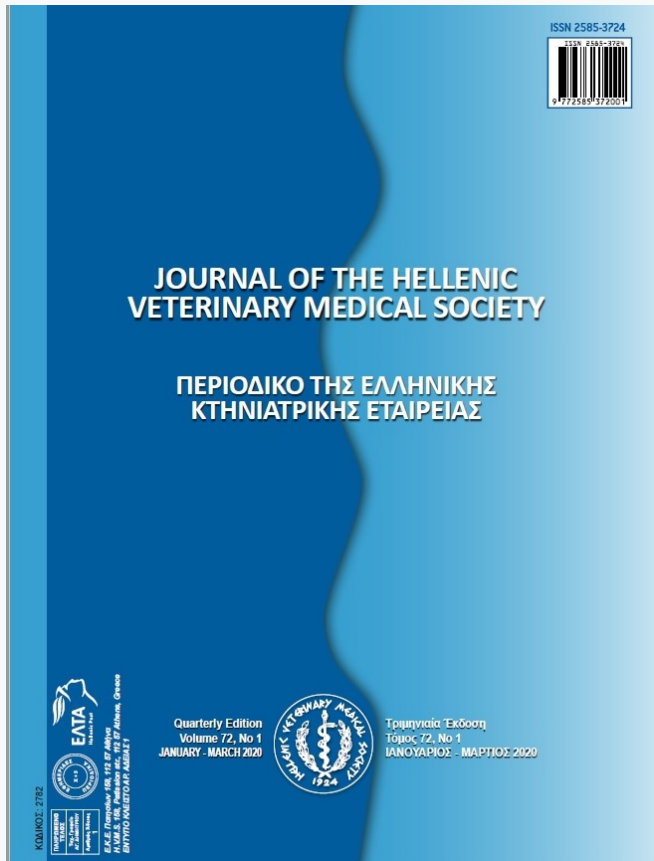


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Update on Tail biting in pigs: An undesirable damaging behavior

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ABSTRACT: Tail-biting is an abnormal behavior of multifactorial origin, that consists a major problem in modern pig industry. It has a serious impact on both welfare and health status of the pigs involved, as well as on economic profitability of the farm. It is considered to be a problem of pig adaptation in poor environment triggered by a plethora of external and internal risk factors interacting with each other. A great variation exists on prevalence of tail biting between different studies across the world. Tail docking is the common practice applied by farmers to prevent this behavior, while treatments are based on enrichment material provision. The aim of this review is to explore the most recent literature on risk factors and impacts of tail biting and to discuss promising areas on early prediction and treatment of the topic.

Keywords: tail biting, pig health, pig welfare, pig behaviour

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INTRODUCTION

Tail biting is an abnormal behavior frequently occurring in pigs compromising welfare, health and economic gain in pig industry (Harley et al., 2014; Larsen et al., 2019; Niemi et al., 2012). It had been reported in pig farms since the 1950's (Schröder-Petersen and Simonsen, 2001). However, it is generally accepted that this abnormality became more severe with the development of more intensive production systems (Edwards, 2006). Although this type of behavior is reported in conventional and organic free-range production systems (Kongsted and Sørensen, 2017), surprisingly, it is not documented in other non-domesticated Suids or Peccaries kept in captivity or found in wild life (Taylor et al., 2010).

The prevalence of severe tail biting can be as high as 3.1% (Van Staaveren et al., 2017b) while it may reach up to 72.0% for mild lesions (Teixeira et al., 2016). In general, abattoir data for tail biting cannot easily help to identify its prevalence, as a standard tail damage scoring system is lacking (Harley et al., 2014; Keeling et al., 2012) and particularly a system associating meat inspection with welfare (Harley et al., 2012a; Vom Brocke et al., 2019).

This pattern of behavior may cause acute pain in bitten pigs but also results in long-term consequences such as secondary infections (Valros and Heinonen, 2015) leading to carcass abscesses (Heinonen et al., 2010), respiratory organ inflammation (Munsterhjelm et al., 2013) and lung pathologies (Kritas and Morrison, 2007). Tail biting consists not only a welfare problem for pigs receiving this behavior, due to the pain caused, but is also an indication of decreased welfare in pigs performing it, since the inadequacies in their environment make them feel discomfort and bite (Thodberg et al., 2018; Valros et al., 2015, 2004).

Although poor health status is considered a high-risk factor for tail biting (European Food Security Authority (EFSA), 2007), suboptimal health has not received adequate attention so far (D'Eath et al., 2014; Valros and Heinonen, 2015). More research is needed on the possible correlations between pig health and the expression of tail biting behavior (Munsterhjelm et al., 2016; van Staaveren et al., 2016; Naya et al., 2019a). Moreover, due to secondary infections, carcasses from tail bitten pigs are trimmed or condemned in abattoirs (Kritas and Morrison, 2007) reflecting a direct economic loss of 1.10 Euro per pig (Harley et al., 2014) while this amount is even higher if we consider the indirect losses due to lower average daily

gain (ADG) that can come up to 3% (Sinisalo et al., 2012).

Tail biting is known to be a multifactorial syndrome which is related to internal risk factors influenced by a great variety of external factors (Schröder-Petersen and Simonsen, 2001). Although a lot of risk factors, especially environmental, have been identified the exact cause remains unknown (Sutherland and Tucker, 2011). As a consequence, tail biting outbreaks are difficult to be predicted and even more challenging to understand their cause as several environmental and husbandry factors associated with this behavior are likely to be unknown at their exact magnitude. Even under one roof where the same managerial practices are implemented, tail biting is sporadic (Edwards, 2006; Sutherland and Tucker, 2011). Furthermore, due to its multifactorial origin, this behavior is rare not to be present in commercial farms (Thodberg et al., 2018) leading farmers to routinely tail dock under fear of economic losses and fear of losing control of the situation (D'Eath et al., 2016). The existing percentages of tail docking over 95% in Europe (EFSA, 2007) indicates that 25 years after the first EU legislation forbidding the procedure on routine basis, there is an information gap in alternative steps that farmers could adopt (D'Eath et al., 2016) while the insufficiencies of current control methods is proven by high prevalence's of tail-docking (Harley et al., 2012b). European Commission audits for tail docking in Germany and Denmark, both being the biggest producers of pork in EU, report over 95% of pigs in Germany and over 98.5% in Denmark are tail docked (EU Commission, 2018). As no experimental curative treatment has stopped 100% of tail biting outbreak (Chou et al., 2019b; Zonderland et al., 2008), farmers could benefit from research in the field of automated monitoring of pigs' behavior in order to predict such outbreak (Niemi et al., 2012; Zonderland et al., 2016).

On the other hand, animal welfare is related to ethics and also a point of concern for the public and a part of EU values (European Commission, 2012). Consequently, this is an important political issue both at National and European level (Harley et al., 2014). Moreover, successful implementation is conditioned by knowing farmers perceptions (Kakanis et al., 2019) and consumer willingness to pay a price premium for better animal welfare (Niemi et al., 2012; D'Eath et al., 2016).

As a lot of research on tail biting is conducted throughout Europe, this review aims at presenting the

main outcomes based on current literature, to pinpoint the possible research gaps and highlight the potential pathways for new research needed.

PREVALENCE

The percentage of tail bitten pigs in a given population is used as the prevalence of tail biting in most studies although time should be also incorporated (Taylor et al., 2010). There seems to be an underestimation of tail biting lesion prevalence in the official statistics as the Official Veterinarians (OVs) record only the severe cases (Keeling et al., 2012; Wallgren et al., 2019c) and data should be used cautiously in order to evaluate the tail biting incidence in farm (Lahrman et al., 2017). Underestimation could also be attributed to the high-speed lines of abattoirs (Correia-Gomes et al., 2017). On the other side, Wallgren et al. (2019c) support that in countries where farmers keep undocked pigs there could be an overestimation of tail damage in abattoirs due to other reasons, like tail necrosis due to toxins in straw. Tail appearance is not always the best way to quantify tail biting activity as under intact tails severe histopathological reactions may be found (Simonsen et al., 1991; Munsterhjelm et al., 2013). Moreover, the standing point of the observer in the abattoir plays a role in this discrepancy between studies, as some do the scoring before scalding and dehairing (Keeling et al., 2012) while others do it after them for better assessment of the minor lesions (Harley et al., 2014) or of every score of severity (Carroll et al., 2015). The variation in abattoir studies is further amplified by different scoring systems (van Staaveren et al., 2016), ways of record keeping (Harley et al., 2012b) and differences in estimation between individuals (Keeling et al., 2012).

Tail biting prevalence based on abattoir data, can't give an exact representation of the problem on farm as it misses out those tail bitten pigs that die due to severe lesions or euthanasia and lesions that get healed (Marques et al., 2012; Harley et al., 2012b; Lahrman et al., 2017). Moreover, docking practices could differentiate the prevalence, as pigs raised under welfare schemes have more odds than conventional farmed pigs for tail

lesions, probably due to being undocked (Kongsted and Sørensen, 2017; Alban et al., 2015). Also, increase of on farm prevalence could be expected in countries where enrichment material is not a prerequisite by legislation, as in USA (Li et al., 2017). In a registered based study performed by Fertner et al. (2017), it was pinpointed that relatively low prevalence in tail biting lesions could be attributed to measures taken for the prevention of tail biting. In addition, variation of prevalence between farms (Becskei et al., 2018) is attributed to some producers being more capable of keeping pigs under optimum conditions thus avoiding tail biting outbreaks (Van Staaveren et al., 2016). This variation indicates the importance of farm related risk factors (Valros et al., 2004) and emphasize the different conditions that exist in pig farms around Europe (Wallgren et al., 2019b).

Overall, tail lesion prevalence may vary greatly between farms (Fertner et al., 2017; Van Staaveren et al., 2017a) abattoirs (Keeling et al., 2012) and regions (Harley et al., 2012b). As the prevalence of this behavior is expected to increase if the trend towards less docking continues in E.U. (Keeling et al., 2012; D'Eath et al., 2016), it is important to have a clear definition and standard record practices in order to have reliable data (Harley et al., 2012b). A summary of the most recent studies data is shown in Table 1.

