

# Pure

## Scotland's Rural College

### The translation of animal welfare research into practice: the case of mixing aggression between pigs

Peden, RSE; Turner, SP; Boyle, LA; Camerlink, I

*Published in:*

Applied Animal Behaviour Science

*DOI:*

[10.1016/j.applanim.2018.03.003](https://doi.org/10.1016/j.applanim.2018.03.003)

First published: 10/03/2018

*Document Version*

Peer reviewed version

[Link to publication](#)

*Citation for published version (APA):*

Peden, RSE., Turner, SP., Boyle, LA., & Camerlink, I. (2018). The translation of animal welfare research into practice: the case of mixing aggression between pigs. *Applied Animal Behaviour Science*, 204, 1 - 9. <https://doi.org/10.1016/j.applanim.2018.03.003>

#### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

#### Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 **The translation of animal welfare research into practice: the case of mixing aggression**  
2 **between pigs**

3 Rachel S. E. Peden<sup>1,2\*</sup>, Simon P. Turner<sup>1</sup>, Laura A. Boyle<sup>3</sup> & Irene Camerlink<sup>1</sup>

4 <sup>1</sup>Animal Behaviour & Welfare, Animal and Veterinary Sciences Research Group, Scotland's  
5 Rural College (SRUC), West Mains Rd., Edinburgh, EH9 3JG, United Kingdom

6 <sup>2</sup>The Roslin Institute and Royal (Dick) School of Veterinary Studies, University of  
7 Edinburgh, Easter Bush Campus, Midlothian EH25 9RG

8 <sup>3</sup>Teagasc, Pig Development Department, Animal & Grassland Research and Innovation  
9 Centre, Moorepark, Fermoy Co. Cork. P61 C997

10 \*Correspondence: R. Peden, Animal Behaviour & Welfare, Animal and Veterinary Sciences  
11 Research Group, Scotland's Rural College (SRUC), West Mains Rd., Edinburgh, EH9 3JG,  
12 UK, Tel. +44 131 6519360, E-mail address: Rachel.peden@sruc.ac.uk

13

14 **Abstract**

15 Aggression between unfamiliar pigs at mixing is a major animal welfare problem in  
16 commercial farming. It has been studied since the 1970s and remains an important topic in  
17 animal welfare research. Methods to reduce pig aggression at mixing have been reviewed  
18 previously, but there has been little translation of the advocated techniques and building  
19 designs into practice. As a result, the problem persists on many commercial units. A similar  
20 situation exists for many other animal welfare issues. This article takes a new approach in not  
21 only reviewing the recent scientific literature, but also reviewing the evidence of uptake in  
22 industry. Firstly, the current state of aggression mitigation research is reviewed; including the  
23 most successful recent developments in breeding against aggression, early life socialisation,  
24 the use of pheromones and nutrition. Secondly, information is extracted from both peer  
25 reviewed and industry literature to establish the extent to which these strategies have been  
26 transferred from research to practice. Finally, we discuss why in spite of the amount of  
27 research on reducing aggression at mixing the problem has not reduced in intensive farming  
28 systems. The limited uptake in practice appears to be due to low prioritisation of the problem,  
29 the practicalities of implementation, lack of information on cost-effectiveness and ineffective  
30 communication of research to the farming community. To bridge this gap, industry must be  
31 involved in the design of practical solutions and the cost-effectiveness of these must be  
32 quantified. This approach should also be considered for other animal welfare issues under  
33 investigation. We recommend a better alignment between research questions and industry  
34 interests to increase the success of research efforts to improve animal welfare in practice.

35

36

37 **Keywords:** Pig; Sow; Aggression; Industry; Farmers; Animal welfare

38

39

40 **1. Introduction**

41  
42 When regrouping ('mixing') unfamiliar pigs, aggression occurs as they establish a dominance  
43 hierarchy. 'Mixing aggression' between both growing pigs and sows is a major animal  
44 welfare issue. It has been studied since the 1970s and a large body of peer-reviewed literature  
45 exists. Many strategies to reduce aggression have been identified. Methods for growing pigs  
46 and sows were reviewed by Marchant-Forde and Marchant-Forde (2005), whilst other reviews  
47 focussed specifically on growing pigs (Petherick and Blackshaw, 1987) or sows (Arey and  
48 Edwards, 1998; Greenwood et al., 2014). Despite the amount of past and on-going research,  
49 aggression at mixing is largely undiminished in practice, which is partly evidenced by the on-  
50 going research efforts on this topic. Projects on aggression in pigs continue to receive funding  
51 as it is still regarded an important welfare issue, in fact, research on pig aggression has  
52 increased since the reviews cited above (Figure 1). Data from 1,928 farms in the UK show a  
53 prevalence of 0.24% for severe skin lesions (Pandolfi et al., 2017) and 11% for mild body  
54 lesions (Real Welfare, 2017), which are a result of aggression.

55  
56 *[Insert Figure 1 here]*

57  
58 Aggression between pigs arises from their need to establish and reinforce dominance  
59 relationships (McGlone, 1985). Although aggression is a natural behaviour, it is exacerbated  
60 by unnatural intensive farming conditions and practices such as social disruption, limited  
61 space and homogeneity in competitive ability of group members. In the wild, pigs live in  
62 small stable groups where subordinate animals tend to actively avoid conflict with dominant  
63 animals (Jensen and Wood-Gush, 1984), and males actively avoid confrontation with each  
64 other outside of the mating season (Gabor et al., 1999). Social hierarchies are therefore  
65 maintained mostly through agonistic display and with little physical aggression. In

66 commercial pig production pigs are regrouped several times from birth to slaughter  
67 (Camerlink and Turner, 2017). Regrouping is a common management strategy 1) to create  
68 groups appropriate to the size of the pens available (Guy et al., 2009); 2) to equalise body  
69 weights to achieve more homogenous slaughter weights (Rushen, 1987); and 3) to return  
70 breeding sows to the gestation group after weaning. Farmers report mixing growing pigs up to  
71 four times during production (Camerlink and Turner, 2017). For the majority of farmers, the  
72 avoidance of mixing is impractical due to inefficient use of space and concern that  
73 heterogeneity in pig weights will be exacerbated. Moreover, the mixing of sows is  
74 unavoidable in the EU due to Council Directive 2008/120/EC which requires that sows and  
75 gilts are group housed from 4 weeks after service to 1 week before expected farrowing.  
76 Regrouping, and thus aggression, is therefore common at weaning (for both piglets and sows),  
77 at the beginning of the growing-finishing period (Manteca and Jones, 2013) and at transport  
78 to slaughter (Terlouw et al., 2008).

79 Aggression has a negative impact on farm profit and animal welfare. During fights pigs  
80 acquire skin injuries as a result of bites (McGlone, 1985), risk lameness (Rydhmer et al.,  
81 2006), and are more susceptible to infection due to the transient effects of stress upon the  
82 immune system (Morrow-Tesch et al., 1994). Aggression can negatively affect growth rate  
83 (Stookey and Gonyou, 1994; Coutellier et al., 2007) and meat quality (D'Eath et al., 2010). In  
84 sows, aggression can result in economic losses due to reduced reproductive performance  
85 (Mendl et al., 1992; Greenwood et al., 2014). The movement away from individual sow stalls,  
86 which is now taking place globally, means research into aggression when re-grouping sows is  
87 of increasing importance (e.g. Greenwood et al., 2014; Ison et al., in press).

88 In this paper we review the current state of research into reducing mixing aggression between  
89 growing pigs and sows, and identify the most promising techniques in terms of their scientific  
90 progress. Moreover, we review the impact of these strategies on commercial practice, and  
91 address why the large amount of research on this topic has failed to reduce aggression on  
92 commercial pig farms. Finally, we provide suggestions on how to bridge the gap between

93 animal welfare research and actual animal welfare improvement. We focus specifically on the  
94 aggression that occurs between unfamiliar pigs at regrouping. Strategies to address problems  
95 of aggression between pigs in stable groups are not explored in this review.

96

## 97 **2. Method of selecting literature**

98 The review of aggression mitigation strategies for both sows and growing pigs carried out by  
99 Marchant-Forde and Marchant-Forde (2005) was used in this review to refer to the scientific  
100 literature up to 2005. Peer-reviewed literature published between 2005 and 2017 was  
101 identified using Google Scholar and Web of Science using the following search terms: Pig,  
102 Sow and Aggression. The uptake of methods to reduce aggression in practice was assessed  
103 through data from farmer surveys and a Web based search of commercial publications,  
104 websites, and farmers' magazines. Findings from farmer surveys were identified using  
105 Google Scholar and Web of Science under the following search terms: Pig, Sow, Aggression  
106 and Survey. Websites included those of pig farming magazines, pig breeding companies, pig  
107 feed companies and equipment manufacturers or suppliers based in the United Kingdom.  
108 Information obtained from websites included items promoting specific aggression mitigation  
109 strategies and the availability of relevant products on the market. Social media, blogs, and  
110 posts by lay people were excluded. Literature on aggression between pigs in stable groups  
111 was also excluded.

