	24
Natural flooring mud or grass (ground)	0	0	0
Mixed	1	0	0
Partially slatted	89	0	78
Solid	9	5	0
Unknown	4	8	9

Table E3: Number of farms reporting tail-docking in relation to provision of straw.

Straw	No tail docking	Unknown	Tail docking
No	0	10	111
Unknown	2	5	0
Yes	107	7	0

Table E4: Number of farms reporting tail-docking in relation to feeder type.

Feeders type	No tail docking	Unknown	Tail docking
Ground	0	0	0
Hopper	9	11	71
Mixed	0	10	22
Trough	99	1	18
Unknown	1	0	0

Table E5: Number of farms reporting tail-docking in relation to feed form.

Feed formulation	No tail docking	Unknown	Tail docking
Dry	11	16	79
Liquid or wet	98	6	32

Table E6: Number of farms reporting tail-docking in relation to drinker (or water supply) types.

Drinkers types	No tail docking	Unknown	Tail docking
Bowl	0	6	12
Mixed	0	12	21
Nipples	12	2	73
None	0	0	1
Others	0	0	0
Trough	0	2	4
Unknown	97	0	0

Table E7: Number of farms reporting tail-docking in relation to drinker (or water supply) functionality.

Drinkers functionality	No tail docking	Unknown	Tail docking
Function correctly	0	0	62
No function correctly	12	22	49

Table E8: Number of farms reporting tail-docking in relation to drinker (or water supply) cleanliness.

Drinkers cleanliness	No tail docking	Unknown	Tail docking
Clean	0	0	62
Dirty	12	22	49

Table E9: Number of farms reporting tail-docking in relation to pig cleanliness (mild lack of cleanliness, scored 1 as per WQ® as presence of more than 20 % but less than 50 % of the body surface soiled)

Mild pig cleanliness	No tail docking	Unknown	Tail docking
Absence	8	2	3
Presence	101	20	108

Table E10: Number of farms reporting tail-docking in relation to pig cleanliness (severe lack of cleanliness, scored 2 as per WQ® as presence of over 50 % of the body surface soiled).

Sever pig cleanliness	No tail docking	Unknown	Tail docking
Absence	69	5	30
Presence	40	17	81

Table E11: Number of farms reporting tail-docking in relation to pen cleanliness.

Pen cleanliness	No tail docking	Unknown	Tail docking
Clean	3	4	36
Dirty	9	18	75

Table E12: Number of farms reporting tail-docking per type of manipulable material provided.

Type of manipulable material	No tail docking	Unknown	Tail docking
Chain	0	0	10
Combined substrates	61	2	7
None	0	9	45
At least a substrate material plus an object	0	0	48
Straw	46	11	0
Unknown	2	0	1

Table E13: Number of farms reporting tail-docking in relation to access to an outdoor area.

Outside access	No tail docking	Unknown	Tail docking
No	108	3	92
Yes	1	8	1

Table E14: Detailed statistical outcome

	No tail docking		Unknown		Tail docking	
	Mean	StDev	Mean	StDev	Mean	StDev
N_Pigs[a]	1106.8	902.6	1582.3	1388.3	1891.7	1468.9
Initial weight[b]	29.2	3.75	n/a	n/a	25	0
Slaughter weight[c]	92.7	11.57	n/a	n/a	120	0
Age[d]	71.2	38.23	141.2	57.12	111.5	27.68
Pen Size[e]	11.20	4.76	75.20	62.17	19.08	38.73
Space per pig[f]	1.03	0.238	1.66	1.124	0.81	0.213
Space per 100kg[g]	1.74	0.525	2.30	0.8833	1.36	0.345
Temperature[h]	19.2	1.92	22.4	2.82	21.7	2.30
N_Watersupply[i]	1.9	0.72	0.5	0.24	0.9	0.38

[a] N_Pigs: number of pigs on farm
[b] Initial_weight: starting weight for fattening in kg
[c] Slaughter_Weight: final weigh at slaughter in kg
[d] Age: age of pigs in days at visit
[e] Pen_Size: pen area in m^2
[f] Space per pig: space allowance in m^2 per pig
[g] Space_100 kg: space allowance in m^2/ 100 kg animal
[h] Temperature: room temperature
[i] N_Watersupply: number of drinkers

Appendix F. Detailed results of analyses of the combined Welfare Quality® datasets at pen level to assess the interactive relationships between different factors and the animal-based welfare outcome of tail biting

Data from 2748 pens in 5 countries [Finland (1127), France (304), the Netherlands (839), Spain (358) and Sweden (120)] were collated regarding potential risk factors for tail biting. The proportion of pens presenting tail lesions (severity level 2) per country is shown in Figure F1. It is clear that the proportion of pens with tail lesions is small, ranging from 1 to 6 %. The total number of pens reporting tail lesions was 139, while 2609 did not report tail lesions of severity score 2. Also, it is important to note that Finland and Sweden do not perform tail docking, while in the France dataset all pens visited had pigs with docked tails. For the case of the Netherlands and Spain the percentage of tail docked animals are 87.5 and 84 respectively (Figure F2).

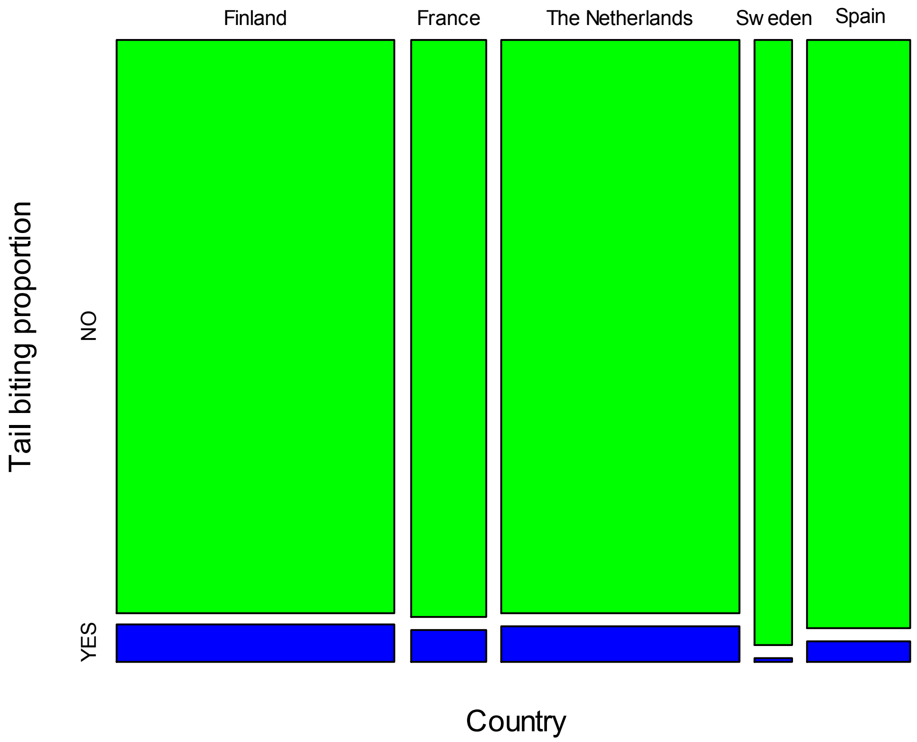


Figure F1. Proportion of pens with tail lesions reported by Country (bar width is related to the number of pens of each country).

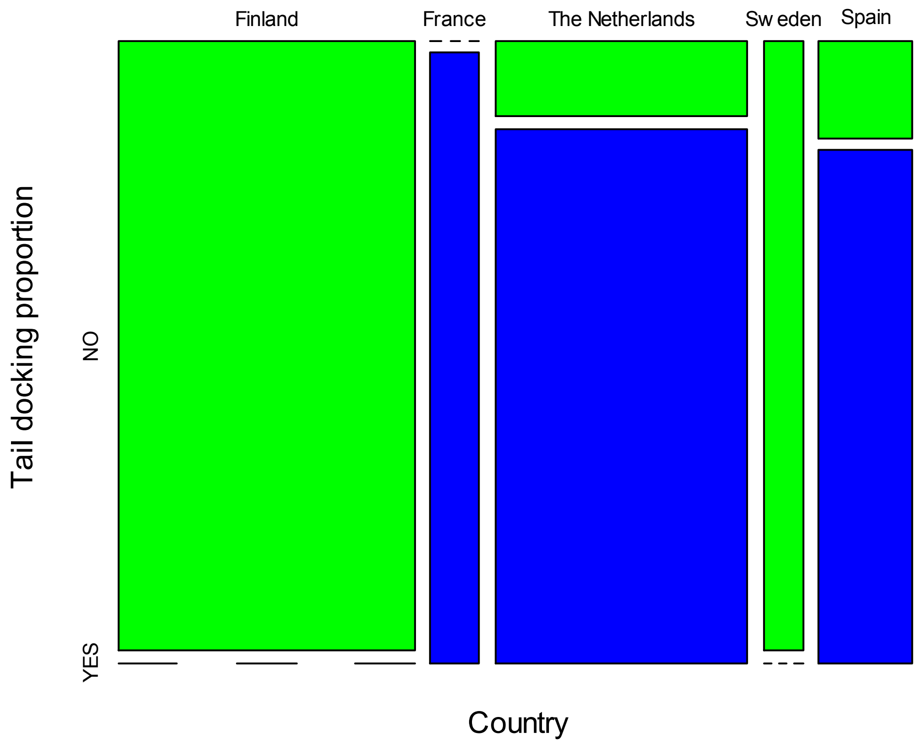


Figure F2. Proportion of pens with tail-docking (bar width is related to the number of pens of each country).

In order to explore potential differences between pens that performed tail-docking with those that did not perform tail-docking with respect to tail lesion (severity level 2) occurrence, the proportion of pens reporting tail lesions in the two groups (tail docked or not) was calculated (Figure F3). This shows that no clear difference is observed in terms of the proportion of pens reporting tail lesions if the pen applied tail-docking (5 %) or not (6 %). Other summary tables as well as exploratory graphs are presented in Appendix G.