It is evident that the lack of a clear definition of tail biting scoring system makes difficult the comparison of the studies run among different countries. Tail biting research could benefit from incorporating scoring in official veterinary duties, and thus an increased volume of data to become available. This will also allow correlations between different welfare indicators in slaughterhouse (e.g. hind-limb bursitis) to be made, resulting in the establishment of a welfare indicator system applied among all countries.

Table 1. Tail biting prevalence between different studies

COUNTRY	DATE	Number of pigs	PLACE	DOCKED		UNDOCKED		Reference
				MILD*	SEVERE**	MILD*	SEVERE**	
FINLAND	2000	10852	ABBATOIR			34.60%	1.30%	Valros et al., 2004
USA	2002	1895	FARM	16.30%	9.70%			Kritas & Morrison, 2004
SWEDEN	2003	15068	ABBATOIR			7.00%	1.5%-1.9%	Keeling et al., 2012
IRELAND	2010	35288	ABBATOIR	58.10%	1.03%			Harley et al. 2012b
IRELAND	2012	3422	ABBATOIR	72.50%	2.50%			Harley et al. 2014
IRELAND	2014	3889	ABBATOIR	30.80%	1.60%			Carrol et al. 2015
ITALY	2014	128/320	FARM				3.60%	Martino et al., 2015
DENMARK	2015	472	FARM	2.20%	0.00%	3.30%	2.40%	Paoli et al., 2016
IRELAND	2012	3143	ABBATOIR	72.00%	2.30%			Teixeira et al., 2016
IRELAND	2015	4491	ABBATOIR	7.30%	2.40%			Staaveren et al., 2016
IRELAND	2014	13133	ABBATOIR	25.20%	3.10%			Staaveren et al., 2017
DENMARK	2016	1624	FARM	49.00%				Larsen et al., 2017
DENMARK	2015	962/960	FARM	0.00%	0.00%	23.00%		Larhmann et al., 2017
USA	2016	120/120	FARM	42.50%	5.00%	59.20%	30.00%	Li et al., 2017
GREECE	2017	461	ABBATOIR	46.42%***				Beckskei Zolt, 2017

5 scale climax: 0=No evidence of tail biting 1= Healed of mild lesions 2=Evidence of chewing or puncture wounds, no swelling 3= Evidence of chewing or puncture wounds with swelling and signs of infection 4=Partial or total loss of the tail

3 scale climax : 0= No visible tail lesion. Earlier lesion is healed 1= Tail appears red and/or has minor scratches 2= Visible wound with obvious tissue damage

*Mild: Tail biting lesions of score 1 and 2 in a 5-scale climax or 1 in a three-scale climax.

**Severe: Tail biting lesions of score 3 and 4 in a 5-scale climax or 2 in a three-scale climax.

*** Mild & Severe tail biting lesions

TAIL BITING IMPACT ON PIG HEALTH AND WELFARE

Pigs that are tail bitten feel acute pain meaning lower welfare but also later they might develop health problems through infection of the biting wound (Valros, 2017). Wallenbeck and Keeling (2013) found that pigs that are mostly tail bitten (victims) had lower daily feed consumption up to 2 weeks after a tail biting outbreak while Munsterhjelm et al. (2015) reports reduced feed intake for even 20 days before becoming a victim and additionally suggest that feed intake on day 0 of tail biting could be used as predictor of recovery. Li et al. (2017) didn't observe any differences in body weight (BW) between tail biters and victims although they recorded reduced ADG in the period of production when most of the tail biting outbreaks occurred.

Victim pigs have a lower ADG (Marques et al., 2012; van Staaveren et al., 2017b) up to 3% although the latter is not correlated with feed conversion ratio (Sinisalo et al., 2012). Marques et al. (2012) explained this reduction by means of stress, secondary effects

or lower feed intake. A correlation between high percentage of tail lesions and lower ADG has been found also at farm level (Pandolfi et al., 2018).

The infection from tail wound due to tail biting can spread through the body and lead to secondary infection to different organs (Schröder-Petersen and Simonsen, 2001). Pigs with severe tail lesions present more often locomotion disorders and a higher mortality rate (Marques et al., 2012). In their epidemiological study, Pandolfi et al. (2018) reported a correlation between tail bitten pigs and hepatic scarring. Tail bitten pigs have more abscesses in lungs and at vertebral column (Marques et al., 2012). Table 2 presents the major outcome of tail biting on health of pigs as reported by previous research efforts.

The lack of available data on the topic, reveals the need for further research to investigate the link between tail biting and health status of the animal on a cause and effect basis. Moreover, the overall mortality on farm due to tail biting should be quantified to complete the record of tail biting effect.

Table 2. Major outcomes of tail biting on health of pigs

Main outcomes	Reference
Tail lesions increases the risk of carcass condemnation mainly due to abscesses and arthritis. Healed tail damage also increases the risk significantly.	Valros et al. (2004)
The severity of tail biting is associated with the presence of pleuritis and lung abscesses.	Kritas and Morrison. (2007)
There are significant association between the severity of tail-biting and external carcass abscesses.	
Along with suboptimal production systems, tail biting wounds can increase the risk of disease and injury lesions in pigs sent for slaughter.	Harley et al. (2012b)
In addition to an increased mortality rate, tail biting is associated with locomotion disorders and with the presence of abscesses at vertebral column, inguinal area and lungs.	Marques et al. (2012)
The average daily gain of tail biting victims is reduced by 1 to 3%.	Sinisalo et al. (2012)
Pigs with tail injuries due to tail biting consume decreased amounts of feed.	Wallenbeck and Keeling. (2013)
Prevalence of severe tail lesions is associated with the prevalence of enzootic pneumonia-like lesions and pyaemia.	Pandolfi et al. (2018)
Pigs with severe tail lesions tend to have more severe pleurisy where the lungs remained attached to the chest wall than pigs with moderate tail lesions.	Staaveren et al. (2016)
Severe tail lesions are correlated with a lower average daily gain	Staaveren et al. (2017)

TAIL BITING IMPACT ON FARM ECONOMY

Financial losses due to tail biting are significant and a constant threat for a pig farm (Harley et al., 2014). The cost of tail biting for a finishing farm of 4,000 pigs is estimated to be at 2,383 Euro per year (Zonderland et al., 2011c). In their study, Harley et al. (2014) estimated the profit loss per pig at 0.59 Euro considering only carcass reduced weight, while this amount goes up to 1.69 Euro when carcass condemnations, trimmings and smaller carcass weight are considered.

The risk of carcass condemnation has been positively correlated with the severity of tail lesion (Marques et al., 2012; Harley et al., 2014) while even healed lesions raise the above risk significantly (Valros et al., 2004). This positive association exists also between tail lesions severity and carcass trimmings (Harley et al., 2014; Kritas and Morrison, 2007). Moreover, tail lesions have a negative correlation with carcass weight (Harley et al. 2014; Carroll et al., 2015) while Valros et al. (2013) suggest that due to lower carcass weight they produce less lean meat.

Indirect economic losses have also to be estimated due to possible morbidity and mortality such as drug use for treatment of tail bitten pigs and increased labor costs (Marques et al., 2012). In a simulation study, the cost per tail bitten pig in a pen was estimated at 18.96

Euro due to increased medicine, veterinary, labor and material costs, increased mortality, carcass disposal and carcass condemnations, reduced daily gain and extra feed consumption (D'Eath et al., 2016).

On the economic impact of tail biting, it seems that farmers will treat tail biting in time if they are aware of the impact on their income. Thus, there is a need for more studies in the correlation between tail biting and production loss. Studies should quantify and take into account all the possible factors tail biting lesions affect the farmers' revenue.

BEHAVIORAL BASIS OF PIG TAIL BITING

Due to its sporadic and unpredictable presentation tail biting behavior is hard to be studied. The associations between tail damage and other lesions could be explained by shared risk factors (Teixeira et al., 2016), let alone the weakness of experimental studies to provoke it (Edwards, 2006; D'Eath et al., 2014) and the fact that treatments that work once maybe proven useless to another outbreak (Hunter et al., 2001).

Three distinct types of tail biting have been proposed (Taylor et al., 2010): a) Two stage: a pre-injury one followed by an injurious one, b) sudden-forceful, and c) obsessive, based on a

different motivation basis. Later studies seem to support the different motivation (Ursinus et al., 2014a,2014c). The three types could be prevented by the identification of the different factors that are more usually involved to each type. Not all tail bites result in a tail biting outbreak (Holling et al., 2017; Lahrmann et al., 2018b). In most cases however, finding the pathway of actions that each risk factor triggers the processes that control tail biting expression is very difficult (Brunberg et al., 2016; D'Eath et al., 2016). Some studies are categorizing pigs as 'tail-biters' that do most of the biting, 'victims' who receive most of the bites and 'neutrals' that neither perform nor receive (Zonderland et al., 2011b; Brunberg et al., 2011) in order to find distinctive characteristics of pig behavior. In addition, Ursinus et al. (2014a) suggest that while there is an inconsistency in tail biting behavior by tail biters through rearing phases, victims seem to stay victims throughout their lives.

According to Valros et al. (2015) tail biters have differences in certain neurotransmitter's metabolism, dopamine and serotonin, in different brain areas than victims, indicating different ways of coping with stress between these two behavioral phenotypes. In addition, Brunberg et al., 2013 who reported differences in gene expression in the hypothalamus and prefrontal cortex among tail biters, receivers and neutral pigs suggested that pigs perform more pig-directed abnormal behavior due to selection for better production traits. Ursinus et al. (2014c) support that tail biters in enriched pens may be motivated by unsatisfied high nutrition demands while in barren pens (pens without enrichment material) this behavior could be associated with boredom. Brunberg et al. (2016) suggested a possible mechanism for tail biting behavior that includes gut microbiota, the immune system, hypothalamic-pituitary-adrenal (HPA)-axis reactivity, and the ability to cope with challenges. More specifically, insufficient ingredients in feed provoke a response from the stress-related HPA-axis and consequently the immune system, altering this way the individual's behavior. Preweaning behavior seems to correlate with tail biting behavior later in life (Ursi-

nus et al., 2014a).