112

## 113 **3. Current state of research**

114 In this section we summarise the successful methods to reduce aggression identified in  
115 previous reviews. Thereafter, four newer approaches are described, namely: genetic selection,  
116 nutritional supplementation, early-life socialisation and use of pheromones. In recent years

117 these four approaches have emerged as some of the most promising aggression mitigation  
118 strategies in terms of their scientific progress and practical impact.

119

### 120 *3.1 Previously identified control strategies*

121 Research has moved away from methods that do not deliver long term benefits and prove  
122 difficult to manage under commercial conditions, such as tranquilisers, boar presence and  
123 variation in weight at mixing (described by Marchant-Forde and Marchant-Forde, 2005).  
124 Methods with continued efficacy in empirical studies include providing adequate space  
125 (Spoolder et al., 2009; Hemsworth et al., 2013) and large social groups (Samarakone and  
126 Gonyou, 2009). Space allowance should be sufficient for pigs to display submissive  
127 behaviour (Turner et al., 2000; Spoolder et al., 2009; Hemsworth et al., 2013); however, to  
128 date it is difficult to define what can be regarded as adequate space allowances for growing  
129 pigs and sows, partly since this is affected by floor type and feeding system design. Group  
130 size must be sufficiently large (more than 12 individuals) to have an impact on aggression  
131 levels (Andersen et al., 2004), however much larger groups (>80 pigs) are more effective  
132 (Turner et al., 2001; Samarakone and Gonyou, 2009). It is suggested that the reduction in  
133 aggression with increasing group size is related to the formation of subgroups of a more  
134 natural size when pigs can no longer maintain a definitive social order (Gonyou, 2001).  
135 However, there is no clear evidence for this in domestic pigs (Turner et al., 2003), and it more  
136 likely reflects the adoption of a less aggressive social strategy when the costs associated with  
137 aggression outweigh the benefits (Andersen et al., 2004; Samarakone and Gonyou, 2009).

138

### 139 *3.2 Advances in genetics*

140 Aggressiveness is a moderately stable temperament trait with consistent differences existing  
141 between individuals. For example, resident pigs exposed to intruders at three time points (60,  
142 95 and 130 days old) revealed consistency in their aggressive behaviour within and between  
143 interactions (Clark and D'Eath, 2013). The distribution of aggressive behaviour within a

144 group tends to be skewed by the presence of a minority of highly aggressive animals (Turner  
145 et al., 2006b). The aim of breeding against aggression would be to reduce the aggressiveness  
146 of all animals in the population with greatest impact on the occurrence of highly aggressive  
147 individuals. Reciprocated fighting and the delivery of non-reciprocated bullying have a  
148 moderate heritability ( $h^2 = 0.17-0.43$ ) (Lovendahl et al., 2005; Turner et al., 2008, 2009)  
149 whereby the heritability indicates the proportion of the phenotypic variance that can be  
150 attributed to additive genetic effects. Reciprocated fighting involves decisions made by two  
151 pigs and the significant heritability estimated for this behaviour reflects an individual's  
152 propensity either to initiate aggression or to retaliate aggressively when attacked, leading to a  
153 reciprocal fight. However, the heritability for the receipt of bullying is low ( $h^2 = 0.04-0.08$ ;  
154 Lovendahl et al., 2005; Turner et al., 2009). Skin lesions are used as a proxy measure of  
155 aggression, with a differentiation being made between skin lesions due to reciprocal fighting  
156 (primarily located on the head, neck and shoulders) and lesions due to the receipt of bullying  
157 (primarily located on the flanks, back and rump) (Turner et al., 2006a; Desire et al., 2015b).  
158 Skin lesions, particularly towards the front of the body, are genetically correlated with  
159 engagement in reciprocal fighting and pigs which perform this behaviour typically also direct  
160 non-reciprocated bullying towards others (Turner et al., 2009). Therefore the amount of  
161 lesions and their location on individual pigs can be used as a genetic indicator trait to select  
162 against the expression of reciprocal fighting and aggressive behaviour (Turner et al., 2006b,  
163 2008, 2010; D'Eath et al., 2009; Desire et al., 2015).  
164 Counting lesions takes less than 2 minutes per animal (Turner et al., 2009) and requires no  
165 additional animal handling, no equipment and minimal training (Turner et al., 2010).  
166 Therefore genetic selection on the basis of skin lesions has the potential to lead to cumulative  
167 and long term benefits at relatively little cost to individual producers. However, the costs of  
168 recording lesions (phenotyping) and the reduction in selection pressure that can be exerted on  
169 other traits in an index by the inclusion of a new trait are barriers to selection against skin  
170 lesions. Furthermore, there is evidence from one population that reducing skin lesions may  
171 slow genetic progress in growth rate and feed efficiency (Desire et al., 2015a) due to an

172 undesirable genetic association between the traits. Nevertheless, it is important to note that  
173 lesions are primarily received to the anterior part of the body during aggressive behaviour and  
174 these are not genetically related to production traits (Desire et al., 2015a).

175 A novel approach to address animal welfare issues through breeding is through indirect  
176 genetic effects (IGEs, also known as social or associative genetic effects). An individual's  
177 performance is influenced not only by its own genotype, but also by that of the individuals  
178 with which it interacts (Moore et al., 1997; Ellen et al., 2014). IGEs refer to the genetic effects  
179 that an individual has on the phenotype of its group mates. These effects can have either  
180 positive or negative implications for welfare, productivity, and health of livestock and are  
181 hypothesised to be related to behaviour (Ellen et al., 2014). Indeed, research on the behaviour  
182 of pigs selected for positive IGEs regarding productivity showed differences in biting  
183 behaviour (Canario et al., 2012; Camerlink et al., 2013). IGEs may, therefore, provide a  
184 promising method for reducing negative social interactions whilst improving productivity.  
185 This approach negates the need for additional phenotyping as it is expected to change social  
186 behaviour as an indirect consequence of improving productivity traits that are already  
187 recorded.

188

### 189 *3.3 Nutrition*

190 Scientific research on how nutrition can reduce aggression is sparse but promising. There is  
191 some evidence to suggest that magnesium supplementation may reduce aggressive behaviour  
192 at mixing (O'Driscoll et al., 2013a, b), although there is also evidence to suggest that it can  
193 actually increase the frequency of aggressive behaviour (Caine et al., 2000). Therefore further  
194 research is required to establish the effect of magnesium on aggression and the optimum  
195 supplementation level.

196

197 Dietary manipulation of amino acid precursors of neurotransmitters may offer a practical  
198 means of reducing susceptibility of pigs to stress (Adeola and Ball, 1992; Koopmans et al.,

199 2005). Tryptophan (TRP) is an essential amino acid acquired through the diet, and is typically  
200 supplied at levels required for maximum growth (Li et al., 2006). The supply of excess TRP  
201 may be used as a therapeutic supplement as it is the primary precursor for serotonin (5-HT),  
202 an inhibitory neurotransmitter in the central nervous system (Li et al., 2006). Serotonin  
203 regulates a variety of processes such as sleep, appetite, mood, susceptibility to stress and  
204 aggressive behaviour (D'Eath et al., 2005; Koopmans et al., 2005; Poletto et al., 2010). By  
205 feeding pigs a high TRP diet it is possible to indirectly raise brain availability of 5-HT  
206 (Adeola and Ball, 1992; Koopmans et al., 2006; Shen et al., 2012a). A four day enhanced  
207 TRP diet was associated with a 50% decrease in fight duration and intensity at regrouping in  
208 male and female growing/finishing pigs compared to an untreated control group (Li et al.,  
209 2006). There was no effect of an enhanced TRP diet on the number of fights that occurred or  
210 the latency to fight (Li et al., 2006). Poletto et al. (2010) found that a high TRP diet  
211 significantly reduced the aggressiveness of grower gilts in a resident intruder test as they took  
212 longer to attack the intruder pig and they initiated fewer fights (Poletto et al., 2010).  
213 Moreover, providing a TRP-enriched diet around mixing led to a reduction in aggressive  
214 behaviour in gestating sows (Poletto et al., 2014), although Li and co-authors (2011) did not  
215 find such an effect (Li et al., 2011). Hypothalamic 5-HT concentrations peak after 4-5 days of  
216 eating an enhanced TRP diet (Adeola and Ball, 1992; Koopmans et al., 2005), and this was  
217 missed in the study of Li et al. (2011).

