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Consistency of piglet crushing by sows

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Abstract

Piglet mortality is a major welfare and economic problem in the pig industry. Despite the use of farrowing crates, piglet crushing remains a major contributor to pre-weaning piglet mortality, which is typically around 12%. Our aims in this study were to quantify variability between sows and consistency across parities in crushing mortality, and to examine the effect of the environment on variability. In our first study, we compared the variability in crushing mortality in 122 primiparous sows (gilts) that farrowed in crates (71) or open pens (51). Certain sows crushed more or fewer piglets than expected by chance. Crushing was more frequent and more variable in pens compared to crates, indicating that crates may mask differences between sows. In our second study, we recorded piglet mortality for 125 sows, which farrowed in crates over several (4–9) parities. After adjusting for litter size, litter weight and parity effects, consistent individual differences between sows were evident. The repeatability of crushing was estimated at 0.14, with estimates of 0.18 and 0.05 for stillborns and total liveborn mortality, respectively. Although these repeatabilities are relatively low, there was a high degree of phenotypic variance (eg sows crushed between 0 and 30.8% of their piglets). Given that sows show some consistency in piglet mortality over parities, this could be used to inform culling decisions. Additionally, if differences in piglet crushing between sows have a genetic component, a breeding programme might reduce mortality from crushing. Because crates restrict maternal behaviour, genetic selection in this system may have relaxed selection for good maternal behaviour. Selection for reduced piglet mortality, and thus improved maternal abilities, could remove a major obstacle to the wider adoption of less restrictive farrowing systems, with positive welfare consequences for the sow and piglets.

Keywords: *animal welfare, breeding goals, individual differences, pre-weaning piglet mortality, repeatability, sow*

Introduction

A high level of pre-weaning piglet mortality (12.2% [indoors] according to the MLC [2002]) continues to be a major economic and welfare problem in the pig industry in the UK and overseas. A major cause of piglet death is crushing by the sow (Dyck & Swierstra 1987; Vrbanac *et al* 1995; Edwards 2002; Grandinson *et al* 2002). Farrowing crates have been partly successful in reducing the incidence of crushing mortality (Edwards & Fraser 1997), but it is possible that they cause an increase in other types of mortality such as stillbirths and savaging, perhaps as a result of the stress imposed by restriction of the sow's natural nest-building (Lawrence *et al* 1994; Jarvis *et al* 1997) and piglet-bonding behaviour (Jensen 1986; Blackshaw & Hagelsø 1990; Jarvis *et al* 2004).

Farrowing crates have negative consequences on the welfare of parturient sows (Lawrence *et al* 1994; Jarvis *et al* 1997), and there is increasing public concern about their use. The European Union Scientific Veterinary Committee's review of the welfare of pigs (EUSVC 1997) recommended the "further development of farrowing systems in which the sow can be kept loose and carry out normal nest building", a view recently echoed by the Council of Europe (2003). Various attempts have been made to design alternative farrowing systems that allow the sow more freedom of movement while maintaining a high production output (Edwards & Fraser 1997). Unfortunately, small-scale studies using alternative loose-housing systems have often resulted in increased problems concerning piglet survival (McGlone & Morrow-Tesch 1990; Bøe 1994) or have encountered these problems when tested on a commercial scale (Edwards & Fraser 1997). In particular, crushing mortality is generally higher in pens and outdoor systems than in farrowing crates (Blackshaw *et al* 1994; Edwards *et al* 1994; Marchant *et al* 2000). The high level of crushing deaths in loose-housing systems is bad for piglet welfare and for productivity, and remains a major obstacle to their adoption. The suggested compromise — the use of crates only before farrowing and for the first few days after farrowing (eg RSPCA 2000) — is not ideal from the sow's perspective. This is because the greatest welfare impact of the crate occurs in the hours preceding farrowing, when the sow's attempts to build a nest are restricted (Lawrence *et al* 1994; Jarvis *et al* 1997, 2002).