On the behavioral basis of tail biting, studies focus on three possible phenotypes in pig level: the biter, the victim and the neutral. Molecular studies should also be performed to help the early diagnosis of the biter. Comparison in genes expressions of these three phenotypes could reveal new characteristics of the different phenotypes.

RISK FACTORS FOR PIG TAIL BITING

Most of the studies on risk factors focused on the use of environmental enrichment are experimental while studies focused on farm conditions, health status and feeding are based mainly on epidemiological data (Valros et al., 2016). Table 3 presents the main results of studies on main risk factors for pig's tail biting.

On a breed basis, Breuer et al., (2005) found tail biting to be heritable in Landrace breed but not in Large White breed. Moreover, above-mentioned authors concluded that in the Landrace population, tail-biting was unfavorably genetically correlated with leanness (lean tissue growth rate) and back fat thickness at 90 kg. A link between production traits (fat content) and both performing and receiving tail biting, as well as other pig-directed abnormal behaviors, was also confirmed by Brunberg et al. (2013) meaning that the genetic background has to be taken into account when dealing with tail biting (Bulens et al., 2018). Furthermore, (Sinisalo et al., 2012) indicated that Yorkshire breed is more susceptible to become victim than Landrace breed. Taylor et al. (2010) suggests it is better to look in strains or lines inside a breed for tail biting correlations while D 'Eath et al. (2014) support that the evidence for a breed predisposal to be a victim or a biter is quite weak.

The relationship between health and biting behavior is complex and thus difficult to be established in a cause and effect way (Munsterhjelm et al., 2017; Van Der Meer et al., 2017) and there is no clear proof of evidence until now (Munsterhjelm et al., 2019). Tail biting has been positively associated with respiratory diseases and greater mortality on farm (Moinard et al., 2003). Pleuritis and lung abscesses are correlated with severe tail biting but not enzootic pneumonia (EP) (Kritas and Morrison, 2007) although an association with EP-like lesions has been reported in an epidemiological study (Pandolfi et al., 2018). Moreover, pigs from batches with higher tail lesions had high

prevalence of pleurisy, pneumonia and pleuropneumonia supporting the association between poor health and poor welfare on farm (Teixeira et al., 2016). On the contrary, van Staaveren et al., (2016) established this association only for severe pleurisy where lungs are attached to chest wall. A connection between infected tail lesions and respiratory organ inflammation has also been shown by (Munsterhjelm et al., 2013) who also suggested that tail biting behavior can be induced by a combination of individual factors and disease.

Additionally, it has been shown that tail biting victims have higher concentration of Acute phase proteins (APPs) triggering this way an acute phase response and the creation of abscesses (Heinonen et al., 2010) while Ursinus et al. (2014b), who found lower blood serotonin in tail biters, suggest that fluctuations

of serotonergic measures and tail biting behavior over rearing phases should be taking into account before characterizing individual pigs. In addition, Li et al. (2017) observed higher concentrations of total serum protein and IgG in victim pigs 5 days after tail biting outbreak suggesting inflammation while the lower IgG and serum proteins concentrations of tail biters could indicate a possible compromised immune function due to chronic stress. In addition, it is suggested that living in a tail biting pen affects some physiological parameters of pigs (Palander et al., 2013). Furthermore, Munsterhjelm et al. (2019) suggested that pens with sick pigs are more in danger to show tail biting after the sick pigs have recovered than in the acute phase while there is an indication of correlation of specific cytokines with behaviors characterizing tail biters (Munsterhjelm et al., 2017).

Table 3. Studies on main risk factors for pig's tail biting and their results.

Risk Factor	Materials	Age	D/I	Sex	Results	Reference
ENRICHMENT	Easyfix® floor toy for weaners and a Piglyx® lick block for finishers- Floor toy-Wood post-Hanging wood-Loose material in long rack-Fabric-Hanging chew toy-Loose material in container	W-G-F	I	Mx	The types of enrichment provided over time doesn't significantly reduce tail damage or tail directed behavior (TDB). Pigs have preferences for certain enrichment materials, it is important to consider enrichment characteristics, presentation, location, and maintenance when providing enrichment.	Chou et al (2019a)
	Straw (7 g/pig/day) Bite-Rite Rope	W	I	Mxc	Providing additional straw on the floor during a tail biting outbreak reduced the risk of an escalation in tail damage more effectively than providing a Bite-Rite, Bite-Rite cannot keep pigs interested in very long and it should be combined or rotated with other materials to successfully stop tail biting.	Lahrman et al (2019)
	Straw (7 g/pig/day) Haylage (22 g/pig/day) Rope	W	I	Mxc	Tail biting outbreaks can in many cases be prevented by giving the pigs access to extra enrichment material, when the first minor tail damage is noticed Not every case of tail biting behavior escalate into a tail biting outbreak	Lahrman et al (2018)

	Hanging toy Straw blocks Hiding wall Pigs predisposed to better carcass traits vs. pigs predisposed to better growth	G-F	I	Mxc	Pigs with intact tails have higher daily weight gains in enriched pens when hiding walls and straw dispensers are provided. Genetic background should be considered when investigating the cause of tail-biting outbreaks and when evaluating the effect of enrichment on tail biting.	Bulens et al. (2018)
	Wood	F	***	F	A wooden stick close to the feeder is associated with more exploratory behavior in growing female pigs compared with a similar stick placed opposite to the feeder, Novelty of enrichment material plays a significant role.	Dalmau et al. (2018)
	Tail docking at ½ Straw (150gr/pig/day) Stocking density (S.D.) 0,73m ² /pig -1,21 m ² /pig	G-F	D/I	Mxc	Incidences of first tail damage mainly in week 1 and in the first half of the finisher period. Tail docking is more successful preventive measure than provision of straw. Combination of straw provision and lower stocking density is as preventive as tail docking	Larsen et al. (2017)
	Jute sack	W-G	I	F	The provision of a jute sack can reduce tail-biting behavior of gilts directed to pen mates by up to half as much compared to gilts kept in barren pens. For tail biting boredom rather than a metabolic motivation plays the largest role in pigs kept in barren pens. Displaying high levels of tail-biting behavior is generally related to displaying higher levels of all kinds of biting behavior, a relatively high (phenotypic and possibly genotypic) growth, and originating from a large litter.	Ursinus et al. (2014c)
	Straw	G	D/I	Mc/F	Straw is an important tool in both increasing explorative behavior and preventing biting and lesions, particularly in the early stage of fattening. Tail biting represents an issue for heavy pigs as for standard rearing weights.	Scollo et al. (2013)
HEALTH		F	I	Mc/F	Tail biting induces inflammation in the tail end leading to a strong systemic acute phase response and formation of abscesses in the carcass	Heinonen et al. (2010)

		G	***	F	Recovered animals from sickness may have an increased propensity to become tail biters. Increased attention towards a sick animal by penmates, may increase the risk for the sick individual to become a victim of tail biting. The pen-level risk for tail biting may be higher after a bout of illness in the group than during the acute stage.	Munsterheim et al. (2019)
		P-W-G-F	I	Mxc	Within specific phases of life, tail biters and to a lesser extent also victims have lower levels of blood serotonin compared to non-performers/receivers. Tail biters also seems to have higher blood platelet uptake velocities.	Ursinus et al. (2014b)
		G-F	I	Mc/F	No associations between health status and tail-biting activity. Being a victim of tail biting is associated with severe inflammatory lesions in the respiratory organs. Deep infections may exist under healthy skin in bitten tails	Munsterheim et al. (2013)
		G-F	I	Mc/F	Free access feeding with restricted feeding space, compared with feeding twice a day with unrestricted feeding space was associated with an overall reduction in EAA levels in blood and deepened crypts in the jejunum. The observed differences differ according to the behavioral role of pigs (Biter, victim, neutral) in a tail-biting pen during the outbreak.	Palander et al. (2013)
GENDER		W	I	Mu/F Mx	Female piglets are more likely to tail bite than male piglets	Zonderland et al. (2010)
		F	D	Mxc	Barrows have 2.6-fold higher odds to be bitten compared to gilts. Victim pigs are smaller in size.	Kritas & Morrison (2004)
GROUP HOUSING		W-G	I	Mxc	No clear results of group housing before weaning and a prolongation of the suckling period from four to five weeks on tail biting.	Naya et al. (2019a)
STOCKING DENSITY	Solid floor area:1/3-2/3 S.D.:0.7m ² /p-0.89m ² /p Group Size:15p-12p Straw: Floor-Rack	G-F	I	Mxc	Increased space allowance + increased area of solid flooring+ straw allocated onto the floor + reduced group size= lower tail damage +tendency for more tail-directed behavior.	Brandt et al. (2019)
	Solid floor area:1/3-2/3 S.D.:0.77m ² /p-1.00m ² /p Group Size:15p-12p Straw: Floor-Rack	G-F	I	Mxc	No difference in tail directed behavior in pens with fewer pigs, a higher space allowance per pig and a larger area of solid floor.	Klaborg et al. (2019)

	W	D/I	***	Higher prevalence of tail lesions in undocked weaner pigs Higher prevalence of tail lesions when <7.5 litters are mixed at weaning In docked pigs lower prevalence of tail lesions in pens with lower stocking density	Grumpel et al. (2018)
MIXING	W	I	Mx	No direct effect of mixing animals at weaning on tail-biting at rearing.	Veit et al. (2017)
TAIL DOCKING	W	D/I	Mxc	Tail docking may be more effective because pigs are able to perform more damaging bites to intact tails because they are longer, so pigs are able to hold them across the mouth and crush them with the premolar teeth, which is not possible for the shorter docked tails.	Paoli et al. (2016)
	W-G-F	D/I	Mc/F	In a rearing cycle prolonged up to 40 weeks of age, the presence of intact tails causes higher levels of tail lesions but not a generalized welfare endangerment	Martino et al. (2015)
	W-G-F	D/I	Mxc	Tail lesions are more prevalent among 30 to 60 kg pigs than in the late finishing period (60 to 90 kg). Recordings from abattoir routine meat inspection when used to evaluate the level of tail biting in a herd, highly underestimates the number of bitten pigs.	Lahrman et al. (2017)
	G-F	D/I	Mxc	Pigs with short docking length manipulates pen mates' tail less compared with pigs with longest docked tails Pigs with short docking length have a lower risk of a tail biting outbreak compared with undocked pigs .	Thodberg et al. (2018)
GENETICS	W-G-F	I	Mu/F	Landrace tends to show a higher prevalence of tail-biting than Large White under the same farm conditions. The heritability of tail biting in Landrace is correlated to two key performance parameters, lean tissue growth rate and back fat thickness.	Breuer et al. (2005)
	G-F	I	Mx	Selection on production traits, especially those related to meat/fat ratios, has contributed to the development of pigs that are more vulnerable to become performers and victims of tail biting behaviors. The development of abnormal behaviors may be influenced by the dopaminergic system.	Brunberg et. al. (2013a)