218 A TRP-enriched diet is also associated with reduced salivary cortisol (Koopmans et al., 2005;  
219 Guzik et al., 2006; Koopmans et al., 2006; Shen et al., 2012a) and reduced adrenaline and  
220 noradrenaline at regrouping (Koopmans et al., 2005). Moreover, growing pigs with a TRP-  
221 enriched diet display a reduced long term hormonal response to regrouping, indicating  
222 enhanced recovery following social confrontations (Koopmans et al., 2005). When weaned  
223 pigs are placed on a TRP-enriched diet immediately following weaning, no adverse effects on  
224 feed intake and average daily gain are reported (Koopmans et al., 2006) and there can be  
225 improvements in feed efficiency (Shen et al., 2012b). However, there is no reduction in  
226 aggressive behaviour when mixed five days after weaning (Koopmans et al., 2006).

227

228 *3.4 Early life socialisation*

229 Early life socialisation of piglets, also termed co-mingling, involves the mixing of litters  
230 during the lactation period and is probably the most studied method for mitigating aggression  
231 at weaning. Suckling litters are allowed to integrate usually in the second week of life, when  
232 piglets would start to encounter other litters under natural conditions (Stolba and Wood-Gush,  
233 1989), and remain together until weaning. Unless using purpose-built multi-suckling systems,  
234 in which piglets naturally co-mingle, socialisation requires the removal of the barriers  
235 between adjacent farrowing pens (Hessel et al., 2006).

236 There is little increase in agonistic behaviour in piglets at pre-weaning socialisation (Weary et  
237 al., 1999), and when aggression does occur it is without the risk of severe injuries due to the  
238 limited size and strength of young piglets (Ledergerber et al., 2015). This social experience  
239 results in reduced aggression at weaning, and is presumed to do so by allowing piglets to  
240 learn social skills which permit more rapid formation of stable dominance relationships in  
241 subsequent social encounters (D'Eath, 2005; Kanaan et al., 2008; Kutzer et al., 2009).

242 Moreover, pre-weaning socialisation can improve weaner performance by increasing growth  
243 rate following weaning (Hessel et al., 2006; Ledergerber et al., 2015).

244 There is some concern that the benefits of socialisation may be offset by production costs  
245 resulting from a disruption to pre-weaning feeding behaviour (Wattanakul et al., 1997b;  
246 Parratt et al., 2006). The main concern regards cross-suckling, which can lead to reduced milk  
247 intake due to competitive exclusion of subordinate piglets (Pedersen et al., 1998) and a  
248 disruption to sow lactation at mixing (D'Eath, 2005). There is inconsistent evidence regarding  
249 the prevalence of cross-suckling in multi-suckling systems; some studies found that it  
250 occurred frequently (Wattanakul et al., 1997a; Olsen et al., 1998; Maletinska and Špinko,  
251 2001) whilst others did not (D'Eath, 2005; Kutzer et al., 2009). Moreover, there is evidence to  
252 suggest that even where cross suckling is common it does not have an adverse effect on the  
253 overall milk intake of the piglets (Maletinska and Špinko, 2001). Experimental studies suggest  
254 that pre-weaning socialisation of pairs of litters does not affect pre-weaning growth rate

255 (D'Eath, 2005; Kanaan et al., 2008) or mortality (D'Eath, 2005). However, heightened  
256 mortality was observed in multi-suckling systems where more than two litters were  
257 simultaneously co-mingled (van Nieuwamerongen et al., 2015).

258

### 259 *3.5 Pheromones*

260 Pig appeasing pheromone (PAP) is a maternal pheromone released by sows through skin  
261 secretions, and functions to regulate nursing behaviours (Morrow-Tesch and McGlone, 1990).  
262 Pageat (Pageat, 2001) synthesised a mixture containing several fatty acids similar in  
263 composition to PAP and it is currently on the market as an odour diffuser to reduce pig  
264 aggression. This synthetic pheromone reduces the frequency of fights at mixing in sows  
265 (Yonezawa et al., 2009; Plush et al., 2016) and weaners under experimental (McGlone and  
266 Anderson, 2002) and commercial farming conditions (Guy et al., 2009). This technique is  
267 therefore targeted at breeding and weaner stock. Research applying synthetic PAP in either  
268 aerosol or liquid form directly to pens and feeders found that pigs showed a reduction in  
269 salivary cortisol (Yonezawa et al., 2009) and skin lesions related to aggression (Guy et al.,  
270 2009) and a higher average daily weight gain (McGlone and Anderson, 2002) when compared  
271 to pigs not exposed to PAP. The use of synthetic PAP for sows does not appear to affect the  
272 subsequent conception rate (Plush et al., 2016). The number of skin lesions in groups  
273 exposed to synthetic PAP is reduced up to seven days following mixing (Guy et al., 2009),  
274 suggesting that it does not merely postpone the occurrence of aggression but results in the  
275 more rapid formation of stable social relationships (Guy et al., 2009).

276

## 277 **4. Implementation of aggression mitigation methods in practice**

278 We summarise the translation of aggression research into commercial practice in Table 1. All  
279 aggression mitigation methods were tabulated, even those that research found ineffective but  
280 industry found useful in the study of Ison et al. (in press). Methods were grouped by breeding  
281 strategy, nutrition, and management adaptations. In the rest of this section, we summarise the  
282 evidence for implementation of the most promising control strategies. Firstly, we summarise

283 uptake of the most promising previously identified strategies (increased space allowance and  
284 group size) before summarising uptake of the most promising recent developments in  
285 aggression research (genetic selection, nutritional supplementation, early life socialisation and  
286 use of appeasing pheromones).

287

288 *[Insert Table 1 here]*

#### 289 *4.1 Previously identified control strategies*

290 A recent survey found that only two respondents from a sample of 132 British and Irish pig  
291 farmers reported using increased space allowance to control aggression at mixing (Peden et  
292 al., Unpublished work) suggesting limited uptake of this strategy in practice. Keeping pigs in  
293 large groups of anything from 50 to 1000 pigs gained popularity over the last 15 years (Gadd,  
294 2009) due to a reduction in aggressive behaviour (Turner et al., 2001; Samarakone and  
295 Gonyou, 2009), and benefits in terms of reduced cost and ease of management (Gadd, 2009).  
296 The growth in group size for growing pigs has been accelerated by the development and  
297 launch of Automatic Sorting Technology (AST) in 2002, which is based on maintaining pigs  
298 in groups of 500 - 1000 (Brummer et al., 2008).

299

#### 300 *4.2 Breeding*

301 Although direct genetic selection against aggression shows promise and continues to be  
302 researched it is not being implemented in pig breeding schemes. The finding that lesions to  
303 the anterior part of the body (which are most associated with aggressive behaviour) are not  
304 genetically related to production traits (Desire et al., 2015a) is promising for future  
305 implementation. As the costs of high density genotyping (i.e. determination of the nucleotide  
306 identity at many locations on the genome) fall, genomic selection based on lesions is likely to  
307 become more feasible and will avoid the need for routine phenotyping. The estimation of

308 indirect genetic effects, which could also affect aggression, is routinely conducted by two  
309 large pig breeding companies and is being evaluated by others. To date, only a limited  
310 number of lines selected for indirect genetic effects are commercially available from two  
311 companies.

312

#### 313 *4.3 Nutrition*

314 Several articles have appeared in popular farmer magazines and websites that promote the use  
315 of an enhanced tryptophan diet to reduce aggression (Dapoza, 2009; Ziggers, 2009; National  
316 Hog Farmer, 2010; Phys.Org, 2010; Salvage, 2010; ter Beek, 2010; Ziggers, 2010). Despite  
317 these, tryptophan is not commonly used above the minimum requirements for growth in  
318 commercial practice. Tryptophan is not readily available for supplementing feed, nor is its  
319 supplementation routinely recommended by feed companies. This is likely related to the  
320 inconsistent dose response reported in the literature, and lack of information on the economic  
321 benefits. In order to bring enhanced TRP out of the research phase and into practical  
322 application we recommend that research establishes the optimum dose and the associated cost  
323 to farmers. Moreover, it is important to establish a way of administering an enhanced TRP  
324 diet for the necessary period with minimal disruption to management.

