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

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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

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 25m² 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

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448

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450

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