	G-F	I	Mx	Genes differently expressed in neutral pigs are associated with the cause, rather than the consequence, of them not performing and receiving tail biting. Given similar physical environmental conditions, whether an individual becomes a tail biter, has its tail bitten or remains neutral to a tail biting outbreak, is related to how much its behavior is targeted towards pen mates. Neutral pigs are less pig-directed in their behavior	Brunberg et. al. (2013b)
FEED	P-W- G-F	I	Mx	No distinct effect of a higher content of fibre in the piglet diet on tail biting in growing pigs.	Naya et al. (2019b)
	P-W- G-F	I	Mx	Provision of raw material through life reduces occurrence of tail biting but doesn't prevent it.	Veit et al. (2016)

Production Stage: P=Piglets (0-4weeks), W=Weaners (4-9 weeks), G=Growers (10-17 weeks), F=Finishers(17-Abattoir)
I=Intact tail (Not docked), D=Docked tail (at first week of life)

Sex: Mx (Mixed group of uncastrated males and females) Mxc (Mixed group of castrated males and females) Mc/
F(Single sex group MaleCastrated/Female), Mu/F(Single sex group MaleUncastrated/Female)

*** Not Reported

Tail biting is increasing with time starting mainly at two weeks after weaning (Veit et al., 2017) independent of the weaning age (Naya et al., 2019b), although Ursinus et al. (2014a) reported tail damage even at preweaning phase. Severe tail lesions are recorded in pigs aged 10 weeks (Carroll et al., 2018) or more (van Staaveren et al., 2018; Scollo et al., 2016) probably as damage is accumulated over time (Haigh et al., 2019; Chou et al., 2019a). On the other side, some authors report a decrease in tail lesions during the fattening cycle (Vermeer et al., 2017) even in pigs with a prolonged fattening cycle reared in intensive production (Scollo et al., 2013).

Gender is considered to be a risk factor for tail damage as castrated male pigs tend to have more tail biting lesions than gilts (Valros et al., 2004; Kritas and Morrison, 2004, 2007) and these lesions are more likely to be severe in mixed groups (Keeling et al., 2012). Similar findings regarding frequency and severity of tail lesions apply also to entire male pigs (Harley et al., 2014; van Staaveren et al., 2016; Calderon Diaz et al., 2017). In single sex groups, a higher frequency of biting behavior in females compared to males has been documented in weaners (Zonderland et al., 2010) and later in finishers (Haigh et al., 2019) while the same goes for castrated males and females

(Kritas and Morrisson, 2004; Li et al., 2017).

Climate in the barn (temperature, gas, dust) keeping constantly out of the comfort zone could act as stressor that create discomfort and chronic stress to the animal leading to tail biting outbreaks (Taylor et al., 2010; Schröder-Petersen and Simonsen, 2001). The same applies for great fluctuations in temperature during the day at certain times of the year or intense draughts as the capacity of the ventilation/heating/cooling systems is not limitless (D'Eath et al., 2014). In an epidemiological study in intensive pig production from weaning to 170 Kg live weight (Scollo et al., 2016) found poor air quality (as perceived by the author) to be a significant factor for tail biting.

Slatted floors are considered to be an important risk factor for tail biting outbreaks both in weaning and fattening phase of production (Schröder-Petersen and Simonsen, 2001; Moinard et al., 2003; Van De Weerd et al., 2005). An increase in internal biosecurity has been positively associated with a reduction in tail biting (Pandolfi et al., 2018).

Up to some extent bigger herd size farms have lower risk of moderate tail lesions (van Staaveren et al., 2016) while tail biting sequelae (osteomyelitis and hind abscesses) have also low occurrence (Fertner

et al., 2017). On the contrary, Harley et al. (2012b) suggested that risk of injury and illness in animals in large herds is bigger than small herds based on an association of batch size and carcass condemnations at slaughterhouse while Scollo et al. (2017) are indicating that middle size farms seem to be more in danger of tail biting as big farms have good level of automation and small ones good stockman per pig analogy.

High stocking density is associated with the risk of tail biting as it interrupts normal social interactions (Moinard et al., 2003). Surprisingly, stocking density and group size as risk factors are not well documented in experimental studies (D'Eath et al., 2014) and available studies are not conclusive for the effect of group size in negative social behavior (Averós et al., 2010; Sutherland and Tucker, 2011). Tail lesions have been associated with high stocking density (Grümpel et al., 2018) and pens with more than 30 pigs (Pandolfi et al., 2018). However, Klaaborg et al. (2019) found no effect of bigger space allowance on pen mate directed behavior and Meyer-Hamme et al., (2016) didn't consider group size as a risk factor in tail docked pigs. We have to consider that in most studies is difficult to differentiate space allowance and group size as they are confounded (Klaaborg et al., 2019) while there are interactions with other factors. According to Averos et al. (2010) the positive effect of increased space allowance is conditioned to the provision of enrichment material.

Although EFSA (2007) considers mixing of piglets to be a risk factor, Veit et al. (2017) indicated that there is no direct effect between mixing and tail biting at rearing period while Grümpel et al. (2018) found more tail lesions in farms that mixed less than 7.5 liters. In addition, Li et al. (2018) suggested that pigs from same litter could be predisposed to tail biting as they are less socially connected.

Enrichment material in pig's pen play a vital role in controlling tail biting (Schröder-Petersen and Simonsen, 2001) although they cannot eliminate it (Ursinus et al., 2014c) as the genetic predisposition to tail bite remains (Camerlink et al., 2014). This material has to be economic, labor not intensive and durable in order for farmers to adopt it (van de Weerd and Day., 2009; Chou et al., 2018). According to Commission recommendation EU 2016/336, the optimum enrichment material is described as: edible, chewable, investivable and manipulable (EU Commission, 2016).

Straw as a bedding material allows pigs to express

their species-specific behavior (van de Weerd and Day., 2009) reduces tail biting prevalence (van de Weerd et al., 2005; Wallgren et al., 2019b) and keeps pig more occupied than plastic objects (Scott et al., 2009). The most serious problem about enrichment material given as a bedding is the possible blockage of the slurry system (Zonderland et al., 2008; D'Eath et al., 2014; Lahrmann et al., 2018b) but also problems with availability (Wallgren et al., 2019b) mycotoxins ingestion (Nordkvist and Häggblom, 2014) and biosecurity in times of African Swine Fever have to be considered (Wallgren et al., 2019c). Straw effectiveness as environmental enrichment is decreased when given in other ways (Zonderland et al., 2008) or forms (Haigh et al., 2019) and when provided through dispensers doesn't totally prevent tail biting (Holling et al., 2017) but still remains better than toys (Bulens et al., 2018).

Although chains are considered of marginal interest and must be accompanied by an optimal or suboptimal enrichment material (Commission Recommendation (EU) 2016/336) still are the main enrichment provided (Bracke et al., 2013; Valros et al., 2016), especially in countries that don't use straw (Bracke and Koene, 2019). The value of chains as enrichment material is the lowest comparing to hard wood or plastic (Boyle et al., 2019) or freshly cut wood (Telkänranta et al., 2014) and doesn't seem to have an effect on tail biting prevalence (Buijs and Muns, 2019). However, it could benefit from a new design of branched ends (Bracke, 2017). Dry wood keeps the interest of pigs more than plastic "toys" (Beaudoin et al., 2019) although type of wood seems to have no differences in efficacy (Chou et al., 2018).

Object manipulation is affected by space, other enrichment materials offered to pigs, (Larsen et al., 2019; van de Weerd et al., 2009) and the position of it (Scott et al., 2009; Larsen et al., 2019; Dalmau et al., 2019). Object manipulation diminishes by time as pigs become habituated to them and as aging changes their choices (Trickett et al., 2009; van de Weerd et al., 2009; Dalmau et al., 2019) while the variation of enrichment materials does not seem to have a significant effect in reducing tail biting severity (Chou et al., 2019a). Cleanliness plays a role (Averos et al., 2010) but everyday cleaning or replacement doesn't seem to have an effect on attractiveness for short periods (Beaudoin et al., 2019).

Although a lot of research is ongoing in enrichment material and its efficacy on preventing tail bit-

ing there is no consensus between experts on what is acceptable enrichment (Scott et al., 2009; Bracke and Koene, 2019; Briyne et al., 2018) nor does legislation helps competent authorities assess the degree that this need is fulfilled (Weerd et al., 2009; Wallgren et al., 2019c). Except materials used as beddings, only a combination of other enrichment could possibly comply with EU criteria (Buis and Muns, 2019) whereas the kind of environmental enrichment a farmer uses as preventive measure, could indicate the efficiency of management (Boyle et al., 2019)

Variations and delays in feeding time pose a risk for tail-biting (Scollo et al., 2017). Also feed type plays a role as there is higher prevalence of tail biting when pigs are fed liquid (Pandolfi et al., 2017) or pellets (Hunter et al., 2001) than meal. Moreover, artificially fed piglets show more tail lesions than piglets that are fed by a sow (Schmitt et al., 2019) while restricted feeding space is suggested to be associated with a reduction of amino acids in blood of victims and control pigs due to stressful environment or because they can't access as successfully as tail biters the feeder (Palander et al., 2013). The external factors that affect pig behavior have been widely investigated, however, the research is still in need of studies for identification of internal factors, including health and genetics, and their impact on pig behavior.