325

#### 326 *4.4 Early life socialisation*

327 A recent survey amongst UK pig farmers indicated that 27% of the 167 respondents currently  
328 applied socialisation of piglets, or had done so in the past (Camerlink and Turner, 2017).  
329 However, 50% of participants said they would not employ socialisation, and most raised  
330 multiple concerns about the strategy. The most frequently mentioned concern regarded the  
331 practical management of piglets and sows (60%), followed by aggression of the sow towards  
332 piglets (37%) and reduced growth of piglets (32%). These concerns are not supported by  
333 experimental trials but results in practice may differ from those generated under highly  
334 controlled experimental conditions. Producers may be more willing to implement early-life

335 socialisation if more evidence is provided and disseminated to demonstrate that growth and  
336 mortality are comparable to standard practice (Ison et al., in press).  
337 Implementation of this technique outside of the UK is currently unknown. Unusually, as  
338 much as 40% of the British pig herd is outdoor bred (Agriculture and Horticulture  
339 Development Board, 2016), and early life socialisation frequently occurs as a consequence of  
340 these outdoor rearing systems. Therefore implementation reported in the UK is likely to be  
341 relatively high in comparison to countries where indoor intensive breeding systems are more  
342 common. Indeed, a recent survey of North American producers found poor uptake of  
343 socialisation in these systems (Ison et al., in press). It is worth noting that those who used the  
344 technique found it to be more useful than any other mitigation strategy (Ison et al., in press).

345

#### 346 *4.5 Pheromones*

347 PAP diffusers have been commercially available from at least one company since 2015  
348 (Semikeys); they advise that one diffuser covers an area of 25m<sup>2</sup> and should be replaced  
349 every six weeks. Importantly, the Semikeys website provides a calculator allowing  
350 customers to track behavioural changes in their treated pens, compare performance to  
351 untreated controls, and to assess the economic impact of using pheromones on their own  
352 farms (SemiKeys). Furthermore, several articles were written in French magazines and  
353 newsletters promoting the product. These mainly report the positive effects of the product,  
354 including: reductions in the number of fights, the duration of fights, cortisol, lesions, and tail  
355 biting (Huet, 2016; Semikeys, 2016; 2017).

356 The majority of published research into PAP applied the pheromone in either liquid or aerosol  
357 form directly to the pens and feeders, and did not employ the commercially available  
358 diffusers. The only published research investigating the effectiveness of diffusers found  
359 limited efficacy (Plush et al., 2016). Research into PAP is ongoing and it is recommended that  
360 priority is given to determining the optimal application protocol under commercial conditions.

361

## 362 **5. The gap between research and practice**

363 Farmer willingness to change current practice and implement strategies to reduce aggression  
364 relies strongly on their perception of the situation. Pig farmers self-report having high regard  
365 for animal welfare (Wilson et al., 2014). However, they are faced with a myriad of often  
366 competing welfare problems such as tail biting; lameness; pain caused by routine husbandry  
367 procedures such as ear tagging and tail docking (Wilson et al., 2014); and heat stress (Pearce  
368 et al., 2013). Welfare may also compete with profit margins, food safety, product quality and  
369 environmental regulations (Millman et al., 2004). Therefore several factors compete for  
370 farmer attention, and it is possible that the costs associated with aggression are perceived as  
371 minor in comparison to those incurred by other threats to welfare and production. In a recent  
372 survey in the UK, 73% of 167 farmers did not regard aggression at weaning as a problem that  
373 needed to be addressed, compared to 57% at the growing-finishing stage (Camerlink and  
374 Turner, 2017). The farmers who perceived aggression as a problem displayed variable  
375 willingness to change the situation (Camerlink and Turner, 2017). This variation in response  
376 probably reflects the fact that human behaviour is determined by a wide range of intrinsic and  
377 extrinsic factors such as culture, social norms, education, awareness of legislation, attitudes,  
378 age and gender. Such factors were influential in determining antibiotic use and campaigns that  
379 understood and addressed them managed to change human behaviour in both medical and  
380 agricultural/veterinary practice (Sabuncu et al., 2009; Huttner et al., 2010; Aarestrup, 2012).

381 Characteristics of the aggression mitigation strategy are also important. Reluctance to  
382 implement welfare improvement strategies is associated with the perception that they are  
383 ineffective, not financially feasible, or difficult to practically manage (Fredriksen and Nafstad,  
384 2006). Motivation is limited when farmers distrust the economic advantages of implementing  
385 strategies or when the benefits are simply unknown (Bock and van Huik, 2007; Gocsik et al.,  
386 2015). Motivation is also reduced by a perceived lack of time, skilled labour (Morgan-Davies  
387 et al., 2006), or knowledge (de Lauwere et al., 2012). Commercial pig farmers have little  
388 choice but to farm animals in a way that will retain their competitive position in the market  
389 (Webster, 1982), and pig farmers are motivated markedly by economic factors (Bock and van

390 Huik, 2007). Farmers are willing to adopt higher animal welfare standards as long as they fit  
391 the current farm set-up, are reversible and cover the additional costs (Gocsik et al., 2015). The  
392 lack of insight into the economic costs of aggression is likely to limit farmers' willingness to  
393 put resources into controlling the problem. There is a need for cost-effectiveness analysis of  
394 aggression mitigation strategies to identify the most economically feasible approaches. This  
395 should complement efforts to quantify farmers' willingness to pay for welfare improvements  
396 that take the different capital and labour costs of implementing strategies into account.

397 Effective communication between researchers and farmers is vital at all stages of the research  
398 process for the successful development, acceptance, and adoption of innovations or  
399 techniques (Clarke, 2003). It is acknowledged that, although communication of science is  
400 important, it is generally not done well (Treise and Weigold, 2002) and requires improvement  
401 (Clarke, 2003; Grandin, 2003). It was previously recognised that there is a need for one-to-  
402 one communication and discussion, and for a move away from the unidirectional lecture  
403 format that both intimidates farmers and denies scientists the opportunity to respond based on  
404 the knowledge base of their audience (Clarke, 2003; Benard and Buning, 2013). For  
405 innovations to be implemented into industry they need to be well communicated and tested,  
406 and early adopters need to be supported to ensure successful implementation (Grandin, 2003).  
407 Who delivers the information may be important. Alacorn et al. (2014) found that veterinarians  
408 are a trusted source of information whilst researchers are associated with several negative  
409 themes, such as 'lack of communication', 'not knowing where to look', and 'information bias'  
410 (Alarcon et al., 2014). Therefore, the support of mitigation strategies by veterinarians may  
411 improve the practical application of research findings.

412 Societal concern about animal welfare has driven change in practice for several animal  
413 welfare issues, with campaigns to bring change either resulting in government regulations or  
414 change in retailer standards, for example in restricting use of conventional battery cages for  
415 laying hens (Appleby, 2003), sow stalls and veal crates for calves in the EU (Druce and  
416 Lymbery, 2006). A European Commission study found that 76% of EU citizens (from a

417 sample of over 24000) believe that they can influence the welfare of farmed animals for the  
418 better through their purchasing behaviour (Eurobarometer, 2005). However, consumers have  
419 limited knowledge of intensive animal husbandry systems (Schröder and McEachern, 2004),  
420 and problems like pig aggression are unknown to the majority of society and therefore may  
421 not drive industry towards change on this matter.

422

## 423 **6. Conclusions and recommendations**

424 Mixing aggression between pigs continues to be an important topic in animal welfare research  
425 as the problem persists in practice. Although research has identified a number of aggression  
426 mitigation strategies they are not being implemented much at industry level. Apart from  
427 keeping pigs in stable groups throughout the production cycle there is no unified solution to  
428 effectively reduce aggression. Rather, aggression like many other welfare problems requires a  
429 multidisciplinary solution. Breeding and pre-weaning socialisation can help animals to better  
430 cope with the commercial farming environment. Housing pigs in relatively large groups,  
431 while providing a diet high in tryptophan, synthetic maternal pheromones and sufficient  
432 space, may create an environment that reduces aggressive behaviour. There is minimal uptake  
433 of these mitigation strategies which may be due to low prioritisation of the problem, the  
434 practicalities of implementation, ineffective communication of research to the farming  
435 community and economic factors.

436 We recommend that researchers provide evidence that strategies are practical in a commercial  
437 farming environment; that they calculate the economic cost-effectiveness of doing so; and that  
438 they effectively communicate this information to farmers and other stakeholders. Where  
439 possible, farmers and other stakeholders should be involved in the early stages of a project so  
440 that they can contribute effectively to designing interventions. We recommend a better  
441 alignment between research questions and industry interests to increase the success of  
442 research efforts to improve animal welfare in practice.

443

## 444 **Acknowledgements**

445 This research was funded by Scotland's Rural College (SRUC). SRUC receives financial  
446 support from the Scottish Government. We would like to thank Professor Eddie Clutton for  
447 providing constructive comments on the manuscript.