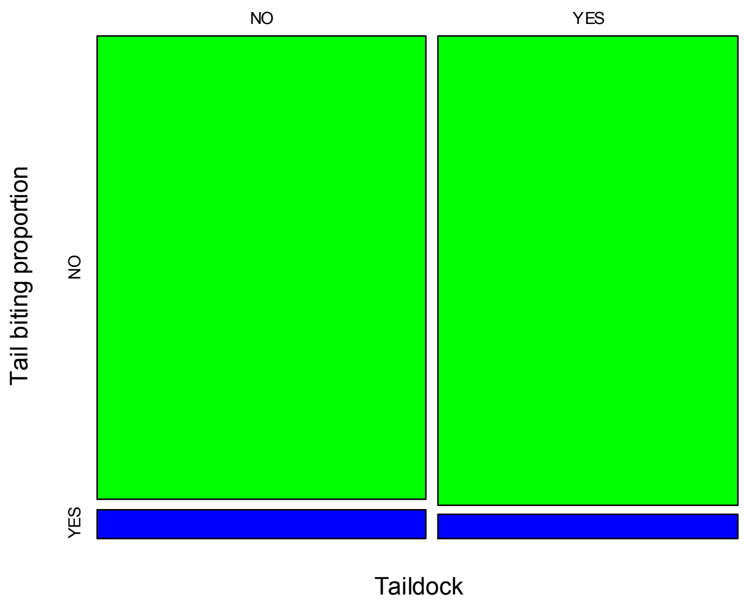


Figure F3. Proportion of pens with tail lesions when tail-docking is or not used in the pen.

In order to identify the relevant interactions between risk factors to establish a classification rule able to predict pens having tail lesion (severity level 2) CART is applied. The final tree obtained is shown in Figure F4.

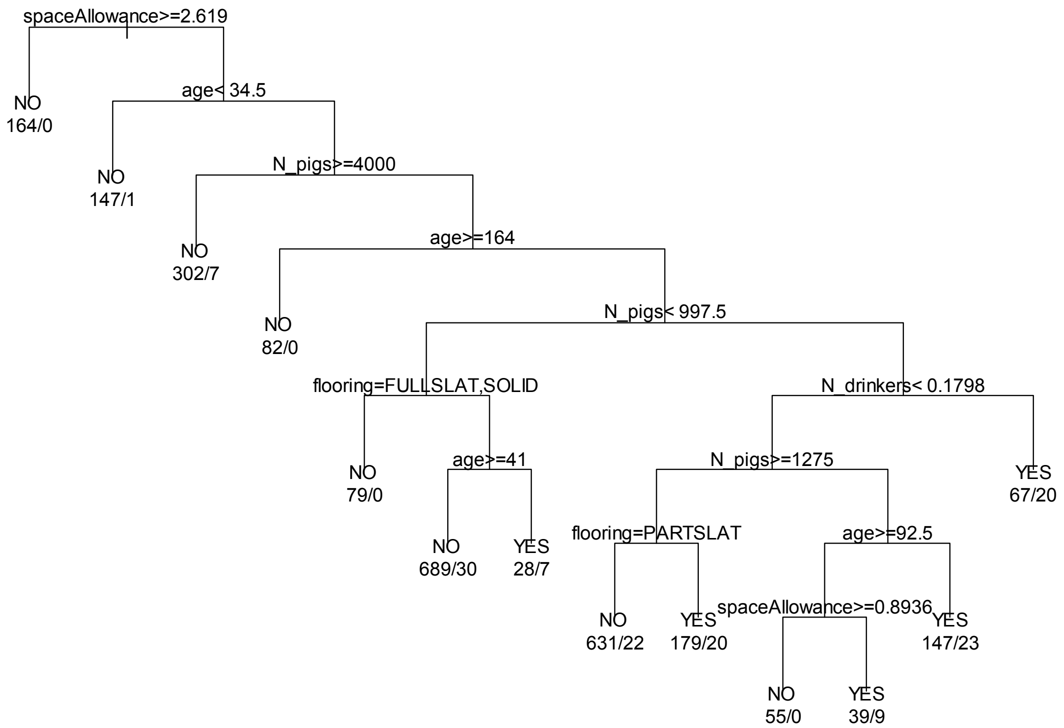
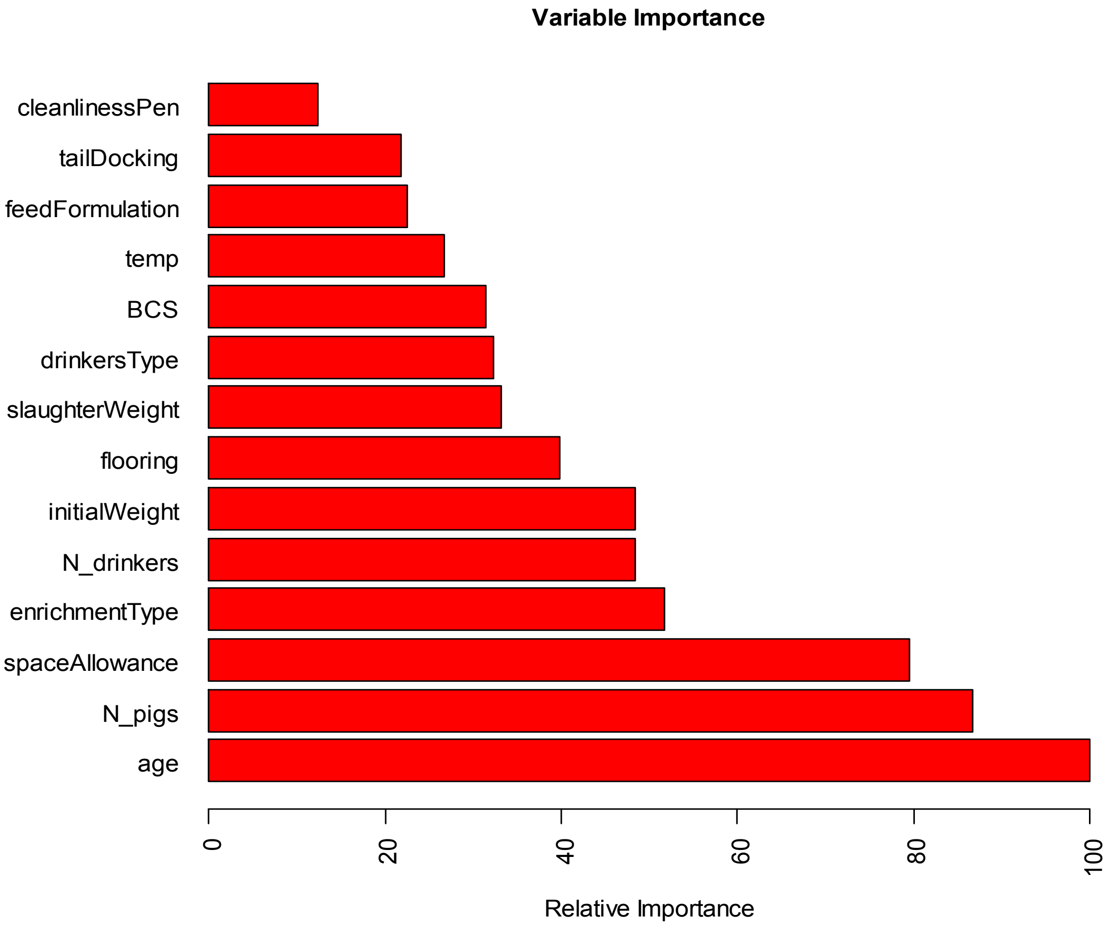


Figure F4. Classification tree obtained after pruning. The numbers presented in the final nodes represent the pens without tail biting issues and the number of pens with tail biting issues (e.g. 164/0, meaning 164 pens without tail biting issues and 0 pens with tail biting issues classified in that node).

It is clear that pens with space allowance of more than 2.6 m^2 do not present tail lesions, and if the space is smaller than that, but the age is below 34.5 days, the pens do not present tail lesions in general. If the age is above 34.5 days and the number of animals is above 4000 in the farm the proportion of pens with tail lesions is very low. If the farm has less than 4000 animals and the age is above 164 days, tail lesions are not observed; within the farms with less than 998 animals with full slatted or solid floors no tail lesions were reported. The interpretation of the rest of the branch could be done in a similar manner to that previously explained. It should be highlighted the importance of the interactions identified by the technique, including space allowance with age, a triple interaction between age, number of animals and space allowance, a four way interaction between age, flooring type, space allowance and number of animals in the farm, etc.

In terms of variable importance to predict the pens with potential tail-biting issues, it should be mentioned that the most important variables are the age of the animal, number of animals in the farm, space allowance, followed by enrichment type, number of drinkers per animal, initial weight, flooring type, average slaughter weight (which could be interpreted as a proxy variable for the time animals remain in the pen), drinker type and body condition score (Figure F5). The classification rule performance was evaluated using the overall error as well as the error for each of the classes of pens using cross validation methods in order to obtain an unbiased estimate of the different misclassification errors. The number of pens well classified as pen reporting not tail lesions are 2135 out of 2609 (error of 18 %), from the pens reporting tail lesion (severity level 2) 65 out of 139 resulted well classified (error of 53 %), producing an overall error of 20 %.