PREVENTION AND TREATMENT

It's been over 25 years since the first EU legislation (EU Council Directive, 91/630/EEC) prohibited tail docking on a routine basis (Nalon and De Briyne, 2019). However, even though a new directive came in force in 2008 (EU Council Directive, 2008/120/EC), this practice is still the most widely preventive measure against tail biting used by up to 95% of farms in Europe (EFSA, 2007; EU Commission, 2018). The Directive itself leaves enough place for misinterpretation by Competent Authorities in Member States (D'Eath et al., 2016). The high prevalence of tail docking indicates a serious and chronic problem of tail biting in pig farming (Harley et al., 2012b) as it is used to conceal other welfare problems (Zonderland et al., 2008; D'Eath et al., 2016).

The equipment used for tail docking in pigs includes teeth clippers, cutting pliers, scissors, a scalpel blade, gas or electrical cautery iron while the length of the remaining part of the tail varies among different countries (Sutherland and Tucker, 2011). Moreover, Thodberg et al. (2018) demonstrated that leaving a

very short tail lowers the risk of tail biting outbreak in comparison not only with undocked tails but also to tails with a longer remnant.

Pigs that are tail docked have lower incidence and severity of tail lesions compared to intact ones in weaner (Fu et al., 2018; Grümpel et al. 2018) and finisher phase of production (Di Martino et al., 2015; Li et al. 2017; Lahrmann et al. 2017). However, there is no clear explanation why tail docking reduces tail biting (Paoli et al., 2016; Valros, 2017; Grümpel et al., 2018). Simonsen et al. (1991) suggested that formation of neuromas in tail tip could lead to hypersensitivity or another explanation could be that the hairy intact tail remains more attractive to bite. However, there is the idea that the shorter the tail the less time will a pig be bitten (Harley et al., 2012b). Paoli et al. (2016) suggest that the longer the tail the more powerful the grasp of the tail by the biter as he demonstrates that pigs with intact tails don't show more tail directed behavior than the docked ones. This finding is inconsistent with the results of Thodberg et al. (2018) who support that pigs with short docked tails manipulate other pigs' tails less in comparisons with undocked, while tail docking doesn't seem to alter the social functions of finisher pigs.

Tail docking has an acute impact on the welfare of the pig due to pain demonstrated by histopathological studies (Simonsen et al., 1991) and by behavioral studies (Sutherland and Tucker, 2011). At the long term, in the site of amputation, there is possible neuroma development (Herskin et al., 2015) that still goes on even 16 weeks after (Sandercock et al., 2016) and is accompanied with significant changes in gene expression linked with possible chronic pain in the tail stump (Sandercock et al., 2019). It is generally accepted that tail docking reduces the incidents of tail biting (Kakanis et al., 2019; Bracke et al., 2013; Valros et al., 2016), but it cannot eliminate the problem (Li et al., 2017; Larsen 2018a) especially when environmental conditions remain the same (EFSA, 2007; Thodberg et al. 2018).

On the other hand, there are not so many studies to offer effective treatments of tail biting (Zonderland et al., 2008; Chou et al., 2019b) although straw provision is the most successful (Lahrmann et al., 2019). Allocating extra manipulable material early can prevent a tail biting outbreak (Zonderland et al., 2008; Lahrmann et al., 2018b). The biters/victim's ratio seems to play more important role to the success of a treatment than the method selected but no real dif-

ferences were found between removing the biter or the victim for an outbreak stop (Chou et al., 2019b) although Zonderland et al. (2011a) suggested is better to remove the biter than the victim. Experimental curative treatment of removing pigs (biters or victims) or adding enrichment material (straw or ropes) hasn't stopped 100% of tail biting (Zonderland et al., 2008; Chou et al., 2019b).

Tail docking is still perceived by many farmers to be the only way to deal with the problem even though it is not permitted by legislation. Research should be driven to identify successful prevention and treatment schemes. Moreover, as strategies are implemented on a farm basis approach, those schemes should be diversified between different countries and farming system to be effectively adopted by farmers.

PREDICTION OF PIG TAIL BITING

Today the EU regulation 2008/120 EC requires that staff do inspect the pigs at least once a day. Tail biting behavior is difficult to follow due to the sporadic nature of outbreaks (Statham et al., 2009), the diurnal pattern of behaviors (Domun et al., 2019; Chou et al., 2019b) and small changes in early predictors that are difficult to be detected by caretakers daily (Wedin et al., 2018). The ability to automatically detect and track individual pigs without the need for human observation could help in early detection of potential welfare problems (Zhang et al., 2019) and could help develop on farm strategies to reduce tail biting outbreaks (Zonderland et al., 2011b). Precision livestock farming techniques, besides the disadvantages of cost and technical challenges, gives the opportunity to farmers to go from group level to individual level welfare (Benjamin et al., 2019).

Back to 1969, van Putten et al. concluded that tail is an indicator of unpleasant surroundings. Tail posture seems to be correlated with tail biting (Schröder-Petersen and Simonsen 2001). Statham et al. (2009) found evidence that before an outbreak occurs there are more pigs with tails tucked under. Zonderland et al. (2009) also found that piglets who had their tail between their legs had significantly higher possibility to have tail damage 2-3 days afterwards even though at that moment they didn't have any, while the number of pigs with lowered tails is increasing in pens towards day 0 of the outbreak (Lahrman et al., 2018a; Wedin et al., 2018). D'Eath et al. (2018) using 3D cameras also found lowered tail posture in pen level as far as 2 weeks prior to a tail biting outbreak and interestingly

the same effect even 2 weeks post outbreak although they comment that each pen has its own baseline of low posture tails. At pig level, a hanging tail is correlated positively with having a lesion (Larsen et al., 2018b; D'Eath et al., 2018; Wallgren et al., 2019a) although we must take into account tail posture in relation to different activities and emotions expressed by pigs (Wallgren et al., 2019a) or the diurnal pattern of pig behavior (Larsen et al., 2019) in order to use it as an early predictor.

Except tail posture, a higher level of pen activity days prior to a tail biting outbreak (Statham et al., 2009; Zonderland et al., 2011b; Ursinus et al., 2014a; Larsen et al., 2019) object manipulation (Ursinus et al., 2014a; Larsen et al., 2019) as well as a lower feeding frequency at pen level (Wallenbeck and Keeling, 2013) could be used as early behavioral indicators of tail biting outbreaks. There are indications that these differences in activity could be attributed to different phenotypes of pigs categorized by their tail in mouth behavior as performers, receivers or neutral but also that a pen level threshold exists (Munsterhjelm et al., 2016).

The advances in technology have helped to better understand the behavioral patterns of pigs. Precision livestock farming studies are already being performed for a number of production characteristics and behaviors, including tail biting. This kind of studies should be focused on early diagnosis of tail biting outbreaks and interestingly on a pig level of recognizing the possible biter.

POLICY MEASURES TO ADDRESS PIG TAIL BITING

EU as a major pig exporter has set high standards of welfare driving the trends in pig welfare worldwide while they do not seem to have a significant effect on competitiveness (Nalon and Briyne, 2019). More research is needed in order to get away of amputation methods towards a sustainable pig production in welfare aspects (Larsen et al., 2018a). As welfare policy is mainly considered to be driven by views of the non-producers public, farmers' concerns should be taken into account (Spooner et al., 2014) even though it seems to differ across countries (Valros et al., 2016). This is especially important for choosing public policy measures that are more efficient in improving animal welfare (Niemi et al., 2012). Additionally, the differ-

ent perceptions between farmers and experts (Valros and Barber., 2019) indicate a problem of communication between research and industry (Camerlink and Turner, 2016) that should be considered when designing communication strategies for better implementation of legislation (Kakanis et al., 2019).

CONCLUSION

Tail biting remains one of the major welfare problems for pig industry with direct and indirect economic losses while farmers end up to tail dock on a routine basis as the main preventive measure throughout Europe.

Although a lot of research is undertaken in the last decade, this is mainly focused on some risk factors while some like health status and genetics need further investigation. This could be facilitated through research on the motivational basis of tail biting on a pig level and possible predisposing factors. The chronic consequences of tail amputation and the real functions of pig tails should be clearly defined

to the community. There seems to be a potential on early prognosis using Precision Livestock Farming techniques (by means of purpose-built algorithms to evaluate in real time data from sensors in the stable) and more studies are needed on how to recognize an upcoming tail biting outbreak and how to prevent or control it.

Moreover, studies in recent years made prominent the different perspective of farmers and scientists and the possible implications in developing information strategies. The prevalence of the problem could be pointed out to the industry by the development of one concrete unbiased system for recording tail biting lesions in abattoirs that is lacking nowadays while data on economic impact of the behavior is largely missing in literature. Thus academia, industry and policy makers could all benefit by a close collaboration towards raising pigs with intact tails.

CONFLICT OF INTEREST

None declared by the authors.