448

449 Conflicts of interest: The authors declare to have no conflicts of interest.

450

451 **References**

- 452 Aarestrup, F., 2012. Get pigs off antibiotics. *Nature* 486, 465-466.
- 453 Adeola, O., Ball, R.O., 1992. Hypothalamic neurotransmitter concentration and meat quality  
454 in stressed pigs offered excess dietary tryptophan and tyrosine. *Journal of Animal Science* 70,  
455 1888-1894.
- 456 Agriculture and Horticulture Development Board, 2016. The current state of the UK pig  
457 market, Briefing Document.
- 458 Alarcon, P., Wieland, B., Mateus, A.L.P., Dewberry, C., 2014. Pig farmers' perceptions,  
459 attitudes, influences and management of information in the decision-making process for  
460 disease control. *Preventive Veterinary Medicine* 116, 223-242.
- 461 Andersen, I.L., Andenaes, H., Boe, K.E., Jensen, P., Bakken, M., 2000. The effects of weight  
462 asymmetry and resource distribution on aggression in groups of unacquainted pigs. *Applied*  
463 *Animal Behaviour Science* 68, 107-120.
- 464 Andersen, I.L., Naevdal, E., Bakken, M., Boe, K.E., 2004. Aggression and group size in  
465 domesticated pigs, *Sus scrofa*: 'when the winner takes it all and the loser is standing small'.  
466 *Animal Behaviour* 68, 965-975.
- 467 Appleby, M.C., 2003. European Union Ban on Conventional Cages for Laying Hens: History  
468 and Prospects. *Journal of applied animal welfare science* 6, 103-121.
- 469 Arey, D.S., Edwards, S.A., 1998. Factors influencing aggression between sows after mixing  
470 and the consequences for welfare and production. *Livestock Production Science* 56, 61-70.
- 471 Barnett, J.L., Cronin, G.M., McCallum, T.H., Newman, E.A., 1994. Effects of food and time  
472 of day on aggression when grouping unfamiliar pigs. *Applied Animal Behaviour Science* 39,  
473 339-347.
- 474 Benard, M., Buning, T.D., 2013. Exploring the Potential of Dutch Pig Farmers and Urban-  
475 Citizens to Learn Through Frame Reflection. *Journal of Agricultural & Environmental Ethics*  
476 26, 1015-1036.

477 Bijma, P., 2014. The quantitative genetics of indirect genetic effects: a selective review of  
478 modelling issues. *Heredity* 112, 61-69.

479 Blackshaw, J.K., 1981. The effect of pen design and the tranquilizing drug, azaperone, on the  
480 growth and behaviour of weaned pigs. *Australian Veterinary Journal* 57, 272-276.

481 Bock, B.B., van Huik, M.M., 2007. Animal welfare: the attitudes and behaviour of European  
482 pig farmers. *British Food Journal* 109, 931-944.

483 Brummer, F., Moeller, S.J., Bernick, K., 2008. Automatic Sorting Technology for Large Pen  
484 Finishing, In: Gateway, P.I. (Ed.), <http://porkgateway.org>.

485 Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2017. Hiding walls  
486 for fattening pigs: do they affect behavior and performance? *Applied Animal Behaviour*  
487 *Science*.

488 Caine, W.R., Schaefer, A.L., Aalhus, J.L., Dugan, M.E.R., 2000. Behaviour, growth  
489 performance and pork quality of pigs differing in porcine stress syndrome genotype receiving  
490 dietary magnesium aspartate hydrochloride. *Canadian Journal of Animal Science* 80, 175-  
491 182.

492 Camerlink, I., Bijma, P., Kemp, B., Bolhuis, J.E., 2012. Relationship between growth rate and  
493 oral manipulation, social nosing, and aggression in finishing pigs. *Applied Animal Behaviour*  
494 *Science* 142, 11-17.

495 Camerlink, I., Turner, S.P., 2017. Farmers' perceptions of aggression between growing pigs.  
496 *Applied Animal Behaviour Science* 192C 42-47.

497 Camerlink, I., Turner, S.P., Bijma, P., Bolhuis, J.E., 2013. Indirect Genetic Effects and  
498 Housing Conditions in Relation to Aggressive Behaviour in Pigs. *PLoS One* 8, 9.

499 Canario, L., Turner, S.P., Roehe, R., Lundeheim, N., D'Eath, R.B., Lawrence, A.B., Knol, E.,  
500 Bergsma, R., Rydhmer, L., 2012. Genetic associations between behavioral traits and direct-  
501 social effects of growth rate in pigs. *Journal of Animal Science* 90, 4706-4715.

502 Clark, C.C.A., D'Eath, R.B., 2013. Age over experience: Consistency of aggression and  
503 mounting behaviour in male and female pigs. *Applied Animal Behaviour Science* 147, 81-93.

504 Clarke, B., 2003. Report: Farmers and scientists - A case study in facilitating communication.  
505 Sci. Commun. 25, 198-203.

506 Council Directive 2008/120/EC, 2008. Laying down minimum standards for the protection of  
507 pigs, L 47/5, Official Journal of the European Communities.

508 Coutellier, L., Arnould, C., Boissy, A., Orgeur, P., Prunier, A., Veissier, I., Meunier-Salaun,  
509 M.C., 2007. Pig's responses to repeated social regrouping and relocation during the growing-  
510 finishing period. Applied Animal Behaviour Science 105, 102-114.

511 D'Eath, R.B., 2005. Socialising piglets before weaning improves social hierarchy formation  
512 when pigs are mixed post-weaning. Applied Animal Behaviour Science 93, 199-211.

513 D'Eath, R.B., Ormandy, E., Lawrence, A.B., Sumner, B.E.H., Meddle, S.L., 2005. Resident-  
514 intruder trait aggression is associated with differences in lysine vasopressin and serotonin  
515 receptor 1A (5-HT1A) mRNA expression in the brain of pre-pubertal female domestic pigs  
516 (*Sus scrofa*). Journal of Neuroendocrinology 17, 679-686.

517 D'Eath, R.B., Turner, S.P., Kurt, E., Evans, G., Tholking, L., Looft, H., Wimmers, K.,  
518 Murani, E., Klont, R., Foury, A., Ison, S.H., Lawrence, A.B., Mormede, P., 2010. Pigs'  
519 aggressive temperament affects pre-slaughter mixing aggression, stress and meat quality.  
520 Animal 4, 604-616.

521 Dapoza, C., 2009. Tryptophan in swine nutrition,  
522 [https://www.pig333.com/nutrition/tryptophan-in-swine-nutrition\\_2088/](https://www.pig333.com/nutrition/tryptophan-in-swine-nutrition_2088/) [Accessed: 6th June  
523 2017].

524 de Lauwere, C., van Asseldonk, M., van't Riet, J., de Hoop, J., ten Pierick, E., 2012.  
525 Understanding farmers' decisions with regard to animal welfare: The case of changing to  
526 group housing for pregnant sows. Livestock Science 143, 151-161.

527 Desire, S., Turner, S.P., D'Eath, R.B., Doeschl-Wilson, A.B., Lewis, C.R.G., Roehe, R.,  
528 2015a. Genetic associations of short- and long-term aggressiveness identified by skin lesion  
529 with growth, feed efficiency, and carcass characteristics in growing pigs. Journal of Animal  
530 Science 93, 3303-3312.

531 Desire, S., Turner, S.P., D'Eath, R.B., Doeschl-Wilson, A.B., Lewis, C.R.G., Roehe, R.,  
532 2015b. Analysis of the phenotypic link between behavioural traits at mixing and increased  
533 long-term social stability. *Applied Animal Behaviour Science*, 52-62.

534 Druce, C., Lymbery, P., 2006. Outlawed in Europe, in: Singer, P. (Ed.), *In Defense of*  
535 *Animals: the second wave*, Blackwell Publishing Ltd.

536 Edwards, S.A., Mauchline, S., Stewart, A.H., 1993. Designing pens to minimize aggression  
537 when sows are mixed. *Farm Building Progress*, 20-23.

538 Ellen, E.D., Rodenburg, T.B., Albers, G.A.A., Bolhuis, J.E., Camerlink, I., Duijvesteijn, N.,  
539 Knol, E.F., Muir, W.M., Peeters, K., Reimert, I., Sell-Kubiak, E., van Arendonk, J.A.M.,  
540 Visscher, J., Bijma, P., 2014. The prospects of selection for social genetic effects to improve  
541 welfare and productivity in livestock. *Frontiers in Genetics* 5.

542 Eurobarometer, 2005. Attitudes of consumers towards the welfare of farmed animals, In:  
543 Commission, E. (Ed.), Brussels.