A potential complementary approach to developing new farrowing systems is to identify and breed for genotypes of sow that can successfully rear piglets in less restrictive farrowing environments without crushing them (eg English 1993). Piglet mortality differs between sow breeds, regardless of piglet genotype (Van der Steen & DeGroot 1992),

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and selection for reduced piglet mortality within commercial lines may be feasible (Grandinson *et al* 2002; Knol *et al* 2002). Genetic selection over the past few decades has been focused mainly on production traits such as number born alive (Avalos & Smith 1987; Rydhmer 2000) and lean tissue growth rate (Herpin *et al* 1993). Mouse models show that selection for numbers born causes females to partition resources to offspring during pregnancy at the expense of lactation, leading to increased pre-weaning mortality (Rauw *et al* 1999), and that selection for total litter weight at weaning was preferable (Luxford & Beilharz 1990). Selection has also resulted in a population of larger sows (Whittemore 1994). Large body size leads to greater restriction of movement in the same size crate, and may also present a greater risk of death to a trapped piglet. Because genetic selection of sows has taken place in the farrowing crate environment, in which a sow's opportunities to affect piglet mortality through her behaviour are restricted, selection pressure on good maternal behaviour has very probably been relaxed. This may account for the current population of sows that are less well adapted to loose-housing systems and perhaps less motivated to perform maternal behaviour (Rudd & Marchant 1995).

Previous studies on the genetics of pre-weaning piglet mortality have generally focused on total mortality from all causes, with the exception of studies showing that piglet-directed aggression (savaging) is heritable (Knap & Merks 1987; Van der Steen *et al* 1988). Heritability estimates reported are 0.11 (Yorkshire Large White, Pietrain [Van Arendonk *et al* 1996]) and 0.08 (TOPIGS commercial lines [Knol *et al* 2002]) for sows farrowing in crates. Different causes of mortality are quite distinct and their incidence varies greatly with the type of farrowing environment used; however, crushing is a major cause of death both in crates and in pens. To our knowledge only one study has estimated heritabilities separately for different causes of mortality in farrowing pens (Yorkshire [Grandinson *et al* 2002]: crushing 0.06, stillbirth 0.15). Although all of the heritability estimates mentioned are low, they are typical for reproductive traits. In addition to heritability, another important criterion that determines whether genetic progress can be made is the level of genetic variation between animals. A demonstration of the genetic and/or phenotypic variation between sows in piglet mortality, particularly crushing, would be important in elucidating the extent of the inter-animal variation and hence the likelihood of making genetic progress. However, the use of farrowing crates may in itself be masking much of the potential variation in crushing. Therefore the first aim of the present study was to demonstrate differences between litters in the frequency of crushing deaths (Fraser 1990; Rudd & Marchant 1995) and to investigate the extent to which differences between sows and litters in piglet crushing are evident in loose and restrictive housing systems.

Our second aim was to test whether variation between sows in piglet crushing is stable over repeated parities of the same sow and can therefore be considered to be a consistent characteristic of that individual. At present, the one existing estimate of the heritability of crushing is based on data from primiparous sows (gilts) only (Grandinson *et al* 2002). Certain litter characteristics known to influence crushing risk such as number of piglets and litter weight were accounted for in our analyses, in order to more accurately assess the sow's contribution to consistency across parities. As well as having implications for genetic studies, evidence of consistency in crushing could inform sow culling decisions made by pig farmers.

Study 1: Individual differences in piglet crushing

Materials and methods

Data were compiled from primiparous sows (gilts) involved in a series of experiments comparing the behaviour and welfare of gilts housed in crates and pens. These studies were carried out under a UK Home Office licence in accordance with the Animals (Scientific Procedures) Act 1986. The studies were also reviewed and approved by the Animal Experiments Committee of the Scottish Agricultural College.

Animals

Data were collected between 1990 and 2000 from 122 Large White × Landrace gilts mated with a Large White boar on a commercial pig farm (Easter Howgate Pig Unit, Milton Bridge, Penicuik, Midlothian, Scotland). The gilts and boars were obtained from the Cotswold Pig Development Company, Lincoln, UK.

Housing and management

Service and pregnancy

The gilts (purchased at approximately six months of age) were housed in straw-bedded pens (2.6 × 4.1 m) in groups of four to six. The individual boar pens were adjacent to the gilt pens. The animals were fed 2.5 kg day^{-1} of home-mixed feed (14.4% crude protein [CP], 13.1 MJ digestible energy [DE] per kg) from individual feeders at 0800h. Water was available *ad libitum* from nipple drinkers. Fresh straw for bedding was provided twice per week. Artificial lighting was provided between 0800h and 1600h. When oestrus was detected, two boars were used to serve the gilt over a period of two days. On a few occasions artificial insemination was used on the second day but the semen used was from the same Cotswold line as the boars on the farm. The expected parturition day was calculated as 114 days after the first service day.