REFERENCES

- Alban, L., Petersen, J. V., Busch, M.E., 2015. A comparison of lesions found during meat inspection of finishing pigs raised under organic/free-range conditions and conventional indoor conditions 85-88.
- Averós, X., Brossard, L., Dourmad, J.Y., de Greef, K.H., Edge, H.L., Edwards, S.A., Meunier-Salaün, M.C., 2010. A meta-analysis of the combined effect of housing and environmental enrichment characteristics on the behaviour and performance of pigs. *Applied Animal Behaviour Science* 127, 73-85.
- Becskei Z., Kakanis M., Janczak A., Sossidou E. 2018. CA 15134 "GROUPHOUSENET" Prevalence of tail biting behavior in Greek pig farms. *Proceedings of 25th International Conference Animal Protection and Welfare 2018*
- Becskei Zolt, 2017. Short-Term Scientific Mission (STSM) Report Cost Action CA15134 „Synergy for preventing damaging behaviour in group housed pigs and chicken (GroupHouseNet)" Available online: https://www.grouphousenet.eu/STSM_Becskei%20Zsolt.pdf [accessed 30/07/2020]
- Beaudoin, J.M., Bergeron, R., Devillers, N., Laforest, J.P., 2019. Growing pigs' interest in enrichment objects with different characteristics and cleanliness. *Animals* 9, 1-13.
- Benjamin, M., Yik, S., 2019. Precision livestock farming in swine welfare: A review for swine practitioners. *Animals* 9, 1-21.
- Boyle, L., 2019. Associations between tail directed behaviour, tail lesions and enrichment type in finisher pigs. *Book of Abstracts of the 70th Annual Meeting of the European Federation of Animal Science* pp 206
- Bracke, M.B.M., 2017. Chapter 6. Chains as proper enrichment material for intensively-farmed pigs? *Advances in Pig Welfare* 1-27.
- Bracke, M.B.M., De Lauwere, C.C., Wind, S.M.M., Zonerland, J.J., 2013. Attitudes of Dutch Pig Farmers Towards Tail Biting and Tail Docking. *Journal of Agricultural and Environmental Ethics* 26, 847-868.
- Bracke, M.B.M., Koene, P., 2019. Expert opinion on metal chains and other indestructible objects as proper enrichment for intensively-farmed pigs. *PLoS ONE* 14, 1-19.
- Breuer, K., Sutcliffe, M.E.M., Mercer, J.T., Rance, K.A., O'Connell, N.E., Sneddon, I.A., Edwards, S.A., 2005. Heritability of clinical tail-biting and its relation to performance traits. *Livestock Production Science* 93, 87-94.
- Brunberg, E., Jensen, P., Isaksson, A., Keeling, L.J., 2013. Brain gene expression differences are associated with abnormal tail biting behavior in pigs. *Genes, Brain and Behavior* 12, 275-281.
- Brunberg, E., Wallenbeck, A., Keeling, L.J., 2011. Tail biting in fattening pigs: Associations between frequency of tail biting and other abnormal behaviours. *Applied Animal Behaviour Science* 133, 18-25.
- Brunberg, E.I., Bas Rodenburg, T., Rydhmer, L., Kjaer, J.B., Jensen, P., Keeling, L.J., 2016. Omnivores going astray: A review and new synthesis of abnormal behavior in pigs and laying hens. *Frontiers in Veterinary Science* 3, 1-15.
- Buijs, S., Muns, R., 2019. A review of the effects of non-straw enrichment on tail biting in pigs. *Animals* 9.
- Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2018. Rearing finishing pigs with intact tails: Do they benefit from an enriched environment? *Journal of Veterinary Behavior: Clinical Applications and Research* 24, 1-8.
- Calderón Díaz, J.A., Boyle, L.A., Diana, A., Leonard, F.C., Moriarty, J.P., McElroy, M.C., McGettrick, S., Kelliher, D., García Manzanilla, E., 2017. Early life indicators predict mortality, illness, reduced welfare and carcass characteristics in finisher pigs. *Preventive Veterinary Medicine* 146, 94-102.
- Camerlink, I., Ursinus, W.W., Bijma, P., Kemp, B., Bolhuis, J.E., 2014. Indirect Genetic Effects for Growth Rate in Domestic Pigs Alter Aggressive and Manipulative Biting Behaviour. *Behavior Genetics* 45, 117-126.
- Camerlink, I. and Turner, S.P. (2016) Farmers' perception of aggression between growing pigs. *Applied Animal Behaviour Science*. ISSN 0309-1740
- Carroll, G.A., Boyle, L.A., Hanlon, A., Collins, L., Griffin, K., Friel, M., Armstrong, D., O'Connell, N.E., 2018. What can carcass-based assessments tell us about the lifetime welfare status of pigs? *Livestock Science* 214, 98-105.

- Carroll, G.A., Boyle, L.A., Teixeira, D.L., Van Staaveren, N., Hanlon, A., O'Connell, N.E., Staaveren, N. Van, Hanlon, A., Connell, N.E.O., Van Staaveren, N., Hanlon, A., O'Connell, N.E., 2015. Effects of scalding and dehairing of pig carcasses at abattoirs on the visibility of welfare-related lesions. *Animal* 10, 460-467.
- Chou, J.-Y.Y., Drique, C.M.V. V., Sandercock, D.A., D'Eath, R.B., O'Driscoll, K., Chou, J.-Y.Y., Drique, C.M.V. V., Sandercock, D.A., D'Eath, R.B., O'Driscoll, K., 2019a. Rearing undocked pigs on fully slatted floors using multiple types and variations of enrichment. *Animals* 9, 1-17.
- Chou, J.-Y.Y., O'Driscoll, K., D'Eath, R.B., Sandercock, D.A., Camerlink, I., 2019b. Multi-step tail biting outbreak intervention protocols for pigs housed on slatted floors. *Animals* 9, 582.
- Chou, J.Y., D'Eath, R.B., Sandercock, D.A., Waran, N., Haigh, A., O'Driscoll, K., 2018. Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system. *Livestock Science* 213, 19-27.
- Correia-Gomes, C., Eze, J.I., Borobia-Belsué, J., Tucker, A.W., Sparrow, D., Strachan, D., Gunn, G.J., 2017. Voluntary monitoring systems for pig health and welfare in the UK: Comparative analysis of prevalence and temporal patterns of selected non-respiratory post mortem conditions. *Preventive Veterinary Medicine* 146, 1-9.
- D'Eath, R.B., Arnott, G., Turner, S.P., Jensen, T., Lahrmann, H.P., Busch, M.E., Niemi, J.K., Lawrence, A.B., Sandøe, P., 2014. Injurious tail biting in pigs: How can it be controlled in existing systems without tail docking? *Animal* 8, 1479-1497.
- D'Eath, R.B., Jack, M., Futro, A., Talbot, D., Zhu, Q., Barclay, D., Baxter, E.M., Zhu, Q., Baxter, E.M., D'Eath, R.B., Jack, M., Talbot, D., 2018. Automatic early warning of tail biting in pigs: 3D cameras can detect lowered tail posture before an outbreak. *PLoS ONE* 13, 1-18.
- D'Eath, R.B., Niemi, J.K., Vosough Ahmadi, B., Rutherford, K.M.D., Ison, S.H., Turner, S.P., Anker, H.T., Jensen, T., Busch, M.E., Jensen, K.K., Lawrence, A.B., Sandøe, P., 2016. Why are most EU pigs tail docked? Economic and ethical analysis of four pig housing and management scenarios in the light of EU legislation and animal welfare outcomes. *Animal* 10, 687-699.
- Dalmau, A., Areal, B., Machado, S., Palliser, J., Velarde, A., 2019. Does the location of enrichment material affect behavior and dirtiness in growing female pigs? *Journal of Applied Animal Welfare Science* 22, 116-126.
- De Briyne, N., Berg, C., Blaha, T., Palzer, A., Temple, D., 2018. "Phasing out pig tail docking in the EU - present state, challenges and possibilities." *Porcine Health Management* 4, 1-9.
- Di Martino, G., Scollo, A., Gottardo, F., Stefani, A.L., Schiavon, E., Cappello, K., Marangon, S., Bonfanti, L., 2015. The effect of tail docking on the welfare of pigs housed under challenging conditions. *Livestock Science* 173, 78-86.
- Domun, Y., Pedersen, L.J., White, D., Adeyemi, O., Norton, T., 2019. Learning patterns from time-series data to discriminate predictions of tail-biting, fouling and diarrhoea in pigs. *Computers and Electronics in Agriculture* 163, 104878.
- Edwards, S.A., 2006. Tail biting in pigs: Understanding the intractable problem. *Veterinary Journal* 171, 198-199.
- European Union. Council of the European Union, 2008. Council Directive 2008/120/EC laying down minimum standards for the protection of pigs. *Official Journal of the European Union* L47/5-13.
- European Union. Council Directive 91/630/EEC of 19 November 1991 laying down minimum standards for the protection of pigs. *Off. J. Eur. Union* 1991,50, 33-38
- European Union. Commission Recommendation (EU) 2016/336 on the application of Council Directive 2008/120/EC laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. *Off. J. Eur. Union* 2016, L62, 20.
- European Union. Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs (Codified version). *Off. J. Eur. Union* 2009, L47, 5-13. 17.
- European Union. Communication from the commission to the European Parliament, the Council and the European Economic and Social Committee on the European Union Strategy for the Protection and Welfare of Animals 2012-2015 COM(2012) 6 final
- European Food Safety Authority EFSA. 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 J.* 2007, 5,611.
- European Commission, Directorate Health and Food Audits and Analysis. Audit Reports. Available online: https://ec.europa.eu/food/audits-analysis/audit_reports/index.cfm [accessed 30/07/2020]
- Fertner, M., Denwood, M., Birkegård, A.C., Stege, H., Boklund, A., 2017. Associations between antibacterial treatment and the prevalence of tail-biting-related sequelae in Danish finishers at slaughter. *Frontiers in Veterinary Science* 4, 1-8.
- Fu, L., Zhou, B., Li, H., Schinckel, A.P., Liang, T., Chu, Q., Li, Y., Xu, F., 2018. Teeth clipping, tail docking and toy enrichment affect physiological indicators, behaviour and lesions of weaned pigs after re-location and mixing. *Livestock Science* 212, 137-142.
- Grümpel, A., Krieter, J., Veit, C., Dippel, S., 2018. Factors influencing the risk for tail lesions in weaner pigs (*Sus scrofa*). *Livestock Science* 216, 219-226.
- Haigh, A., Yun-Chou, J., O'Driscoll, K., 2019. An investigation into the effectiveness of compressed straw blocks in reducing abnormal behaviour in growing pigs. *Animal* 1-10.
- Harley, S., Boyle, L.A., O'Connell, N.E., More, S.J., Teixeira, D.L., Hanlon, A., 2014. Docking the value of pigmeat? Prevalence and financial implications of welfare lesions in Irish slaughter pigs. *Animal Welfare* 23, 275-285.
- Harley, Sarah, More, S., Boyle, L., O'Connell, N., Hanlon, A., 2012a. Good animal welfare makes economic sense: Potential of pig abattoir meat inspection as a welfare surveillance tool. *Irish Veterinary Journal* 65, 1.
- Harley, S., More, S.J., O'Connell, N.E., Hanlon, A., Teixeira, D., Boyle, L., 2012b. Evaluating the prevalence of tail biting and carcass condemnations in slaughter pigs in the Republic and Northern Ireland, and the potential of abattoir meat inspection as a welfare surveillance tool. *Veterinary Record* 171, 621.
- Heinonen, M., Orro, T., Kokkonen, T., Munsterhjelm, C., Peltoniemi, O., Valros, A., 2010. Tail biting induces a strong acute phase response and tail-end inflammation in finishing pigs. *Veterinary Journal* 184, 303-307.
- Herskin, M.S., Thodberg, K., Jensen, H.E., 2015. Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. *Animal* 9, 677-681.
- Holling, C., Beilage, E.G., Vidondo, B., Nathues, C., 2017. Provision of straw by a foraging tower - Effect on tail biting in weaners and fattening pigs. *Porcine Health Management* 3, 1-14.
- Hunter, E.J., Jones, T.A., Guise, H.J., Penny, R.H.C., Hoste, S., 2001. The Relationship between Tail Biting in Pigs, Docking Procedure and Other Management Practices. *Veterinary Journal* 161, 72-79
- Kakanis M., Marinou K., Doudounakis S., Sossidou E., 2019. Greek farmers' attitudes regarding tail biting and tail docking. *Book of Abstracts of the 70th Annual Meeting of the European Federation of Animal Science* p.p. 203
- Keeling, L.J., Wallenbeck, A., Larsen, A., Holmgren, N., 2012. Scoring tail damage in pigs: An evaluation based on recordings at Swedish slaughterhouses. *Acta Veterinaria Scandinavica* 138, 1.
- Klaaborg, J., Kristensen, A.R., Brandt, P., 2019. The effect of pen environment on pen-mate directed behaviour prior to feeding in finisher pigs with intact tails. *Livestock Science* 219, 35-39.
- Kongsted, H., Sørensen, J.T., 2017. Lesions found at routine meat inspection on finishing pigs are associated with production system. *Veterinary Journal* 223, 21-26.
- Kritas, S.K., Morrison, R.B., 2007. Relationships between tail biting in pigs and disease lesions and condemnations at slaughter. *Veterinary Record* 160, 149-152.
- Kritas, S.K., Morrison, R.B., 2004. An observational study on tail biting in commercial grower-finisher barns. *Journal of Swine Health and Production* 12, 17-22.
- Lahrmann, H.P., Busch, M.E., D'Eath, R.B., Forkman, B., Hansen, C.F., 2017. More tail lesions among undocked than tail docked pigs in a conventional herd. *Animal* 11, 1825-1831.
- Lahrmann, H.P., Fastrup, J.F., Hansen, C.F., D'Eath, R.B., Nielsen, J.P., Forkman, B., 2019. The effect of straw, rope, and bite-rite treatment in weaner pens with a tail biting outbreak. *Animals* 9, 1-15.