544 Francis, D.A., Christison, G.I., Cymbaluk, N.F., 1996. Uniform or heterogeneous weight  
545 groups as factors in mixing weanling pigs. *Canadian Journal of Animal Science* 76, 171-176.

546 Fredriksen, B., Lium, B.M., Marka, C.H., Mosveen, B., Nafstad, O., 2008. Entire male pigs in  
547 farrow-to-finish pens—Effects on animal welfare. *Applied Animal Behaviour Science* 110,  
548 258–268.

549 Fredriksen, B., Nafstad, O., 2006. Surveyed attitudes, perceptions and practices in Norway  
550 regarding the use of local anaesthesia in piglet castration. *Research in Veterinary Science* 81,  
551 293-295.

552 Gabor, T.M., Hellgren, E.C., Van den Bussche, R.A., Silvy, N.J., 1999. Demography,  
553 sociospatial behaviour and genetics of feral pigs (*Sus scrofa*) in a semi-arid environment.  
554 *Journal of Zoology* 247, 311-322.

555 Gadd, J., 2009. Some thoughts on big pens, [www.pigprogress.net](http://www.pigprogress.net).

556 Gocsik, E., van der Lans, I.A., Lansink, A., Saatkamp, H.W., 2015. Willingness of Dutch  
557 broiler and pig farmers to convert to production systems with improved welfare. *Animal*  
558 *Welfare* 24, 211-222.

559 Gonyou, H.W., 2001. The social behaviour of pigs, in: Keeling, L.J., Gonyou, H.W. (Eds.),  
560 Social Behaviour in Farm Animals, CAB International, Wallingford, UK, pp. 147–176.

561 Gonyou, H.W., Parfet, K.A.R., Anderson, D.B., Olson, R.D., 1988. Effects of amperozide and  
562 azaperone on aggression and productivity of growing-finishing pigs. Journal of Animal  
563 Science 66, 2856-2864.

564 Grandin, T., 2003. Transferring results of behavioral research to industry to improve animal  
565 welfare on the farm, ranch and the slaughter plant. Applied Animal Behaviour Science 81,  
566 215–228.

567 Grandin, T., Bruning, J., 1992. Boar presence reduces fighting in mixed slaughter-weight  
568 pigs. Applied Animal Behaviour Science 33, 273-276.

569 Greenwood, E.C., Plush, K.J., van Wetters, W., Hughes, P.E., 2014. Hierarchy formation in  
570 newly mixed, group housed sows and management strategies aimed at reducing its impact.  
571 Applied Animal Behaviour Science 160, 1-11.

572 Guy, J.H., Bums, S.E., Barker, J.M., Edwards, S.A., 2009. Reducing post-mixing aggression  
573 and skin lesions in weaned pigs by application of a synthetic maternal pheromone. Animal  
574 Welfare 18, 249-255.

575 Guzik, A.C., Matthews, J.O., Kerr, B.J., Bidner, T.D., Southern, L.L., 2006. Dietary  
576 tryptophan effects on plasma and salivary cortisol and meat quality in pigs. Journal of Animal  
577 Science 84, 2251-2259.

578 Hemsworth, P.H., Rice, M., Nash, J., Giri, K., Butler, K.L., Tilbrook, A.J., Morrison, R.S.,  
579 2013. Effects of group size and floor space allowance on grouped sows: Aggression, stress,  
580 skin injuries, and reproductive performance. Journal of Animal Science 91, 4953-4964.

581 Hessel, E.F., Reiners, K., Van den Weghe, H.F.A., 2006. Socializing piglets before weaning:  
582 Effects on behavior of lactating sows, pre- and postweaning behavior, and performance of  
583 piglets. Journal of Animal Science 84, 2847-2855.

584 Huet, S., 2016. Moins de stress avec les phéromones maternelles [*Less stress with maternal*  
585 *pheromones*]. L'avenir agricole 1779, 14.

586 Huttner, B., Goossens, H., Verheij, T., Harbarth, S., Consortium, C., 2010. Characteristics and  
587 outcomes of public campaigns aimed at improving the use of antibiotics in outpatients in  
588 high-income countries. *Lancet Infect. Dis.* 10, 17-31.

589 Ismayilova, G., Sonoda, L., Fels, M., Rizzi, R., Oczak, M., Viazzi, S., Vranken, E., Hartung,  
590 J., Berckmans, D., Guarino, M., 2014. Acoustic-reward learning as a method to reduce the  
591 incidence of aggressive and abnormal behaviours among newly mixed piglets. *Animal*  
592 *Production Science* 54, 1084–1090.

593 Ison, S.H., Bates, R.O., Ernst, C.W., Steibel, J.P., Siegford, J.M., in press. Housing, ease of  
594 handling and minimizing inter-pig aggression at mixing for nursery to finisher pigs as  
595 reported in a survey to North American pork producers, *Applied Animal Behaviour Science*.

596 Jensen, P., Wood-Gush, D.G.M., 1984. Social interactions in a group of free-ranging sows  
597 *Applied Animal Behaviour Science* 12, 327-337.

598 Jensen, P., Yngvesson, J., 1998. Aggression between unacquainted pigs - sequential  
599 assessment and effects of familiarity and weight. *Applied Animal Behaviour Science* 58, 49-  
600 61.

601 Kanaan, V.T., Pajor, E.A., Lay, D.C., Richert, B.T., Garner, J.P., 2008. A note on the effects  
602 of co-mingling piglet litters on pre-weaning growth, injuries and responses to behavioural  
603 tests. *Applied Animal Behaviour Science* 110, 386-391.

604 Koopmans, S.J., Guzik, A.C., van der Meulen, J., Dekker, R., Kogut, J., Kerr, B.J., Southern,  
605 L.L., 2006. Effects of supplemental L-tryptophan on serotonin, cortisol, intestinal integrity,  
606 and behavior in weanling piglets. *Journal of Animal Science* 84, 963-971.

607 Koopmans, S.J., Ruis, M., Dekker, R., van Diepen, H., Korte, M., Mroz, Z., 2005. Surplus  
608 dietary tryptophan reduces plasma cortisol and noradrenaline concentrations and enhances  
609 recovery after social stress in pigs. *Physiology & Behavior* 85, 469-478.

610 Kutzer, T., Bungler, B., Kjaer, J.B., Schrader, L., 2009. Effects of early contact between non-  
611 littermate piglets and of the complexity of farrowing conditions on social behaviour and  
612 weight gain. *Applied Animal Behaviour Science* 121, 16-24.

613 Ledergerber, K., Bennett, B., Diefenbacher, N., Shilling, C., Whitaker, B.D., 2015. The  
614 effects of socializing and environmental enrichments on sow and piglet behavior and  
615 performance. *The Ohio Journal of Science* 115, 40-47.

616 Li, Y.Z., Baidoo, S.K., Johnston, L.J., Anderson, J.E., 2011. Effects of tryptophan  
617 supplementation on aggression among group-housed gestating sows. *Journal of Animal*  
618 *Science* 89, 1899-1907.

619 Li, Y.Z., Kerr, B.J., Kidd, K.T., Gonyou, H.W., 2006. Use of supplementary tryptophan to  
620 modify the behavior of pigs. *Journal of Animal Science* 84, 212-220.

621 Lovendahl, P., Damgaard, L.H., Nielsen, B.L., Thodberg, K., Su, G.S., Rydhmer, L., 2005.  
622 Aggressive behaviour of sows at mixing and maternal behaviour are heritable and genetically  
623 correlated traits. *Livestock Production Science* 93, 73-85.

624 Maletinska, J., Špinka, M., 2001. Cross-suckling and nursing synchronisation in group housed  
625 lactating sows. *Applied Animal Behaviour Science* 75, 17-32.

626 Manteca, X., Jones, B., 2013. Welfare improvement strategies. *Improving Farm Animal*  
627 *Welfare: Science and Society Working Together: The Welfare Quality Approach*, 175-200.

628 McGlone, J.J., 1985. A quantitative ethogram of aggressive and submissive behaviours in  
629 recently regrouped pigs. *Journal of Animal Science* 61, 559-565.

630 McGlone, J.J., Anderson, D.L., 2002. Synthetic maternal pheromone stimulates feeding  
631 behavior and weight gain in weaned pigs. *Journal of Animal Science* 80, 3179-3183.

632 McGlone, J.J., Curtis, S.E., 1985. Behaviour and performance of weanling pigs in pens  
633 equipped with hide areas *Journal of Animal Science* 60, 20-24.