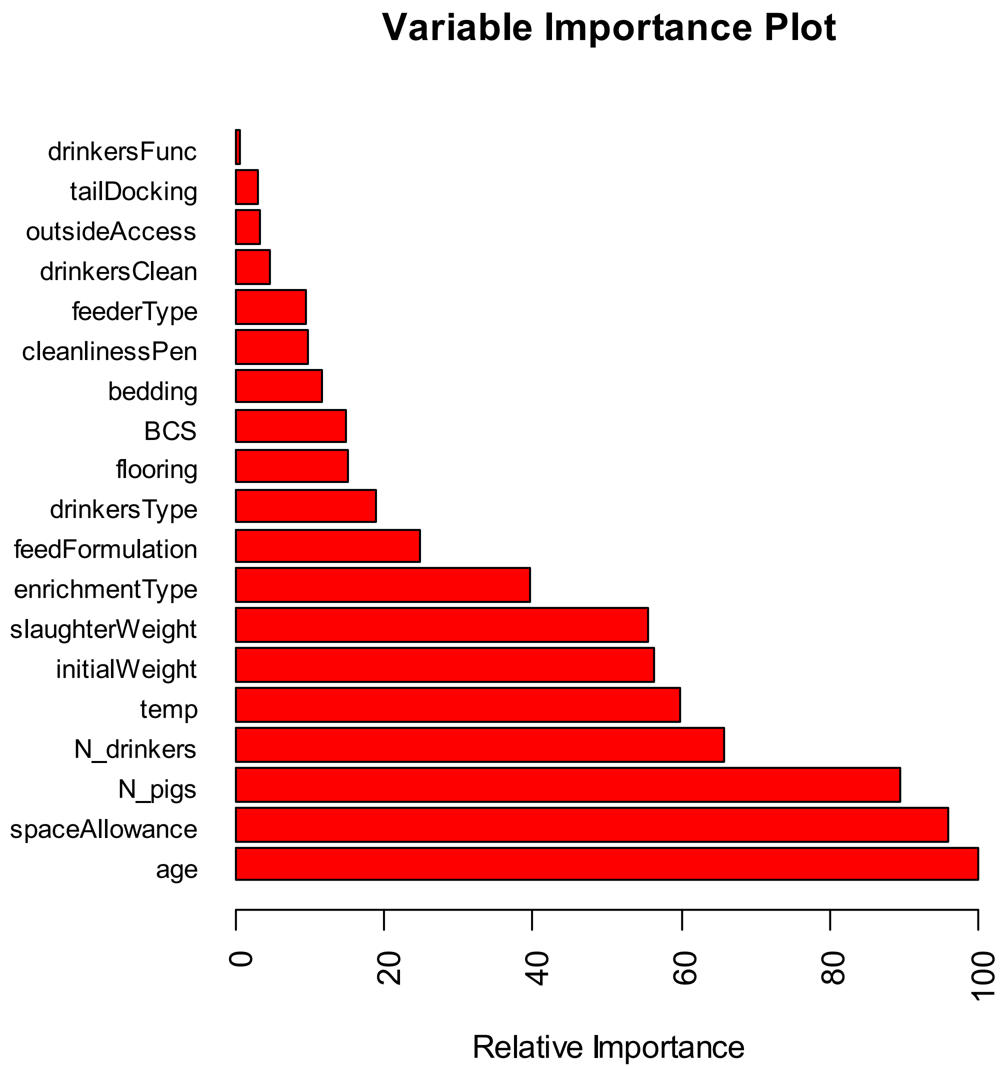


Cleanliness_pen: cleanliness of pen; Feed formulation: feed form; Temperature: room temperature; BCS: Body Condition Score; drinkerType: type of drinkers; Slaughter_Weight: final weigh at slaughter in kg; Flooring: type of flooring; Initial_weight: starting weight for fattening in kg; N_drinkers: number of drinkers; Enrichment type: type of supplied manipulable material; SpaceAllowance: pen space in m^2 per pig; N_Pigs: number of pigs on farm; Age: age of pigs in days at visit.

Figure F5. Relative measure of variable importance using the prune tree.

If, instead, random forest is used to build a predictive model to classify pens according to their status related to tail biting, the results of the tuning process indicate that an overall error of 26 % is obtained, having incorrectly classified 53 % (74 out of 139) of the pens reporting tail lesions (severity level score 2). In terms of variable importance, results show (Figure F6) that similar variables appear to be the most important to predict the presence of tails lesions of severity level score 2 in a pen.

It is important to note that the overall prediction error for all subpopulations considered is between 23 and 29 %, being 26 % when considering all available data, 29 % when analyzing only Finland, 24.9 % in the pens with tail-docking and 23 % in pens without tail docking. However, the predictive performance of the model for tail-biting is only between 47-53 %. It should be highlighted that for all subpopulation analyses, the set of important variables found was similar, indicating consistency across different subpopulations. The overall errors obtained imply the need for additional data, specifically to ensure EU population representativeness to improve the predictive capacity of the model, and results obtained based on these data provide limited evidence on definitively influential risk factors regarding tail lesion.

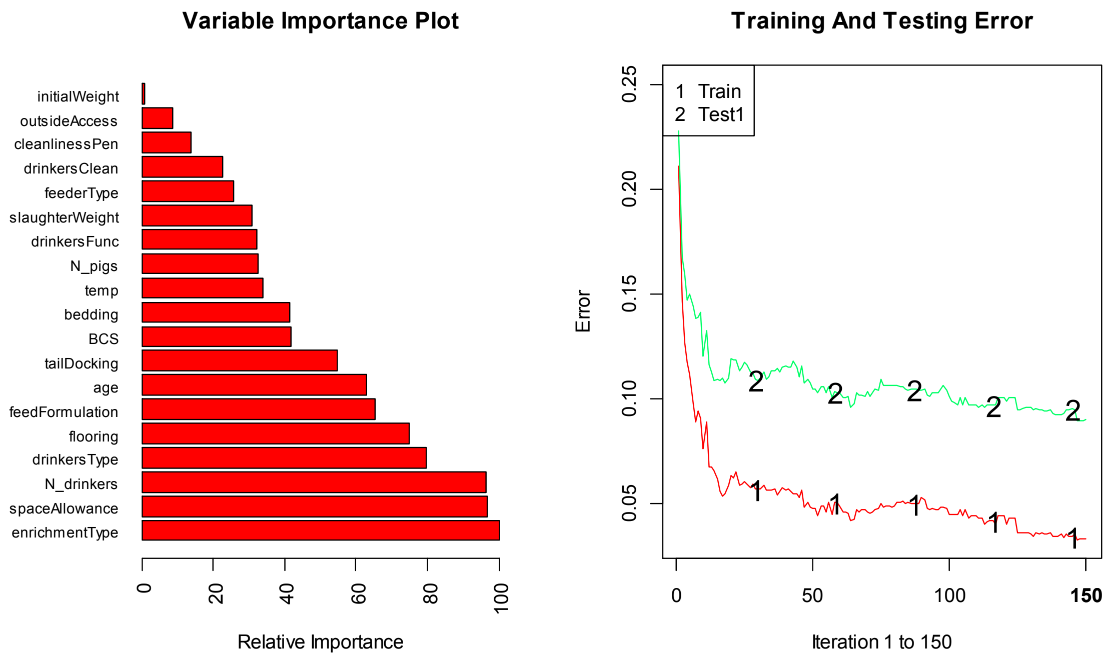


drinkersFunc: number of drinkers functioning properly; tailDocking: tail-docking practice; outsideAccess: access to outside area; drinkerClean: cleanliness of drinkers; bedding: presence of bedding; BCS: Body Condition Score; Flooring: type of flooring; drinkerType: type of drinkers; feedFormulation: feed form; Enrichment type: type of supplied manipulable material; slaughter_Weight: final weigh at slaughter in kg; Initial_weight: starting weight for fattening in kg; Temp: room temperature; N_drinkers: number of drinkers; SpaceAllowance: pen space in m^2 per pig; Age: age of pigs in days at visit.

Figure F6. Relative measure of variable importance using the Gini measure from random forest.

When boosting methods are used, considering the data split into training and test sets, the overall error is reduced below 4 % for the training set, but the final overall error obtained for the testing set was around 9 % (Figure F7), but classifying correctly only 16 % of the pens having tail lesions with severity score 2. Here similar risks factors are found as having an impact on the classification of pens in terms of presence of tail lesions with severity score 2, but other indicators appear to influence the classification as well. It should be noted that in this case the error of misclassifying tail-biting pens is much higher when using this approach.

Finally, the result obtained by applying support vector machine method also indicates an overall error of 41 %, classifying only 47 % of pens having tail lesions correctly (results not shown).



Initial_weight: starting weight for fattening in kg; outsideAccess: access to outside area; cleanlinessPen: cleanliness of pen; drinkerClean: cleanliness of drinkers;feederType: type of feeder; slaughter_Weight: final weigh at slaughter in kg; drinkersFunc: number of drinkers functioning properly; N_Pigs: number of pigs on a farm; Temp: room temperature; bedding: presence of bedding; BCS: Body Condition Score; tailDocking: tail-docking practice; Age: age of pigs in days at visit; feedFormulation: feed form; Flooring: type of flooring; drinkerType: type of drinkers; N_drinkers: number of drinkers; SpaceAllowance: pen space in m^2 or per pig; Enrichment type: type of supplied manipulable material.

Figure F7. Results obtained when using boosting methods.

Appendix G. Summary tail lesion tables at pen level from the Welfare Quality® data

The following tables (G1-G11) classify pens where tail lesions were present or absent in relation to different environmental factors. Data from 2748 pens in 5 countries [Finland (1127), France (304), the Netherlands (839), Spain (358) and Sweden (120)] were collated regarding potential risk factors for tail biting. The total number of pens reporting tail lesions was 139, while 2609 did not report tail lesions of severity score 2.

Table G1: Presence of tail lesions in relation to different flooring types

	Presence of tail lesions		% tail lesions
	no	yes	
Bedding	208	13	6
Fully slatted	349	20	5
Ground [(a)]	57	0	0
Partially slatted	2043	118	5
Solid	123	4	3
Unknown	18	1	5

(a): natural flooring mud or grass

Table G2: Presence of tail lesion in relation to use of bedding

	Presence of tail lesions		% tail lesions
	no	yes	
Presence	699	43	6
Absence	2049	111	5
Unknown	50	2	4

Table G3: Presence of tail lesions in relation to feeder types

	Presence of tail lesions		% tail lesions
	no	yes	
Ground	24	0	0
Hopper	1224	72	6
Trough	1550	84	5

Table G4: Presence of tail lesions in relation to type of water supply (drinkers)

	Presence of tail lesions		% tail lesions
	no	yes	
Bowl	341	13	4
Nipples	2231	128	5
None	15	0	0
Trough	183	14	7
Unknown	28	1	3

Table G5: Presence of tail lesions in relation to feed form

	Presence of tail lesions		% tail lesions
	no	yes	
Dry	1258	68	5
Wet/ Liquid	1391	87	6
Unknown	149	1	1

Table G6: Presence of tail lesions in relation to functionality of drinkers

	Presence of tail lesions		% tail lesions
	no	yes	
Functional drinkers	2761	154	5
No functional drinkers	37	2	5

Table G7: Presence of tail lesions in relation to cleanliness of water supply (drinkers)

	Presence of tail lesions		% tail lesions
	no	yes	
Clean drinkers	2692	152	5
Dirty drinkers	106	4	4

Table G8: Presence of tail lesions in relation to pen cleanliness

	Presence of tail lesions		% tail lesions
	no	yes	
Dirty pen	351	21	6
Clean pen	1389	66	5

Table G9: Presence of tail lesions in relation to outside access

	Presence of tail lesions		% tail lesions
	no	yes	
No outside access	2296	123	5
Outside access	215	17	7