- Lahrman, H.P., Hansen, C.F., D'Eath, R., Busch, M.E., Forkman, B., 2018a. Tail posture predicts tail biting outbreaks at pen level in weaner pigs. *Applied Animal Behaviour Science* 200, 29-35.
- Lahrman, H.P., Hansen, C.F., D'Eath, R.B., Busch, M.E., Nielsen, J.P., Forkman, B., 2018b. Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. *Livestock Science* 214, 272-277.
- Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2019. Changes in activity and object manipulation before tail damage in finisher pigs as an early detector of tail biting. *Animal* 13, 1037-1044.
- Larsen, Mona Lilian Vestbjerg, Andersen, H.M.L., Pedersen, L.J., 2018b. Tail posture as a detector of tail damage and an early detector of tail biting in finishing pigs. *Applied Animal Behaviour Science* 209, 30-35.
- Larsen, M. L.V., Andersen, H.M.L., Pedersen, L.J., 2018a. Which is the most preventive measure against tail damage in finisher pigs: Tail docking, straw provision or lowered stocking density? *Animal* 12, 1260-1267.
- Li, Y., Zhang, H., Johnston, L.J., Martin, W., 2018. Understanding tail-biting in pigs through social network analysis. *Animals* 8, 1-13.
- Li, Y.Z., Zhang, H.F., Johnston, L.J., Martin, W., Peterson, J.D., Coetzee, J.F., 2017. Effects of tail docking and tail biting on performance and welfare of growing-finishing pigs in a confinement housing system. *Journal of Animal Science* 95, 4835-4845.
- Marques, B.M.F.P.P., Bernardi, M.L., Coelho, C.F., Almeida, M., Moraes, O.E., Mores, T.J., Borowski, S.M., Barcellos, D.E.S.N., 2012. Influence of tail biting on weight gain, lesions and condemnations at slaughter of finishing pigs. *Pesquisa Veterinaria Brasileira* 32, 967-974.
- Meyer-Hamme, S.E.K., Lambertz, C., Gauly, M., 2016. Does group size have an impact on welfare indicators in fattening pigs? *Animal* 10, 142-149.
- Moinard, C., Mendl, M., Nicol, C.J., Green, L.E., 2003. A case control study of on-farm risk factors for tail biting in pigs. *Applied Animal Behaviour Science* 81, 333-355.
- Munsterhjelm, C., Heinonen, M., Valros, A., 2016. Can tail-in-mouth behaviour in weaned piglets be predicted by behaviour and performance? *Applied Animal Behaviour Science* 184, 16-24.
- Munsterhjelm, C., Heinonen, M., Valros, A., 2015. Effects of clinical lameness and tail biting lesions on voluntary feed intake in growing pigs. *Livestock Science* 181, 210-219.
- Munsterhjelm, C., Nordgreen, J., Aae, F., Heinonen, M., Olstad, K., Aasmundstad, T., Janczak, A.M., Valros, A., 2017. To be blamed or pitied? The effect of illness on social behavior, cytokine levels and feed intake in undocked boars. *Physiology and Behavior* 179, 298-307.
- Munsterhjelm, C., Nordgreen, J., Aae, F., Heinonen, M., Valros, A., Janczak, A.M., 2019. Sick and grumpy: Changes in social behaviour after a controlled immune stimulation in group-housed gilts. *Physiology and Behavior* 198, 76-83.
- Munsterhjelm, C., Simola, O., Keeling, L., Valros, A., Heinonen, M., 2013. Health parameters in tail biters and bitten pigs in a case-control study. *Animal* 7, 814-821.
- Nalon, E., De Briyne, N., 2019. Efforts to ban the routine tail docking of pigs and to give pigs enrichment materials via EU law: Where do we stand a quarter of a century on? *Animals* 9, Naya, A., Gertz, M., Hasler, M., Große Beilage, E., Krieter, J., 2019a. Does a higher content of fibre in the piglet diet have an influence on tail biting in growing pigs? *Livestock Science* 223, 133-137.
- Naya, A., Traulsen, I., Gertz, M., Hasler, M., Burfeind, O., große Beilage, E., Krieter, J., 2019b. Is tail biting in growing pigs reduced by a prolonged suckling period? *Applied Animal Behaviour Science* 211, 41-46.
- Niemi, J.K., Sinisalo, A., Valros, A., Heinonen, M., 2012. New challenges for EU agricultural sector and rural areas. Which role for public policy? Market and policy-oriented incentives to provide animal welfare: The case of tail biting. 126th EAAE Seminar 1-13.
- Nordkvist E. and Häggblom P., 2014. Fusarium mycotoxin contamination of cereals and bedding straw at Swedish pig farms. *Animal Feed Science and Technology* 198, 231-237.
- Palander, P.A., Heinonen, M., Simpura, I., Edwards, S.A., Valros, A.E., 2013. Jejunal morphology and blood metabolites in tail biting, victim and control pigs. *Animal* 7, 1523-1531.
- Pandolfi, F., Edwards, S.A., Maes, D., Kyriazakis, I., 2018. Connecting different data sources to assess the interconnections between biosecurity, health, welfare, and performance in commercial pig farms in Great Britain. *Frontiers in Veterinary Science* 5, 1-13.
- Pandolfi, F., Kyriazakis, I., Stoddart, K., Wainwright, N., Edwards, S.A., 2017. The "Real Welfare" scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK. *Preventive Veterinary Medicine* 146, 34-43.
- Paoli, M. A., Lahrman, H. P., Jensen, T. and D' Eath, R. B. (2016) Behavioural differences between weaner pigs with intact and Copyright © 2016 Universities Federation for Animal Welfare. This manuscript version is made available after the 287-296.
- Sandercock, D.A., Barnett, M.W., Coe, J.E., Downing, A.C., Nirmal, A.J., Di Giminiani, P., Edwards, S.A., Freeman, T.C., 2019. Transcriptomics Analysis of Porcine Caudal Dorsal Root Ganglia in Tail Amputated Pigs Shows Long-Term Effects on Many Pain-Associated Genes. *Frontiers in Veterinary Science* 6.
- Sandercock, D.A., Smith, S.H., Di Giminiani, P., Edwards, S.A., 2016. Histopathological Characterization of Tail Injury and Traumatic Neuroma Development after Tail Docking in Piglets. *Journal of Comparative Pathology* 155, 40-49.
- Schröder-Petersen, D.L., Simonsen, H.B., 2001. Tail biting in pigs. *The Veterinary Journal* 162, 196-210.
- Schmitt, O., O'Driscoll, K., Boyle, L.A., Baxter, E.M., 2019. Artificial rearing affects piglets pre-weaning behaviour, welfare and growth performance. *Applied Animal Behaviour Science* 210, 16-25.
- Scollo, A., Contiero, B., Gottardo, F., 2016. Frequency of tail lesions and risk factors for tail biting in heavy pig production from weaning to 170 kg live weight. *Veterinary Journal* 207, 92-98.
- Scollo, A., Di Martino, G., Bonfanti, L., Stefani, A.L., Schiavon, E., Marangon, S., Gottardo, F., 2013. Tail docking and the rearing of heavy pigs: The role played by gender and the presence of straw in the control of tail biting. Blood parameters, behaviour and skin lesions. *Research in Veterinary Science* 95, 825-830.
- Scollo, A., Gottardo, F., Contiero, B., Edwards, S.A., 2017. A cross-sectional study for predicting tail biting risk in pig farms using classification and regression tree analysis. *Preventive Veterinary Medicine* 146, 114-120.
- Scott, K., Taylor, L., Gill, B.P., Edwards, S.A., 2009. Influence of different types of environmental enrichment on the behaviour of finishing pigs in two different housing systems. 3. Hanging toy versus rootable toy of the same material. *Applied Animal Behaviour Science* 116, 186-190.
- Simonsen, H.B., Klinken, L., Bindseil, E., 1991. Histopathology of intact and docked pigtails. *British Veterinary Journal* 147, 407-412.
- Sinisalo, A., Niemi, J.K., Heinonen, M., Valros, A., 2012. Tail biting and production performance in fattening pigs. *Livestock Science* 143, 220-225.
- Spooner, J.M., Schuppli, C.A., Fraser, D., 2014. Attitudes of Canadian Pig Producers Toward Animal Welfare. *Journal of Agricultural and Environmental Ethics* 27, 569-589.
- Statham, P., Green, L., Bichard, M., Mendl, M., 2009. Predicting tail-biting from behaviour of pigs prior to outbreaks. *Applied Animal Behaviour Science* 121, 157-164.
- Sutherland, M.A., Tucker, C.B., 2011. The long and short of it: A review of tail docking in farm animals. *Applied Animal Behaviour Science* 135, 179-191.
- Taylor, N.R., Main, D.C.J., Mendl, M., Edwards, S.A., 2010. Tail-biting: A new perspective. *Veterinary Journal* 186, 137-147.
- Teixeira, D.L., Harley, S., Hanlon, A., O'Connell, N.E., More, S.J., Manzanilla, E.G., Boyle, L.A., 2016. Study on the association between tail lesion score, cold carcass weight, and viscera condemnations in slaughter pigs. *Frontiers in Veterinary Science* 3, 1-7.
- Telkänranta, H., Bracke, M.B.M., Valros, A., 2014. Fresh wood reduces tail and ear biting and increases exploratory behaviour in finishing pigs. *Applied Animal Behaviour Science* 161, 51-59.
- Thodberg, K., Herskin, M.S., Jensen, T., Jensen, K.H., 2018. The effect of docking length on the risk of tail biting, tail-directed behaviour, aggression and activity level of growing pigs kept under commercial conditions. *Animal* 12, 2609-2618.
- Trickett, S.L., Guy, J.H., Edwards, S.A., 2009. The role of novelty in environmental enrichment for the weaned pig. *Applied Animal Behaviour*