634 Mendl, M., Zanella, A.J., Broom, D.M., 1992. Physiological and reproductive correlates of  
635 behavioural strategies in female domestic pigs. *Animal Behaviour* 44, 1107-1121.

636 Millman, S.T., Duncan, I.J.H., Stauffacher, M., Stookey, J.A., 2004. The impact of applied  
637 ethologists and the International Society for Applied Ethology in improving animal welfare.  
638 *Applied Animal Behaviour Science* 86, 299-311.

639 Moore, A.J., Brodie, E.D., Wolf, J.B., 1997. Interacting phenotypes and the evolutionary  
640 process .1. Direct and indirect genetic effects of social interactions. *Evolution* 51, 1352-1362.

641 Morgan-Davies, C., Waterhouse, A., Milne, C.E., Stott, A.W., 2006. Farmers' opinions on  
642 welfare, health and production practices in extensive hill sheep flocks in Great Britain.  
643 Livestock Science 104, 268-277.

644 Morrow-Tesch, J.L., McGlone, J.J., 1990. Sources of maternal odors and the development of  
645 odor preferences in baby pigs. Journal of Animal Science 68, 3563-3571.

646 Morrow-Tesch, J.L., McGlone, J.J., Salakjohnson, J.L., 1994. Heat and social stress effects on  
647 pig immune measures. Journal of Animal Science 72, 2599-2609.

648 National Hog Farmer, 2010. Amino Acid Supplement Reduces Aggression in Young Female  
649 Pigs, [http://www.nationalhogfarmer.com/nutrition/ingredients/amino-acid-reduces-](http://www.nationalhogfarmer.com/nutrition/ingredients/amino-acid-reduces-aggression-0319)  
650 [aggression-0319](http://www.nationalhogfarmer.com/nutrition/ingredients/amino-acid-reduces-aggression-0319) [Accessed: 26th June 2017].

651 O'Driscoll, K., O'Gorman, D.M., Taylor, S., Boyle, L.A., 2013a. The influence of a  
652 magnesium-rich marine extract on behaviour, salivary cortisol levels and skin lesions in  
653 growing pigs. Animal 7, 1017-1027.

654 O'Driscoll, K., Teixeira, D.L., O'Gorman, D., Taylor, S., Boyle, L.A., 2013b. The influence of  
655 a magnesium rich marine supplement on behaviour, salivary cortisol levels, and skin lesions  
656 in growing pigs exposed to acute stressors. Applied Animal Behaviour Science 145, 92-101.

657 Olesen, L.S., Nygaard, C.M., Friend, T.H., Bushong, D., Knabe, D.A., Vestergaard, K.S.,  
658 Vaughan, R.K., 1996. Effect of partitioning pens on aggressive behavior of pigs regrouped at  
659 weaning. Applied Animal Behaviour Science 46, 167-174.

660 Olsen, A.N.W., Dybkjaer, L., Vestergaard, K.S., 1998. Cross-suckling and associated  
661 behaviour in piglets and sows. Applied Animal Behaviour Science 61, 13-24.

662 Pageat, P., 2001. Pig appeasing pheromones to decrease stress, anxiety and aggressiveness,  
663 US.

664 Pandolfi, F., Kyriazakis, I., Stoddart, K., Wainwright, N., Edwards, S.A., 2017. The "Real  
665 Welfare" scheme: Identification of risk and protective factors for welfare outcomes in  
666 commercial pig farms in the UK. Preventive Veterinary Medicine 146, 34-43.

667 Parratt, C.A., Chapman, K.J., Turner, C., Jones, P.H., Mendl, M.T., Miller, B.G., 2006. The  
668 fighting behaviour of piglets mixed before and after weaning in the presence or absence of a  
669 sow. *Applied Animal Behaviour Science* 101, 54-67.

670 Pearce, S.C., Gabler, N.K., Ross, J.W., Escobar, J., Patience, J.F., Rhoads, R.P., Baumgard,  
671 L.H., 2013. The effects of heat stress and plane of nutrition on metabolism in growing pigs.  
672 *Journal of Animal Science* 91, 2108-2118.

673 Peden, R.S.E., Turner, S.P., Camerlink, I., Unpublished work. PhD Project: Demand driven  
674 solutions to reduce aggression between pigs, Scotland's Rural College.

675 Pedersen, L.J., Studnitz, M., Jensen, K.H., Giersing, A.M., 1998. Suckling behaviour of  
676 piglets in relation to accessibility to the sow and the presence of foreign litters. *Applied*  
677 *Animal Behaviour Science* 58, 267-279.

678 Petherick, J.C., Blackshaw, J.K., 1987. A review of the factors influencing the aggressive and  
679 agonistic behaviour of the domestic pig. *Australian Journal of Experimental Agriculture* 27,  
680 605-611.

681 Phys.Org, 2010. Tryptophan-enriched diet reduces pig aggression,  
682 <https://phys.org/news/2010-03-tryptophan-enriched-diet-pig-aggression.html> [Accessed: 16  
683 June 2017].

684 Plush, K., Hughes, P., Herde, P., van Wettere, W., 2016. A synthetic olfactory agonist reduces  
685 aggression when sows are mixed into small groups. *Applied Animal Behaviour Science* 185,  
686 45-51.

687 Poletto, R., Kretzer, F.C., Hotzel, M.J., 2014. Minimizing aggression during mixing of  
688 gestating sows with supplementation of a tryptophan-enriched diet. *Physiology & Behavior*  
689 132, 36-43.

690 Poletto, R., Meisel, R.L., Richert, B.T., Cheng, H.W., Marchant-Forde, J.N., 2010.  
691 Aggression in replacement grower and finisher gilts fed a short-term high-tryptophan diet and  
692 the effect of long-term human-animal interaction. *Applied Animal Behaviour Science* 122,  
693 98-110.

694 Real Welfare, 2017. Baseline report: 2013-2016. Measuring welfare outcomes in pigs.  
695 Agriculture and Horticulture Development Board.

696 Rauterberg, S., Sonoda, L.T., Fels, M., Viazzi, S., Ismayilova, G., Oczak, M., Bahr, C.,  
697 Guarino, M., Vranken, E., Berckmans, D., Hartung, J., 2013. Cognitive enrichment in the  
698 farrowing pen - a first approach to use early behavioural conditioning of suckling piglets to  
699 reduce aggressive behaviour during rearing. *Zuchtungskunde* 85, 376-387.

700 Rushen, J., 1987. A difference in weight reduces fighting when unacquainted newly weaned  
701 pigs 1st meet *Canadian Journal of Animal Science* 67, 951-960.

702 Rydhmer, L., Zamaratskaia, G., Andersson, H.K., Algers, B., Guillemet, R., Lundstrom, K.,  
703 2006. Aggressive and sexual behaviour of growing and finishing pigs reared in groups,  
704 without castration. *Acta Agriculturae Scandinavica Section a-Animal Science* 56, 109-119.

705 Sabuncu, E., David, J., Bernede-Bauduin, C., Pepin, S., Leroy, M., Boelle, P.Y., Watier, L.,  
706 Guillemot, D., 2009. Significant Reduction of Antibiotic Use in the Community after a  
707 Nationwide Campaign in France, 2002-2007. *Plos Medicine* 6.

708 Salvage, B., 2010. Pig aggression cut by tryptophan enriched diet, *Meat Poultry*,  
709 [http://www.meatpoultry.com/articles/news\\_home/Business/2010/03/Pig\\_aggression\\_cut\\_by\\_t](http://www.meatpoultry.com/articles/news_home/Business/2010/03/Pig_aggression_cut_by_tryptoph.aspx?ID={0DAD4970-777C-4981-9250-8797E21059FD}&cck=1)  
710 [ryptoph.aspx?ID={0DAD4970-777C-4981-9250-8797E21059FD}&cck=1](http://www.meatpoultry.com/articles/news_home/Business/2010/03/Pig_aggression_cut_by_tryptoph.aspx?ID={0DAD4970-777C-4981-9250-8797E21059FD}&cck=1) [Accessed: 16th  
711 June 2017].

712 Samarakone, T.S., Gonyou, H.W., 2009. Domestic pigs alter their social strategy in response  
713 to social group size. *Applied Animal Behaviour Science* 121, 8-15.

714 Schröder, M.J.A., McEachern, M.G., 2004. Consumer value conflicts surrounding ethical  
715 food purchase decisions: a focus on animal welfare. *International Journal of Consumer*  
716 *Studies* 28, 168-177.

717 Seguin, M.J., Friendship, R.M., Kirkwood, R.N., Zanella, A.J., Widowski, T.M., 2006.  
718 Effects of boar presence on agonistic behavior, shoulder scratches, and stress response of bred  
719 sows at mixing. *Journal of Animal Science* 84, 1227-1237.