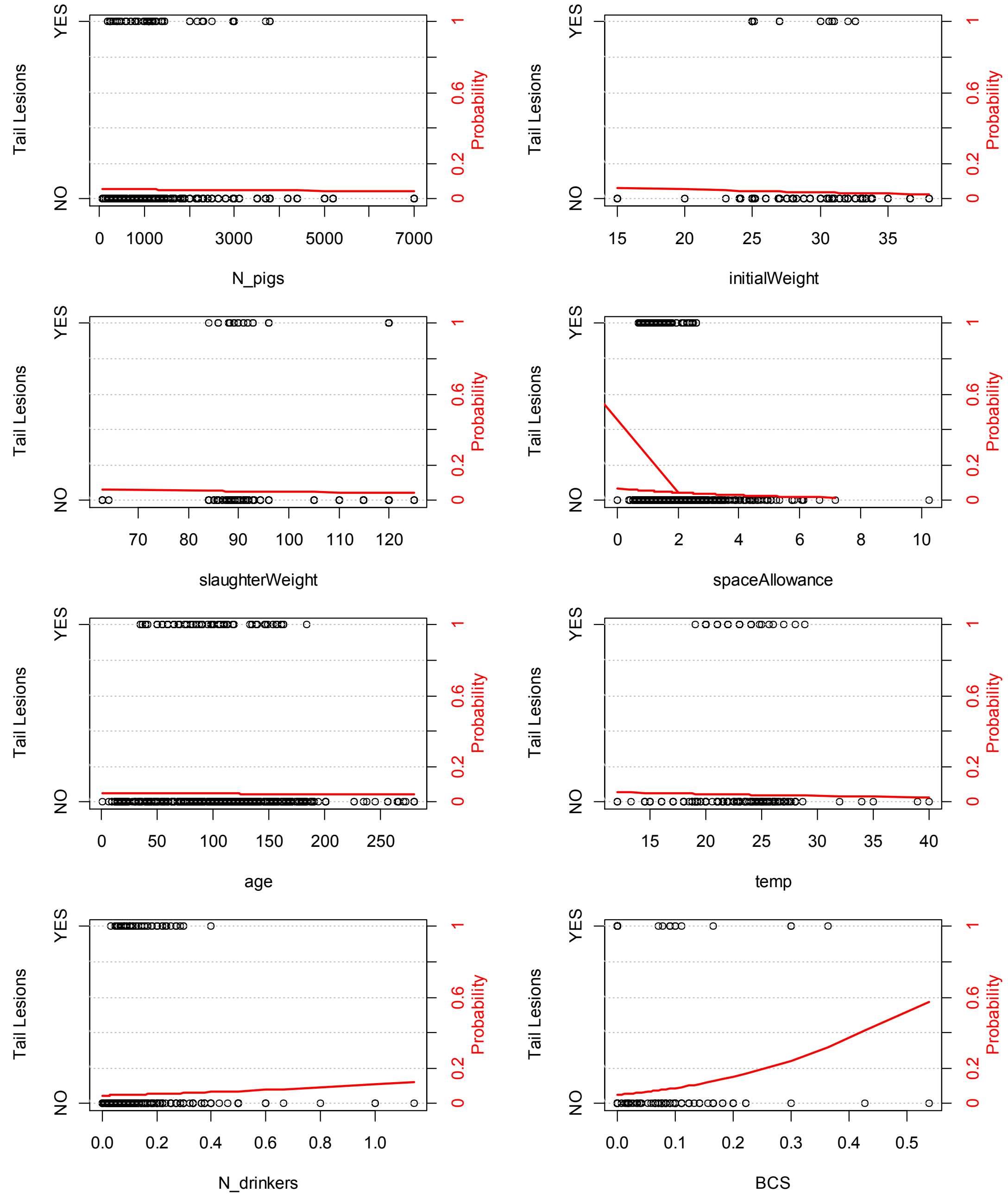
Table G10: Presence of tail lesions in relation to enrichment type

	Presence of tail lesions		% tail lesions
	no	yes	
Chain	673	42	6
Combined substrates	206	10	5
None	742	35	5
At least a substrate plus an object	555	44	7
Straw	622	25	4

Table G11: Presence of tail lesions in docked and undocked pigs

	Presence of tail lesions		% tail lesions
	no	yes	
Undocked	1366	87	6
Docked	1258	64	5

Graphical representation of the continuous factors collected in the Welfare Quality® database and their ranges, together with the potential impact on the probability of having tail-biting in a pen (red line).



Appendix H. Combination of enrichments used together with the frequencies reported in the different holdings in Finland

Finish farm data collected by veterinarians during 2011 and 2012 cover the use of eight different manipulable materials (provided for enrichment) together with the presence of tail-biting at the time of the visit. The combinations of manipulable materials used in the different holdings are shown in Table H1. The total number of combinations of manipulable materials used in the different holdings is 157, with frequencies of usage of any particular combination between 1 and 1521.

Table H1. Combination of enrichments used together with the frequencies reported in the different holdings in Finland.

Combination	Straw	Hay	Peat	Sawdust	Paper	Woodchips	Wood	Toy	Frequencies
1	No	No	Yes	No	No	No	Yes	No	1521
2	No	No	No	No	No	No	Yes	No	1298
3	No	No	No	No	No	No	No	No	1293
4	No	No	Yes	No	No	No	No	No	1284
5	No	No	Yes	Yes	No	No	Yes	No	1106
6	No	No	No	Yes	No	No	Yes	No	827
7	Yes	No	Yes	No	No	No	Yes	No	503
8	No	Yes	No	No	No	No	Yes	No	451
9	Yes	No	Yes	No	No	No	No	No	380
10	No	No	Yes	Yes	No	No	Yes	Yes	351
11	Yes	No	Yes	Yes	No	No	Yes	No	308
12	No	No	Yes	Yes	No	No	No	No	306
13	Yes	No	No	No	No	No	Yes	No	296
14	Yes	No	No	No	No	No	No	No	262
15	No	Yes	No	No	No	No	No	No	245
16	No	No	No	Yes	No	No	No	No	243
17	No	Yes	No	Yes	No	No	Yes	No	224
18	Yes	No	No	Yes	No	No	Yes	No	224
19	No	Yes	Yes	Yes	No	No	Yes	No	203
20	No	No	Yes	Yes	No	Yes	Yes	No	188
21	No	Yes	Yes	No	No	No	No	No	179
22	Yes	Yes	No	No	No	No	No	No	173
23	No	No	No	No	No	Yes	Yes	No	171
24	No	No	No	Yes	No	Yes	Yes	No	157
25	No	No	No	Yes	No	No	Yes	Yes	149
26	No	Yes	Yes	No	No	No	Yes	No	140
27	No	No	Yes	No	No	No	Yes	Yes	126
28	Yes	No	Yes	Yes	No	No	No	No	112
29	No	No	No	No	No	No	No	Yes	102
30	No	No	No	No	No	Yes	No	No	102
31	No	No	Yes	No	No	No	No	Yes	101
32	No	No	Yes	No	No	Yes	Yes	No	96
33	No	No	Yes	No	No	Yes	No	No	91
34	Yes	No	No	Yes	No	No	No	No	89
35	No	No	No	No	No	No	Yes	Yes	87

Combination	Straw	Hay	Peat	Sawdust	Paper	Woodchips	Wood	Toy	Frequencies
36	Yes	Yes	No	No	No	No	Yes	No	82
37	No	No	Yes	Yes	No	No	No	Yes	80
38	Yes	Yes	Yes	No	No	No	Yes	No	65
39	Yes	Yes	Yes	Yes	No	No	Yes	No	65
40	No	No	No	Yes	No	No	No	Yes	61
41	No	No	No	Yes	No	Yes	No	No	61
42	Yes	Yes	No	Yes	No	No	No	No	56
43	No	Yes	Yes	Yes	No	No	No	No	55
44	Yes	Yes	No	Yes	No	No	Yes	No	52
45	No	Yes	No	Yes	No	No	No	No	50
46	Yes	No	No	No	No	Yes	Yes	No	45
47	Yes	No	No	No	No	Yes	No	No	43
48	Yes	No	Yes	Yes	No	Yes	Yes	No	40
49	No	No	Yes	Yes	No	Yes	Yes	Yes	39
50	Yes	No	No	Yes	No	No	Yes	Yes	38
51	Yes	No	Yes	No	No	Yes	Yes	No	34
52	No	Yes	No	No	No	No	No	Yes	30
53	Yes	No	No	Yes	No	Yes	Yes	No	29
54	Yes	No	Yes	Yes	No	No	Yes	Yes	29
55	No	No	Yes	Yes	No	Yes	No	Yes	28
56	No	No	Yes	Yes	No	Yes	No	No	27
57	Yes	Yes	Yes	No	No	No	No	No	25
58	No	No	No	No	No	Yes	Yes	Yes	23
59	No	No	No	Yes	No	Yes	Yes	Yes	22
60	No	No	No	No	Yes	No	Yes	No	21
61	No	Yes	No	Yes	No	Yes	Yes	No	21
62	No	Yes	No	Yes	No	No	Yes	Yes	20
63	Yes	No	Yes	No	Yes	No	Yes	No	20
64	Yes	No	Yes	Yes	No	No	No	Yes	18
65	Yes	No	No	No	No	No	No	Yes	17
66	Yes	No	No	Yes	No	Yes	No	No	17
67	No	No	No	Yes	Yes	No	Yes	No	16
68	No	Yes	No	No	No	Yes	No	No	16
69	No	Yes	No	No	No	Yes	Yes	No	16
70	No	No	Yes	No	No	Yes	Yes	Yes	15
71	No	Yes	Yes	Yes	No	Yes	Yes	No	15
72	Yes	No	Yes	No	No	Yes	No	No	15
73	Yes	No	Yes	Yes	No	Yes	No	No	14
74	Yes	No	Yes	No	No	No	Yes	Yes	12
75	No	Yes	No	No	No	No	Yes	Yes	11
76	No	Yes	Yes	No	No	Yes	Yes	No	11
77	No	No	No	Yes	No	Yes	No	Yes	10
78	No	Yes	No	Yes	No	Yes	No	No	10
79	Yes	No	No	No	No	No	Yes	Yes	10