- Science 116, 45-51.
- Ursinus, Winanda W., Van Reenen, C.G., Kemp, B., Bolhuis, J.E., 2014a. Tail biting behaviour and tail damage in pigs and the relationship with general behaviour: Predicting the inevitable? *Applied Animal Behaviour Science* 156, 22-36.
- Ursinus, Winanda W., Van Reenen, C.G., Reimert, I., Bolhuis, J.E., 2014b. Tail biting in pigs: Blood serotonin and fearfulness as pieces of the puzzle? *PLoS ONE* 9.
- Ursinus, W. W., Wijnen, H.J., Bartel, A.C., Dijkstra, N., van Reenen, C.G., Bolhuis, J.E., 2014c. Damaging biting behaviors in intensively kept rearing gilts: The effect of jute sacks and relations with production characteristics. *Journal of Animal Science* 92, 5193-5202.
- Valros, A., 2017. Tail biting. *Advances in Pig Welfare* 137-166.
- Valros, A., Ahlström, S., Rintala, H., Häkkinen, T., Saloniemi, H., 2004. The prevalence of tail damage in slaughter pigs in Finland and associations to carcass condemnations. *Acta Agriculturae Scandinavica - Section A: Animal Science* 54, 213-219.
- Valros, A., Barber, C., 2019. Producer perceptions of the prevention of tail biting on UK farms: Association to bedding use and tail removal proportion. *Animals* 9, 1-21.
- Valros, A., Heinonen, M., 2015. Save the pig tail. *Porcine Health Management* 1, 1-7.
- Valros, A., Munsterhjelm, C., Hänninen, L., Kauppinen, T., Heinonen, M., 2016. Managing undocked pigs - on-farm prevention of tail biting and attitudes towards tail biting and docking. *Porcine Health Management* 2, 1-11.
- Valros, A., Munsterhjelm, C., Puolanne, E., Ruusunen, M., Heinonen, M., Peltoniemi, O.A.T., Pösö, A.R., 2013. Physiological indicators of stress and meat and carcass characteristics in tail bitten slaughter pigs. *Acta Veterinaria Scandinavica* 55, 1.
- Valros, A., Palander, P., Heinonen, M., Munsterhjelm, C., Brunberg, E., Keeling, L., Piepponen, P., 2015. Evidence for a link between tail biting and central monoamine metabolism in pigs (*Sus scrofa domestica*). *Physiology and Behavior* 143, 151-157.
- Van de Weerd, H.A., Day, J.E.L., 2009. A review of environmental enrichment for pigs housed in intensive housing systems. *Applied Animal Behaviour Science* 116, 1-20.
- Van De Weerd, H.A., Docking, C.M., Day, J.E.L., Edwards, S.A., 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. *Animal Science* 80, 289-298.
- Van Der Meer, Y., Gerrits, W.J.J., Jansman, A.J.M., Kemp, B., Bolhuis, J.E., 2017. A link between damaging behaviour in pigs, sanitary conditions, and dietary protein and amino acid supply. *PLoS ONE* 12, 1-21.
- van Putten, G., 1969. An investigation into tail-biting among fattening pigs. *The British veterinary journal* 125, 511-514.
- Van Staaveren, N., Calderón Díaz, J.A., Garcia Manzanilla, E., Hanlon, A., Boyle, L.A., 2018. Prevalence of welfare outcomes in the weaner and finisher stages of the production cycle on 31 Irish pig farms. *Irish Veterinary Journal* 71, 1-9.
- Van Staaveren, N., Doyle, B., Manzanilla, E.G., Calderón Díaz, J.A., Hanlon, A., Boyle, L.A., 2017a. Validation of carcass lesions as indicators for on-farm health and welfare of pigs. *Journal of Animal Science* 95, 1528-1536.
- Van Staaveren, N., Teixeira, D.L., Hanlon, A., Boyle, L.A., 2017b. Pig carcass tail lesions: The influence of record keeping through an advisory service and the relationship with farm performance parameters. *Animal* 11, 140-146.
- Van Staaveren, N., Vale, A.P., Manzanilla, E.G., Teixeira, D.L., Leonard, F.C., Hanlon, A., Boyle, L.A., 2016. Relationship between tail lesions and lung health in slaughter pigs. *Preventive Veterinary Medicine* 127, 21-26.
- Veit, C., Büttner, K., Traulsen, I., Gertz, M., Hasler, M., Burfeind, O., Beilage, E., grosse, Krieter, J., 2017. The effect of mixing piglets after weaning on the occurrence of tail-biting during rearing. *Livestock Science* 201, 70-73.
- Vermeer, H.M., Dirx-Kuijken, N.C.P.M.M., Bracke, M.B.M., 2017. Exploration feeding and higher space allocation improve welfare of growing-finishing pigs. *Animals* 7, 3-11.
- Vom Brocke, A.L., Karnholz, C., Madey-Rindermann, D., Gauly, M., Leeb, C., Winckler, C., Schrader, L., Dippel, S., 2019. Tail lesions in fattening pigs: Relationships with postmortem meat inspection and influence of a tail biting management tool. *Animal* 13, 835-844.
- Wallenbeck, A., Keeling, L.J., 2013. Using data from electronic feeders on visit frequency and feed consumption to indicate tail biting outbreaks in commercial pig production. *Journal of Animal Science* 91, 2879-2884.
- Wallgren, T., Larsen, A., Gunnarsson, S., 2019a. Tail posture as an indicator of tail biting in undocked finishing pigs. *Animals* 9.
- Wallgren, T., Larsen, A., Lundeheim, N., Westin, R., Gunnarsson, S., 2019b. Implication and impact of straw provision on behaviour, lesions and pen hygiene on commercial farms rearing undocked pigs. *Applied Animal Behaviour Science* 210, 26-37.
- Wallgren, T., Lundeheim, N., Wallenbeck, A., Westin, R., Gunnarsson, S., 2019c. Rearing pigs with intact tails-experiences and practical solutions in Sweden. *Animals* 9. <https://doi.org/10.3390/ani9100812>
- Wedin, M., Baxter, E.M., Jack, M., Futro, A., D'Eath, R.B., 2018. Early indicators of tail biting outbreaks in pigs. *Applied Animal Behaviour Science* 208, 7-13.
- Zhang, L., Gray, H., Ye, X., Collins, L., Allinson, N., 2019. Automatic individual pig detection and tracking in surveillance videos. *Sensors*.
- Zonderland, J.J., Bracke, M.B.M., den Hartog, L.A., Kemp, B., Spoolder, H.A.M., 2010. Gender effects on tail damage development in single- or mixed-sex groups of weaned piglets. *Livestock Science* 129, 151-158.
- Zonderland, J.J., Kemp, B., Bracke, M.B.M., Den Hartog, L.A., Spoolder, H.A.M., 2011a. Individual piglets contribution to the development of tail biting. *Animal* 5, 601-607.
- Zonderland, J.J., Schepers, F., Bracke, M.B.M., Den Hartog, L.A., Kemp, B., Spoolder, H.A.M., 2011b. Characteristics of biter and victim piglets apparent before a tail-biting outbreak. *Animal* 5, 767-775. h
- Zonderland, J.J., van Riel, J.W., Bracke, M.B.M., Kemp, B., den Hartog, L.A., Spoolder, H.A.M., 2009. Tail posture predicts tail damage among weaned piglets. *Applied Animal Behaviour Science* 121, 165-170.
- Zonderland, J.J., Wolthuis-Fillerup, M., van Reenen, C.G., Bracke, M.B.M., Kemp, B., Hartog, L.A. de., Spoolder, H.A.M., 2008. Prevention and treatment of tail biting in weaned piglets. *Applied Animal Behaviour Science* 110, 269-281.
- Zonderland J.j., Bosma B., Hoste R. 2011c Financiële consequenties van staartbijten bij varkens Wageningen UR Livestock Research, onderdeel van Stichting Dienst Landbouwkundig Onderzoek, 2011
- Zonderland, J.J., Zonderland-Thomassen, M.A., 2016. Behavioural change by pig producers is the key factor in raising pigs with intact tails. *Veterinary Journal* 211, 1-2.