720 Semiokeys, SecurePig, <https://www.semiokeys.com/en/> [Accessed: 28th June 2017].

721 SemioKeys, SemioKeys Calculator, <https://matrice.semiokeys.com/> [Accessed: 28th June  
722 2017].

723 Semiokeys, 2016. Limite le stress chez le porc [*Limit stress in pigs*]. Réussir Porc 240, 36.  
724 Semiokeys, 2017. Des pheromones pour des cochons zen [*Pheromones for zen pigs*].  
725 Porcmag 516, 38-39.

726 Shen, Y.B., Voilque, G., Kim, J.D., Odle, J., Kim, S.W., 2012a. Effects of increasing  
727 tryptophan intake on growth and physiological changes in nursery pigs. Journal of Animal  
728 Science 90, 2264-2275.

729 Shen, Y.B., Voilque, G., Odle, J., Kim, S.W., 2012b. Dietary L-Tryptophan Supplementation  
730 with Reduced Large Neutral Amino Acids Enhances Feed Efficiency and Decreases Stress  
731 Hormone Secretion in Nursery Pigs under Social-Mixing Stress. J. Nutr. 142, 1540-1546.

732 Sonoda, L., Fels, M., Rauterberg, S., Viazzi, S., Ismayilova, G., Oczak, M., Bahr, C.,  
733 Guarino, M., Vranken, E., Berckmans, D., Hartung, J., 2013. Cognitive Enrichment in Piglet  
734 Rearing: An Approach to Enhance Animal Welfare and to Reduce Aggressive Behaviour.  
735 ISRN veterinary science.

736 Spoolder, H.A.M., Geudeke, M.J., Van der Peet-Schwering, C.M.C., Soede, N.M., 2009.  
737 Group housing of sows in early pregnancy: A review of success and risk factors. Livestock  
738 Science 125, 1-14.

739 Stolba, A., Wood-Gush, D.G.M., 1989. The behaviour of pigs in a semi-natural environment.  
740 Animal Production 48, 419-425.

741 Stookey, J.M., Gonyou, H.W., 1994. The effects of regrouping on behavioural and production  
742 parameters in finishing swine. Journal of Animal Science 72, 2804-2811.

743 Tan, S.S.L., Shackleton, D.M., 1990. Effects of mixing unfamiliar individuals and of  
744 azaperone on the social-behaviour of finishing pigs. Applied Animal Behaviour Science 26,  
745 157-168.

746 ter Beek, V., 2010. Tryptophan eases aggression in pigs, Pig World,  
747 [http://www.pigprogress.net/Home/General/2010/1/Tryptophan-eases-aggression-in-pigs-  
748 PP003811W/](http://www.pigprogress.net/Home/General/2010/1/Tryptophan-eases-aggression-in-pigs-PP003811W/) [Accessed: 11th May 2017].

749 Terlouw, E.M.C., Arnould, C., Auperin, B., Berri, C., Le Bihan-Duval, E., Deiss, V., Lefevre,  
750 F., Lensink, B.J., Mounier, L., 2008. Pre-slaughter conditions, animal stress and welfare:  
751 current status and possible future research. *Animal* 2, 1501-1517.

752 Treise, D., Weigold, M.F., 2002. Advancing science communication - A survey of science  
753 communicators. *Sci. Commun.* 23, 310-322.

754 Turner, S.P., D'Eath, R.B., Roehe, R., Lawrence, A.B., 2010. Selection against aggressiveness  
755 in pigs at re-grouping: practical application and implications for long-term behavioural  
756 patterns. *Animal Welfare* 19, 123-132.

757 Turner, S.P., Ewen, M., Rooke, J.A., Edwards, S.A., 2000. The effect of space allowance on  
758 performance, aggression and immune competence of growing pigs housed on straw deep-litter  
759 at different group sizes. *Livestock Production Science* 66, 47-55.

760 Turner, S.P., Farnworth, M.J., White, I.M.S., Brotherstone, S., Mendl, M., Knap, P., Penny,  
761 P., Lawrence, A.B., 2006a. The accumulation of skin lesions and their use as a predictor of  
762 individual aggressiveness in pigs. *Applied Animal Behaviour Science* 96, 245-259.

763 Turner, S.P., Horgan, G.W., Edwards, S.A., 2001. Effect of social group size on aggressive  
764 behaviour between unacquainted domestic pigs. *Applied Animal Behaviour Science* 74, 203-  
765 215.

766 Turner, S.P., Horgan, G.W., Edwards, S.A., 2003. Assessment of sub-grouping behaviour in  
767 pigs housed at different group sizes. *Applied Animal Behaviour Science* 83, 291-302.

768 Turner, S.P., Roehe, R., D'Eath, R.B., Ison, S.H., Farish, M., Jack, M.C., Lundeheim, N.,  
769 Rydhmer, L., Lawrence, A.B., 2009. Genetic validation of postmixing skin injuries in pigs as  
770 an indicator of aggressiveness and the relationship with injuries under more stable social  
771 conditions. *Journal of Animal Science* 87, 3076-3082.

772 Turner, S.P., Roehe, R., Mekki, W., Farnworth, M.J., Knap, P.W., Lawrence, A.B., 2008.  
773 Bayesian analysis of genetic associations of skin lesions and behavioural traits to identify  
774 genetic components of individual aggressiveness in pigs. *Behav. Genet.* 38, 67-75.

775 Turner, S.P., White, I.M.S., Brotherstone, S., Farnworth, M.J., Knap, P.W., Penny, P., Mendl,  
776 M., Lawrence, A.B., 2006b. Heritability of post-mixing aggressiveness in grower-stage pigs  
777 and its relationship with production traits. *Animal Science* 82, 615-620.

778 van Nieuwamerongen, S.E., Soede, N.M., van der Peet-Schwering, C.M.C., Kemp, B.,  
779 Bolhuis, J.E., 2015. Development of piglets raised in a new multi-litter housing system vs.  
780 conventional single-litter housing until 9 weeks of age. *Journal of Animal Science* 93, 5442-  
781 5454.

782 Wattanakul, W., Sinclair, A.G., Stewart, A.H., Edwards, S.A., English, P.R., 1997a.  
783 Performance and behaviour of lactating sows and piglets in crate and multisuckling systems:  
784 A study involving European White and Manor Meishan genotypes. *Animal Science* 64, 339-  
785 349.

786 Wattanakul, W., Stewart, A.H., Edwards, S.A., English, P.R., 1997b. Effects of grouping  
787 piglets and changing sow location on suckling behaviour and performance. *Applied Animal*  
788 *Behaviour Science* 55, 21-35.

789 Weary, D.M., Pajor, E.A., Bonenfant, M., Ross, S.K., Fraser, D., Kramer, D.L., 1999.  
790 Alternative housing for sows and litters: 2. Effects of a communal piglet area on pre- and  
791 post-weaning behaviour and performance. *Applied Animal Behaviour Science* 65, 123-135.

792 Webster, A.J.F., 1982. The economics of farm animal-welfare. *International Journal for the*  
793 *Study of Animal Problems* 3, 301-306.

794 Wilson, R.L., Holyoake, P.K., Cronin, G.M., Doyle, R.E., 2014. Managing animal wellbeing:  
795 a preliminary survey of pig farmers. *Australian Veterinary Journal* 92, 206-212.

796 Yonezawa, T., Koori, M., Kikusui, T., Mori, Y., 2009. Appeasing Pheromone Inhibits  
797 Cortisol Augmentation and Agonistic Behaviors During Social Stress in Adult Miniature Pigs.  
798 *Zoological Science* 26, 739-744.

799 Ziggers, D., 2009. Tryptophan eases aggression in pigs, *All About Feed*,  
800 <http://www.allaboutfeed.net/Home/General/2009/12/Tryptophan-eases-aggression-in-pigs->  
801 [AAF003963W/](http://www.allaboutfeed.net/Home/General/2009/12/Tryptophan-eases-aggression-in-pigs-AAF003963W/) [Accessed: 16th June 2017].

802 Ziggers, D., 2010. Tryptophan reduces aggressiveness in pigs, All About Feed,  
803 [http://www.allaboutfeed.net/Home/General/2010/3/Tryptophan-reduces-aggressiveness-in-](http://www.allaboutfeed.net/Home/General/2010/3/Tryptophan-reduces-aggressiveness-in-pigs-AAF004261W/)  
804 [pigs-AAF004261W/](http://www.allaboutfeed.net/Home/General/2010/3/Tryptophan-reduces-aggressiveness-in-pigs-AAF004261W/) [Accessed: 16th June 2017].

805