Combination	Straw	Hay	Peat	Sawdust	Paper	Woodchips	Wood	Toy	Frequencies
80	Yes	Yes	No	No	No	Yes	No	No	10
81	Yes	Yes	No	No	Yes	Yes	Yes	No	10
82	No	No	No	No	Yes	No	No	No	9
83	No	No	Yes	No	Yes	No	Yes	No	9
84	Yes	Yes	No	No	No	Yes	Yes	No	9
85	No	No	Yes	No	No	Yes	No	Yes	8
86	No	No	Yes	No	Yes	No	No	No	7
87	No	No	Yes	Yes	Yes	No	No	No	7
88	Yes	No	No	Yes	Yes	No	Yes	No	7
89	Yes	No	Yes	No	No	No	No	Yes	7
90	Yes	No	Yes	No	Yes	No	No	No	7
91	No	No	No	No	No	Yes	No	Yes	6
92	No	No	No	Yes	Yes	No	Yes	Yes	6
93	Yes	No	No	No	Yes	No	Yes	No	6
94	Yes	No	Yes	Yes	No	Yes	No	Yes	6
95	Yes	No	Yes	Yes	Yes	Yes	Yes	No	6
96	Yes	Yes	Yes	Yes	No	Yes	Yes	No	6
97	No	Yes	Yes	Yes	No	No	Yes	Yes	5
98	Yes	No	No	Yes	Yes	Yes	Yes	No	5
99	Yes	Yes	No	No	No	No	Yes	Yes	5
100	Yes	Yes	No	Yes	No	Yes	Yes	No	5
101	Yes	Yes	Yes	Yes	No	No	No	No	5
102	No	No	No	Yes	Yes	Yes	Yes	No	4
103	No	Yes	Yes	No	No	No	No	Yes	4
104	No	Yes	Yes	No	Yes	No	No	No	4
105	Yes	No	No	No	Yes	No	No	No	4
106	Yes	No	No	Yes	No	No	No	Yes	4
107	Yes	No	Yes	Yes	Yes	Yes	No	No	4
108	Yes	Yes	No	No	Yes	No	No	No	4
109	Yes	Yes	No	No	Yes	No	Yes	No	4
110	Yes	Yes	Yes	No	No	Yes	Yes	No	4
111	No	No	No	No	Yes	No	Yes	Yes	3
112	No	No	No	No	Yes	Yes	No	No	3
113	No	No	Yes	Yes	Yes	Yes	Yes	No	3
114	No	Yes	No	Yes	No	No	No	Yes	3
115	No	Yes	Yes	No	No	No	Yes	Yes	3
116	No	Yes	Yes	Yes	Yes	Yes	Yes	No	3
117	Yes	No	Yes	No	No	Yes	Yes	Yes	3
118	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	3
119	No	No	No	No	Yes	Yes	Yes	No	2
120	No	No	Yes	Yes	Yes	No	Yes	No	2
121	No	Yes	No	No	Yes	No	Yes	No	2
122	No	Yes	No	Yes	No	Yes	Yes	Yes	2
123	No	Yes	No	Yes	Yes	No	No	No	2

Combination	Straw	Hay	Peat	Sawdust	Paper	Woodchips	Wood	Toy	Frequencies
124	No	Yes	No	Yes	Yes	Yes	Yes	No	2
125	No	Yes	Yes	No	Yes	Yes	Yes	No	2
126	No	Yes	Yes	Yes	No	Yes	No	No	2
127	No	Yes	Yes	Yes	No	Yes	No	Yes	2
128	Yes	No	No	No	No	Yes	Yes	Yes	2
129	Yes	No	Yes	No	No	Yes	No	Yes	2
130	Yes	No	Yes	Yes	No	Yes	Yes	Yes	2
131	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	2
132	Yes	Yes	No	No	Yes	Yes	No	No	2
133	Yes	Yes	Yes	No	Yes	No	No	No	2
134	Yes	Yes	Yes	Yes	No	Yes	No	No	2
135	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	2
136	No	No	No	Yes	Yes	No	No	No	1
137	No	No	No	Yes	Yes	Yes	Yes	Yes	1
138	No	No	Yes	No	Yes	No	No	Yes	1
139	No	No	Yes	Yes	Yes	No	Yes	Yes	1
140	No	No	Yes	Yes	Yes	Yes	Yes	Yes	1
141	No	Yes	No	No	Yes	No	No	No	1
142	No	Yes	Yes	No	No	Yes	No	No	1
143	No	Yes	Yes	No	No	Yes	Yes	Yes	1
144	No	Yes	Yes	Yes	No	No	No	Yes	1
145	No	Yes	Yes	Yes	Yes	No	Yes	No	1
146	Yes	No	No	No	No	Yes	No	Yes	1
147	Yes	No	No	No	Yes	Yes	Yes	No	1
148	Yes	No	No	Yes	No	Yes	No	Yes	1
149	Yes	No	No	Yes	No	Yes	Yes	Yes	1
150	Yes	No	No	Yes	Yes	No	No	No	1
151	Yes	No	No	Yes	Yes	Yes	Yes	Yes	1
152	Yes	No	Yes	Yes	Yes	Yes	No	Yes	1
153	Yes	Yes	No	Yes	No	No	No	Yes	1
154	Yes	Yes	Yes	No	No	No	No	Yes	1
155	Yes	Yes	Yes	No	No	Yes	No	No	1
156	Yes	Yes	Yes	Yes	No	No	No	Yes	1
157	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	1

Appendix I. Results of the analysis on the Finnish farm dataset to investigate the relationship between the nature of manipulable material which is provided and the occurrence of tail-biting in rearing pigs and weaners

Rearing pigs

The final model obtained after the model building process contains the following enrichment indicators: Straw, Hay, Peat, Paper, Wood and Objects (referred here as Toys) (Table I1). The main findings of the analysis is that using straw, hay and peat as manipulable material reduces the probability of having tail biting, conditionally on the holding, while paper, wood and toys increases the probability of having tail-biting in a specific holding.

Table I1: Estimated parameters from final model.

Fixed effects	Estimate	Std. Error	Z value	Pr(>|z|)
Intercept	1.31399	0.12688	10.356	< 2e-16 ***
Straw	-0.32597	0.10342	-3.152	0.00162 **
Hay	-0.24956	0.10374	-2.406	0.01615 *
Peat	-0.34048	0.12093	-2.816	0.00487 **
Paper	0.27929	0.08888	3.142	0.00168 **
Wood	0.31813	0.13306	2.391	0.01681 *
Toy	0.33875	0.08097	4.184	2.87e-05 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

In terms of goodness of fit of the final model, Figure I2 shows a random selection of holdings for which the estimated probability of having tail biting, together with the estimated confidence interval and the observed proportion is plotted. It is clear that estimated probabilities for each holding and their confidence limits in general contain the observed proportions, indicating a good fit. The pseudo R^2 obtained for the final model using Cragg and Uhler (1970) formula was 0.476, indicating also an acceptable fit.

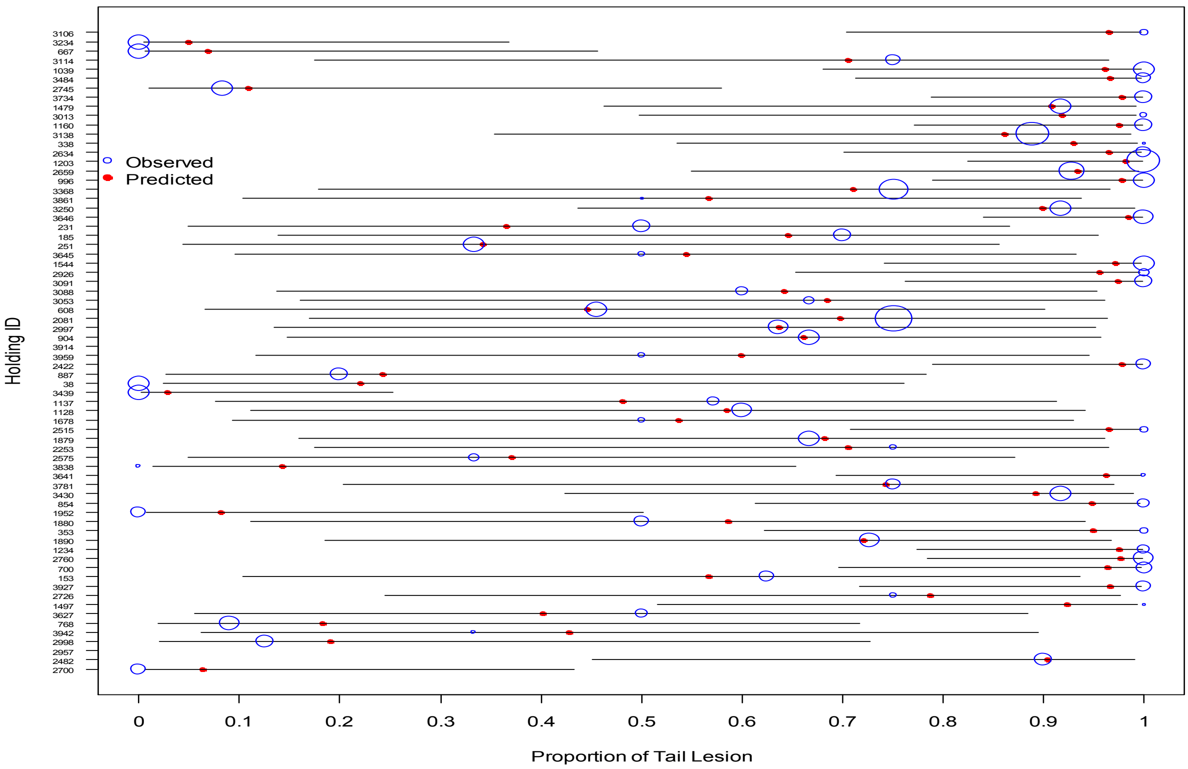


Figure I2. Goodness of fit plot comparing observed (blue circle) with estimated (red dots) proportions, where the size of the circle indicates the number of visits taking place for that holding.

The conditional and marginal (population) probabilities and their confidence intervals have been estimated for each potential combination of the 6 enrichments found statistically significant in the final model (Figure I3 and Figure I4). It should be noted that when marginal probabilities are calculated, their confidence interval are wider, since they are representing a generalization to the whole population (ranging from 0.46 up to 0.98). Also it could be concluded that when using in combination straw, hay and peat the probability of having tail-biting is smaller when using:

- Paper and wood, or
- Wood and toy, or
- Paper, wood and toy, or
- Hay, paper, wood and toy, or
- Straw, paper, wood and toy.

Moreover, it could be concluded that if paper, wood and toys are used in combination, the probability of tail-biting is significantly larger than when the following combination of enrichment are used:

- Straw, hay and peat
- Straw and peat
- Straw, hay, peat and paper
- Straw, hay, peat and wood
- Hay and peat
- Straw, hay, peat and toy
- Straw and hay.

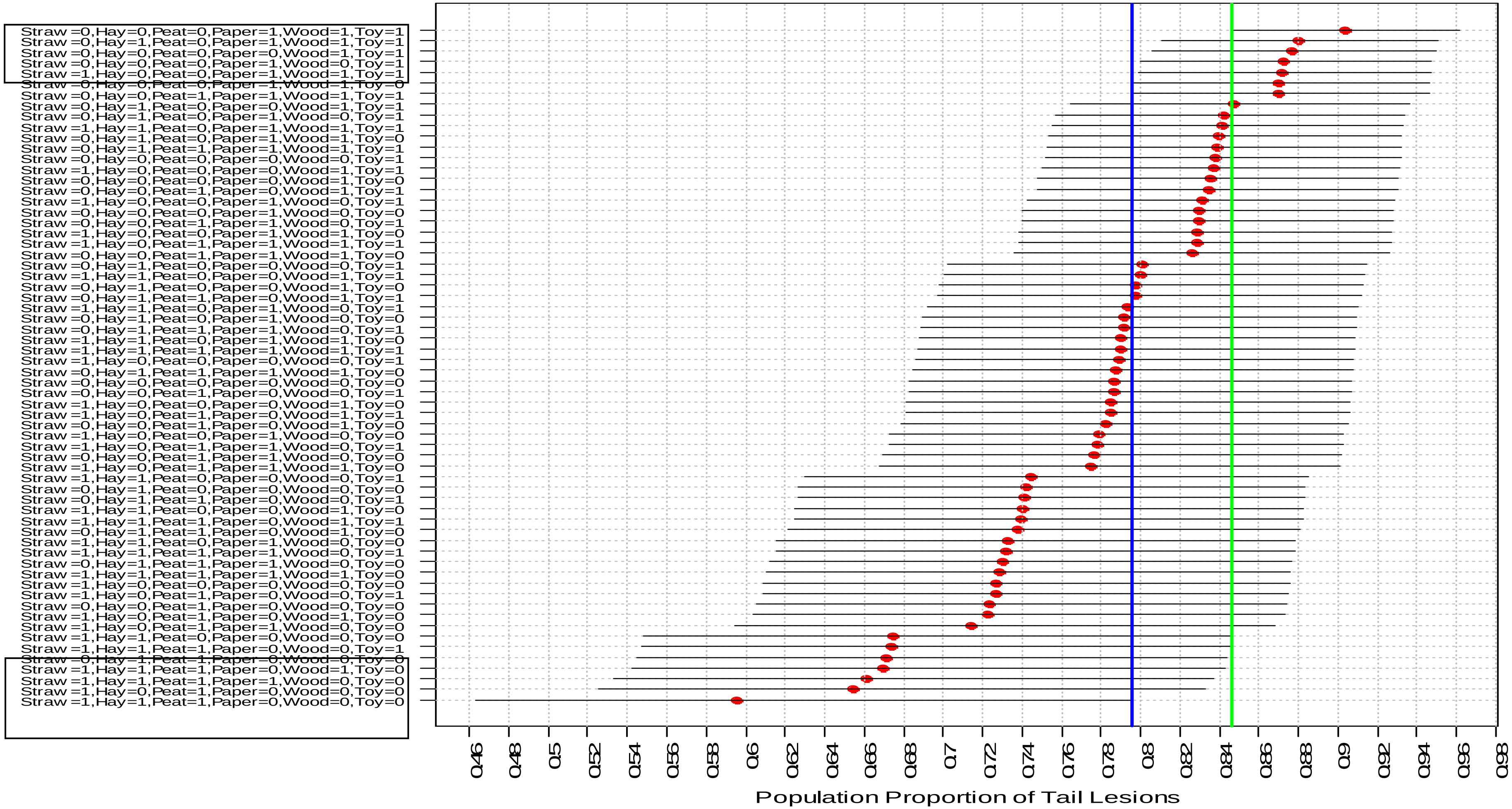


Figure I3. Population probabilities for final fitted model (medians) for each combination of enrichment materials used and their confidence intervals 1 = presence of the material; 0 = absence of the material**.**

The conditional probability of having tail-biting (conditional on the holding, Figure I4) shows 7 groups of combination of enrichment regarding difference on probability of tail-biting (ranging from 0.58 up to 0.92).

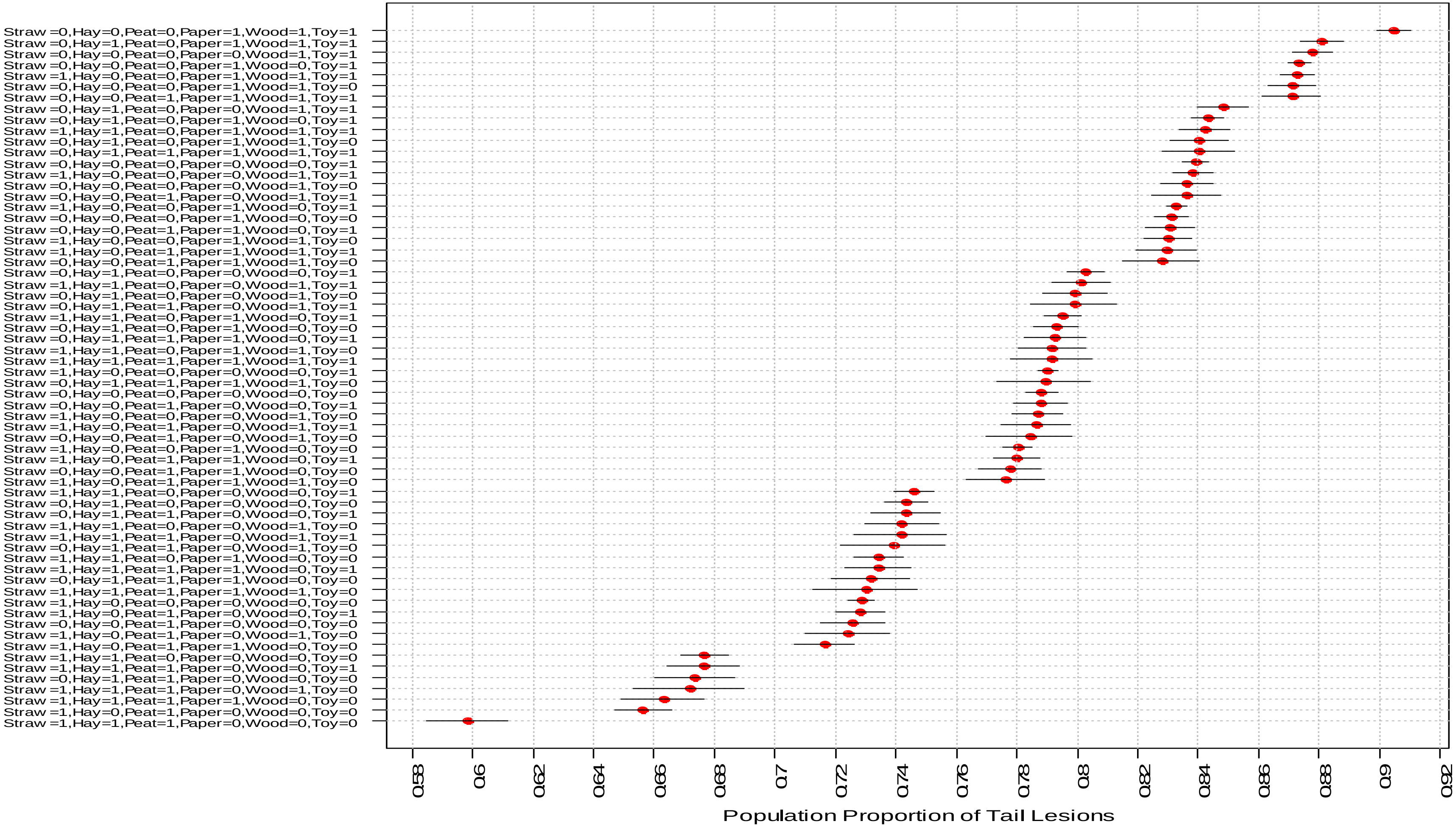


Figure I4. Conditional probabilities for final fitted model (medians) for each combination of enrichment materials used and their confidence intervals. 1 = presence of the material; 0 = absence of the material.

Weaners

The final model obtained after the model building process contains the following enrichment indicators: Straw, Peat, Sawdust and Objects (referred here as Toys) (Table I2). The main finding of the analysis is that using straw, as manipulable material for weaners reduces significantly the probability of having tail biting, conditionally on the holding, while peat and toys increases significantly the probability of having tail-biting in a specific holding.

Table I2: Estimated parameters from final model.

Fixed effects	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.3410	0.1727	-7.767	8.05e-15 ***
Straw	-0.5494	0.1338	-4.105	4.05e-05 ***
Peat	0.3713	0.1352	2.746	0.006024 **
Sawdust	0.2006	0.1100	1.824	0.068176
Toy	0.3383	0.1002	3.377	0.000732 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

In terms of goodness of fit of the final model, Figure I5 shows the same random selection of holdings for which the estimated probability of having tail biting, together with the estimated confidence interval and the observed proportion is plotted (only those holdings having weaners are displayed). It is clear that estimated probabilities for each holding and their confidence limits in general contain the observed proportions and in general the estimated values are close to the observed ones, indicating a good fit. The pseudo R^2 obtained for the final model using Cragg and Uhler (1970) formula was 0.483, indicating also an acceptable fit.

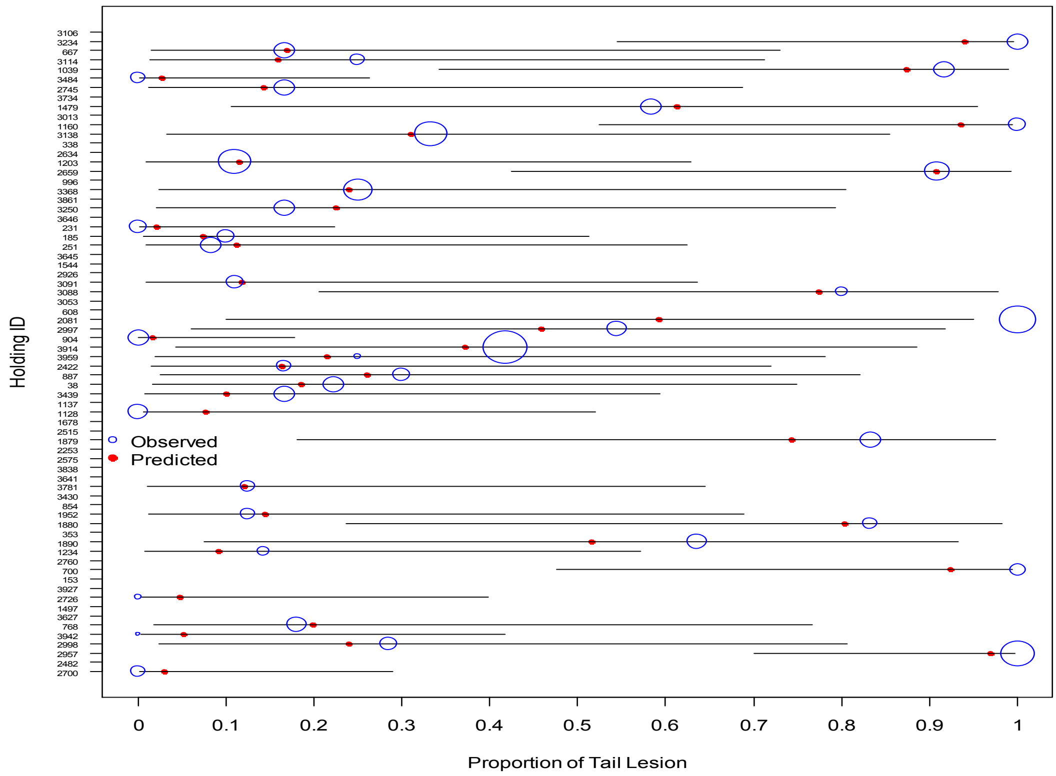


Figure I5. Goodness of fit plot comparing observed (blue circle) with estimated (red dots) proportions, where the size of the circle indicates the number of visits taking place for that holding

The conditional and marginal (population) probabilities and their confidence intervals have been estimated for each potential combination of the 4 enrichments found statistically significant in the final model (Figure I6 and Figure I7). Similarly marginal probabilities and their confidence interval are wider, since they are a potential generalization to the whole population (ranging from 0.08 up to 0.63).

In this particular case (weaners), no clear differences are observed, since all confidence intervals overlap with each other indicating not statistical significant differences between potential combination of enrichments.

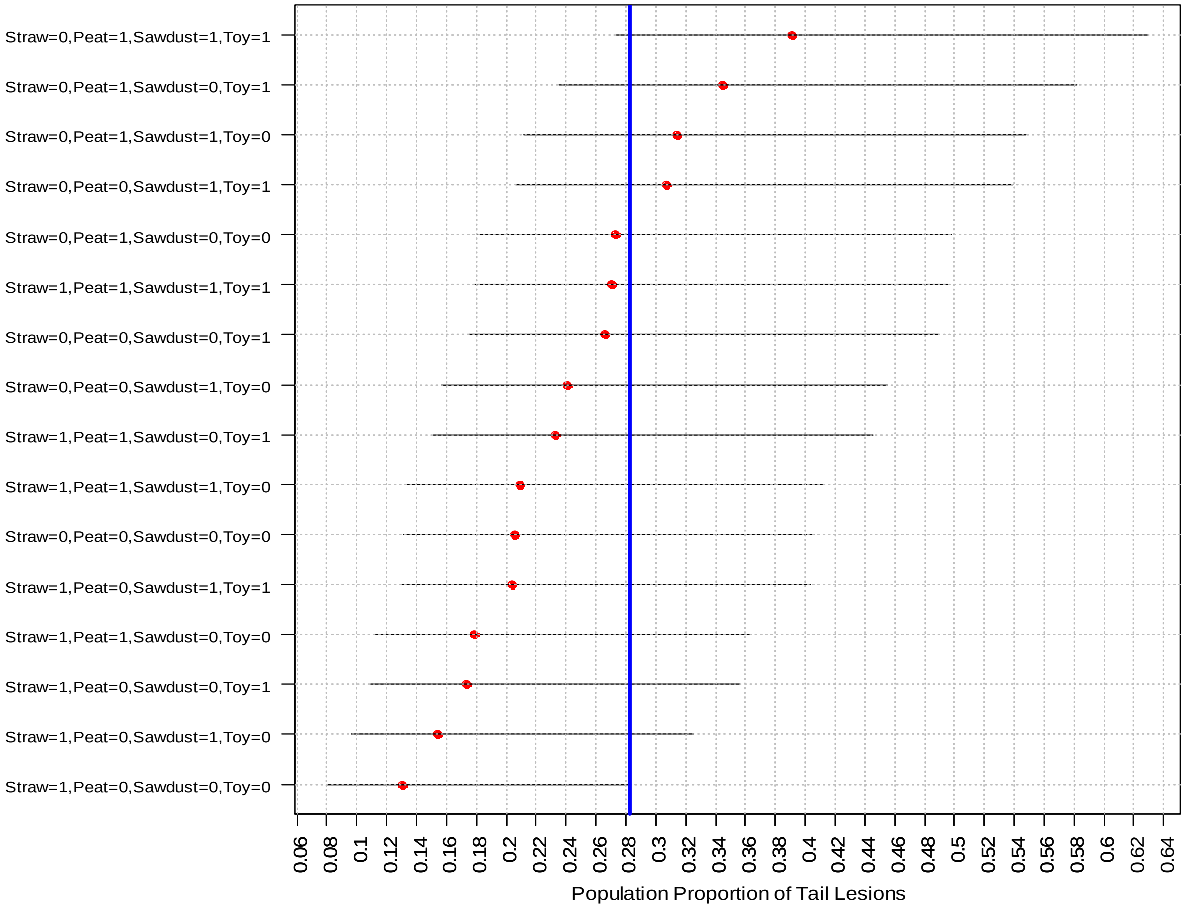


Figure I6. Population proportions for final fitted model (medians) for each combination of enrichment materials used and their confidence intervals.1 = presence of the material; 0 = absence of the material

The conditional probability of having tail-biting (conditional on the holding, Figure I7) shows 9 groups of combination of enrichment regarding difference on probability of tail-biting (ranging from 0.58 up to 0.92). For a specific holding, the probability of having tail-biting when straw is used as enrichment ranges between 0.127 and 0.137, on the other hand if peat, sawdust and toys were provided, then the probability of tail-biting would be between 0.375 and 0.413. The conditional probabilities previously reported show 3 times larger probability of tail-biting when peat, sawdust and toys are used in combination compared to straw only.

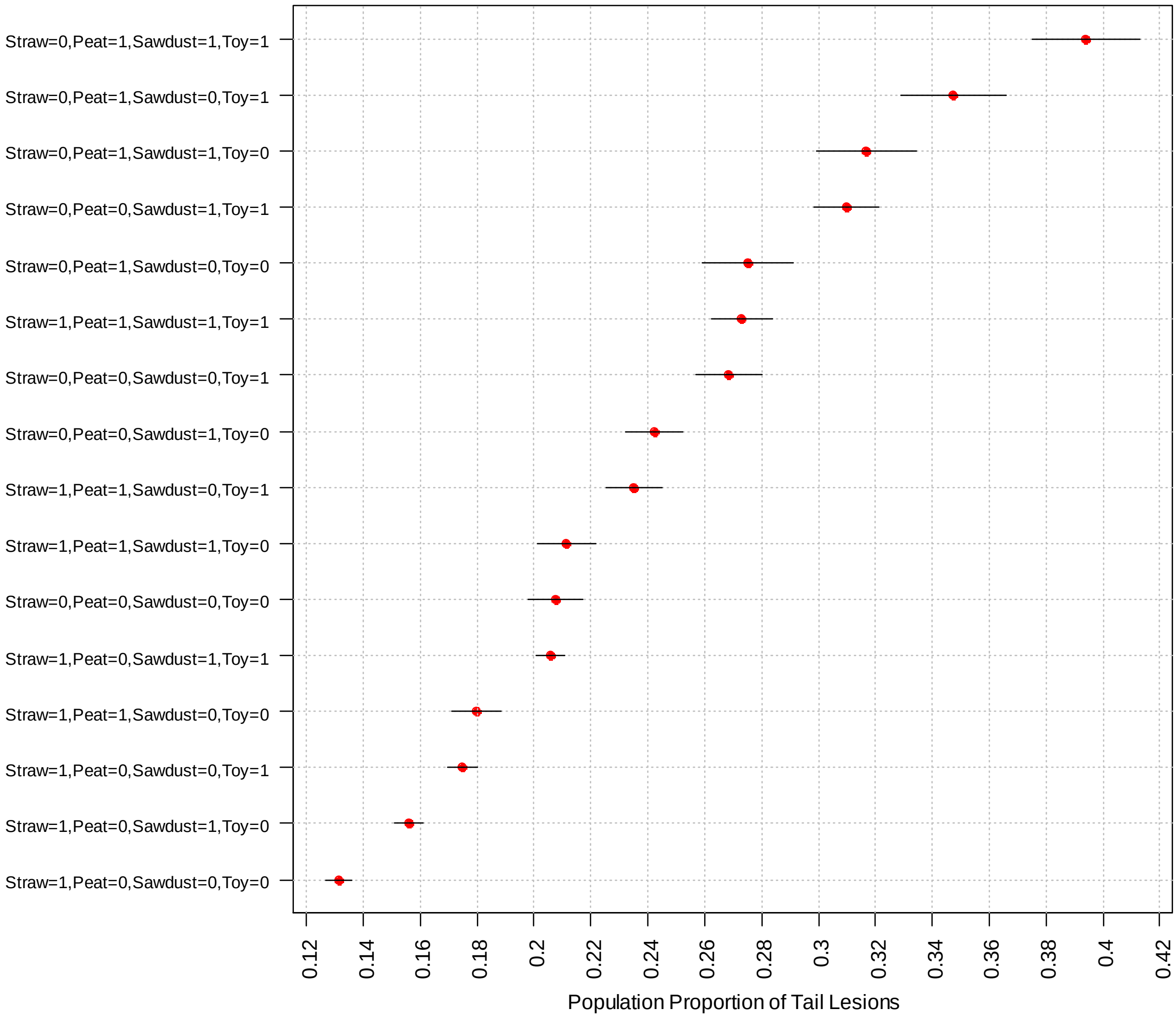


Figure I7. Conditional proportions for final fitted model (medians) for each combination of enrichment materials used and their confidence intervals. 1 = presence of the material; 0 = absence of the material.

Appendix J. Proposal for data model in relation to tail-biting and provision of functional manipulable material

Element Name	Date type	Controlled terminology	Description	Mandatory
Sample details:				
progID	String(100)	"Welfare Quality® Assessment protocol for pigs"	Framework under which the survey was performed	
sampCountry	String(2)	COUNTRY	Country where the farm is located	Y
sampRegion	String(5)	NUTS	Region where the farm is located using Nomenclature of Territorial Units for Statistics codes	
sampY	integer (4)		Year of visit to farm	
sampM	integer (2)		Month of visit to farm	
sampD	integer (2)		Day of visit to farm	
observer	String(5)		Unique code to identify the observer or assessor	
Farm details:				
holdingID	String(250)		Unique Id for the holding where the welfare quality survey is carried out	Y
sampMatCode	String(5)	A0CAE = Fattening pigs A0CAF = Weaners	Code for type of pig surveyed on farm	Y
farmType	String(5)	A07RZ= Outdoor/free-range growing condition A0C6Q = Intensive production A0C6Y = Conventional non-intensive production non-intensive production	Code to describe type of farming system	Y
N_pigs	Integer(20)		Number of pigs for the surveyed type on farm	Y
Animal details:				
Breed			Breed (or breeds) of pig	
initialWeight	Integer(20)		Starting weight for fattening in kilograms	Y
slaughterWeight	Integer(20)		Final weight/slaughter weight in kilograms	Y
age	Integer(20)		Age of pigs in days at visit	Y
mortality	Decimal(20,10)		Number of animals which were found dead (not actively culled) during the last twelve months / Number of animals arriving on the farm (from other locations) in the last twelve months	

Element Name	Date type	Controlled terminology	Description	Mandatory
castration	Integer(1)	0 = No Castration 1 = Castration with use of anaesthetics 2 = Castration without use of anaesthetics	Castration occurs on the farm	
mixing	Integer(1)	0=No 1=Yes	Are the pigs mixed on the farm (or at a previous farm) more than once after weaning (and before leaving finisher pens)?	
Tail history:				
tailDocking	Integer(1)	0 = No tail docking 1 = Tail-docking with use of anaesthetics 2 = Tail-docking without use of anaesthetics	Tail-docking occurs on the farm	Y
tailLength	Integer(1)	0= <0.25 1= 0.25-0.5 2= 0.51-0.75 3= >0.75 4= not docked	Length of tail remaining	
tailVar	Integer(1)	0=No 1=Yes	Is there variation in length of tails in the group (e.g. mix of docked and undocked, docked lengths varying by >1/3 undocked length)?	
tailBatchBite	Integer(1)	0=No 1=Yes	Have any pigs from the current pen been culled due to tail biting or lesions caused by other pigs?	
tailTreat	Integer(20)		Number of pigs on farm treated for bitten tails in the last month (and year if known)	
tailCull	Integer(20)		Number of pigs on farm culled for bitten tails in the last month (and year if known)	
Pen details:				
roomID	String(250)		Unique identifier for the room in the farm where the observed pen is located	Y
penID	String(250)		Unique identifier for pen in the room where the observations are made	Y
N_pen	Integer(20)		Number of pigs in pen which is observed	Y
N_pigs_scored	Integer(20)		Number of pigs observed when this in not equal to the total number of pigs in the pen	
penArea	Integer(20)		Pen area in m^2	Y

Element Name	Date type	Controlled terminology	Description	Mandatory
spaceAllowance	Decimal(20,10)		Space allowance expressed in m^2 per 100kg animal	Y
temp	Integer(20)		Temperature in the room in degrees centigrade	Y
flooring	String(20)	Fullslat= fully slatted, Partslat= partially slatted Solid = concrete or other flooring without slats Ground = natural flooring mud or grass	Type of flooring in the pen	Y
bedding	String(20)	None, Deep Straw, straw with floor still visible, saw dust, Shavings, other types of bedding	Type of bedding in the pen	Y
cleanlinessPen	Integer(0)	0 = Clean pen 1 = Dirty pen	Cleanliness of the pen	Y
outsideAccess	String(1)	Yes, No	Indicate if pigs have access to an outdoor area	Y
Pen environment:				
	Integer(1)	0= No 1= Yes	Is atmosphere in the pen aversive, e.g. strong smell of Ammonia, dust, irritation caused to eyes or lungs?	
	Integer(1)	0= No 1= Yes	Are there draughts in the lying area? (observations of substrate, lying behaviour of pigs, walkthrough)	
	Integer(1)	0= No 1= Yes	Does lying area obstruct simple routes between feeders, drinkers and dunging areas?	
	Integer(1)	0= No 1= Yes	Is there provision to maintain the pigs at thermoneutral temperatures when external temperature gets too high or too low for measures such as existing ventilation? (e.g. additional bedding, showers or wallows)	
	Integer(1)	0= No 1= Yes	Does the dunging area extend into the lying area, e.g. areas of fouled bedding, or fouled floor?	
	Integer(1)	0= No 1= Yes	Are feeders present in the lying area?	
	Integer(1)	0= No 1= Yes	Are drinkers present in the lying area?	
	Integer(1)	0= No 1= Yes	Is the lying area wet or damp?	

Element Name	Date type	Controlled terminology	Description	Mandatory
Feed and water provision:				
feederType	String(250)	Hopper, Trough, Ground	Type of feeder in pen (can be repeated e.g. Hopper&Trough)	Y
feedFormulation	String(20)	Pellets, meal, liquid	Formulation of feed	Y
N_drinkers	Integer(20)		Number of drinking places in the pen	Y
drinkersType	String(250)	Bowl, Trough, Nipples, Pipe	Type of drinking places in pen (can be repeated e.g. Nipples&Bowl)	Y
drinkersFunc	Integer(20)		Number of drinking places functioning	Y
drinkersClean	Integer(20)		Number of clean drinking places	Y
feedMeal	Integer(1)	0= meals 1= *Ad libitum*	Is feed provided in meals or *ad libitum*	
N_feedspace	Integer(20)		No of pigs per feeding space	
drinkersFlow	Integer(1)	0= No 1= Yes	Is water flow rate less than 1 litre per minute? (N/A if reservoirs of clean water present)	
dietEnergy	String(20)		Energy content of diet (MJ NE/kg)	
dietSodium	String(20)		Sodium content of diet (g/kg)	
dietLysine	String(20)		Lysine content of diet (g/kg)	
dietTrypt	String(20)		Tryptophan content of diet (g/kg)	
dietParticle	String(20)		Particle size of diet (fineness of grinding)	
Enrichment provision:				
enrichmentType	String(250)		What is the enrichment provided: describe exactly material type(s), amount/number	
enrichmentChop	Integer(1)	0= No 1= Yes	If straw or a strawlike substance is provided, is it chopped as opposed to long?	
enrichmentRepl	String(20)		Frequency of replenishment	
enrichmentAvail	Integer(1)	0= No 1= Yes	If a straw, strawlike or particulate substrate is provided, are there times of day or night when it is not present in the pen?	

Element Name	Date type	Controlled terminology	Description	Mandatory
enrichmentAccess	Integer(1)	0= No 1= Yes	Is there limited access to the substrate (e.g. not all animals can contact it at once)?	
enrichmentHygiene	Integer(1)	0= No 1= Yes	If objects are provided for enrichment are they fouled e.g. dung on object, or 50% covered in dirt	
enrichmentReplace	String(20)		If objects are provided for enrichment how often are they replaced	
enrichmentFloor	Integer(1)	0= No 1= Yes	If objects are provided for enrichment are they at floor level rather than suspended or fixed above floor level?	
enrichmentFarrow	Integer(1)	0= No 1= Yes	Are the piglets provided with straw or particulate substrate in farrowing accommodation?	
enrichmentPrev1	Integer(1)	0= No 1= Yes	Have the pigs previously been provided with straw or particulate substrate BEFORE ARRIVING at this farm, but now have manipulable objects instead? (only applicable when all stages of rearing NOT present on current farm, otherwise n/a)	
enrichmentPrev2	Integer(1)	0= No 1= Yes	OR Have the pigs previously been provided with straw or particulate substrate during their time in an earlier part of the system WHILST AT this farm but now have no substrate? (only applicable when all stages of rearing ARE present on current farm, otherwise n/a)	
Pig outcome measures:				
manureMild	Integer(20)		Number of pigs with more than 20% and less than 50% manure on the body	
manureSev	Integer(20)		Number of pigs with more than 50% manure on the body	
BCS	Integer(20)		Number of lean pigs in pen	Y
bursitisMild	Integer(20)		Number of pigs with one or several small bursae on the same leg or one large bursa	
bursitisSev	Integer(20)		Number of pigs with several large bursae on the same leg or one extremely large bursa or any bursae that are eroded	
shivering	Integer(20)		Number of pigs shivering	
panting	Integer(20)		Number of pigs panting	

Element Name	Date type	Controlled terminology	Description	Mandatory
huddling	Integer(20)		Number of pigs huddling	
lameMild	Integer(20)		Number of pigs severely lame, minimum weight bearing on the affected limb	
lameSev	Integer(20)		Number of pigs with no weight bearing on the affected limb or unable to walk	
woundMild	Integer(20)		Number of pigs with 5-10 lesions in any region or one region with more than 10 lesions	
woundSevere	Integer(20)		Number of pigs with two or more regions with more than 10 lesions or one region with more than 15 lesions	
tailLesions	Integer(20)		Number of pigs whit fresh blood visible on the tail or evidence of swelling and infection or part of the tail is missing and a crust has formed	Y
coughing	Integer(20)		Number of pigs coughing	
N_coughs	Integer(20)		Number of coughs in 5 minutes	
sneezing	Integer(20)		Number of pigs sneezing	
N_sneeze	Integer(20)		Number of sneezes in 5 minutes	
pumping	Integer(20)		Number of pigs with laboured breathing	
twistedSnout	Integer(20)		Number of pigs with twisted snouts	
rectalProplapse	Integer(20)		Number of pigs with rectal prolapse	
scouring	Integer(1)	0 = No liquid manure 1 = Some liquid manure visible 2 = All faeces visible is liquid manure	Evidence of scouring: Visible and fresh dung on the floor of the pen	
skinCondMild	Integer(20)		Number pigs with up to 10% of the skin inflamed, discoloured or spotted	
skinCondSev	Integer(20)		Number pigs with more than 10% of the skin inflamed, discoloured or spotted	
herniaMild	Integer(20)		Number of pigs with hernias or ruptures present, affected area is not bleeding, touching the floor or affecting locomotion	

Element Name	Date type	Controlled terminology	Description	Mandatory
herniaSev	Integer(20)		Number of pigs with bleeding lesions and/or hernias or ruptures touching the floor and/or hernias or ruptures affecting locomotion	
negativeSocial	Integer(20)		Proportion of sample points with aggressive interaction (including biting) or social behaviour with a response from the disturbed animal	Y
positiveSocial	Integer(20)		Proportion of sample points sniffing, nosing, licking or moving gently away from other animals without aggression or flight reaction	Y
explorFittings	Integer(20)		Proportion of sample points sniffing, nosing, or licking features in the pen	Y
explorEnrichment	Integer(20)		Proportion of sample points playing or investigating enrichment material	Y
HAR	Integer(1)	0 = Up to 60 % of animals showing a panic response; 2 = More than 60 % of animals showing a panic response	Human animal response	

ABBREVIATIONS

AHAW Panel	EFSA Panel on Animal Health and Welfare
AMU	Assessment and Methodological Support
CART	Classification trees
CRT	Classification and Regression Trees
EMats	Model to assess manipulable materials
EU	European Union
GLMM	Generalized linear mixed effect model
MS	Member States
SVM	Support vector machine
ToR	Terms of Reference
Wcat	Weighting categories
WQ®	Welfare Quality®
WFs	Weighting factors