Once pregnancy was confirmed at around 32 days after service, the gilts were housed in groups of three or four in a semi-open building in pens consisting of a concrete yard (6.0 × 4.0 m) with a straw-bedded kennel area at the back (6.0 × 1.5 m). The pens were cleaned daily and fresh straw was provided twice per week. The gilts were floor-fed 2.5 kg day^{-1} of the same home-mixed feed at 0800h. In May of 2000, a disease eradication programme took place. Pregnant sows were temporarily re-housed, before being vaccinated and returned.

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Table 1 Definitions of different causes of piglet deaths. When two causes were involved in the death of a piglet, piglet-based factors were given priority. For instance, when a low viability piglet was found crushed, the death was categorised as 'low viability', thereby avoiding overestimation of crushing rate.

Cause of death	Definition
Stillborn	Fully formed (not mummified) piglet with umbilical cord wet and white in appearance, periople on hooves.
Crushed	Piglet found close to the sow, having a squashed and bruised appearance.
Savaged	Piglet found with severe external lacerations (attributable to piglet-directed aggressive behaviour by the sow).
Low viability	Piglet very thin, in poor condition and emaciated: pin-bones obvious, cavity around tail setting, loin narrow, vertebrae prominent, individual ribs easily felt and seen.
Other causes	Broken legs, bleeding navel, greasy pig disease, scour (diarrhoea), blind anus, splay leg, other deformations, unidentified causes.

Farrowing and lactation

Gilts were moved to the farrowing unit 5–7 days before the expected parturition day. They were randomly assigned to either a conventional farrowing crate (n = 71) or a farrowing pen (n = 51). The crate (2.25 × 0.45 × 1.05 m, length × width × height) had a solid floor with a slatted dunging area at the back, whilst the pen (2.5 × 3.0 m, length × width) had a solid floor that was sloped to allow drainage. Both systems were cleaned daily, and fresh straw was provided daily. Sows were allowed to farrow naturally, supervised by trained staff. If a gilt had not had a piglet for 2.5 h, an internal examination was performed and piglets assisted through the birth canal. These delivered piglets were left at the rear end of the gilt to make their own way to the udder. If gilts savaged one piglet the remaining and any new piglets were moved to the creep area until parturition had finished, at which point the gilt was treated with the sedative azaperone (Stresnil) and the piglets returned. Piglets that were lying shivering away from the gilt or creep area were placed either next to the udder or in the creep, whichever was closer. No piglets were fostered. The farrowing systems were in temperature-controlled rooms with artificial lighting between 0800h and 1600h. Sows were offered a commercial lactation feed, to appetite, daily (18% CP, 13.75 MJ DE kg^{-1}) in two meals at 0800h and 1600h. Piglets were given iron injections and had their teeth clipped and litter weight measured at two days post partum. Piglets were weaned at about four weeks of age, after which the gilts were returned to farm stock.

Data collection

For each individual gilt the number of piglets born alive was recorded, as was the number of piglet deaths and their cause (see Table 1 for definitions). The data were collected by the same experienced stockperson, with occasional input from an assistant, throughout the entire study. Criteria used to identify cause of death were established *post hoc* based on descriptions made by, and discussions with, this stockperson.

Statistical analysis

A logistic regression model was fitted, which allowed data to be analysed assuming a binomial error structure (since each piglet was either alive or dead) and using a Logit transformation (Genstat, Version 5, Lawes Agricultural Trust, Rothamsted Experimental Station). To test the effect of environment (crate or pen) on crushing risk, this model was run with and without environment included. The difference in deviance between these two models was compared using a chi-squared statistic with one degree of freedom. To assess the extent of variation between litters, Generalised Linear Mixed Models (GLMMs) were then fitted in order to model crushing risk in each housing type separately (crates and pens). If the risk of a piglet being crushed is the same in all litters, then the distribution of crushing should fit a binomial distribution. Otherwise, sows with fewer or more piglets crushed than expected would be over-represented in the sample. Evidence for this was assessed by comparing the residual deviance after fitting this binomial model to a chi-squared distribution with appropriate degrees of freedom (Collett 2003).

Results

The mean (± SE) number of piglets born alive in pens and crates was 11.5 (± 0.41) and 10.7 (± 0.38), respectively. Of these, 1.4 piglets (± 0.25) in pens and 0.6 piglets (± 0.12) in crates died from crushing. The crushing risk was significantly greater in pens than in crates ($\chi^2 = 10.48$; $df = 1$; $P = 0.001$).

In both environments, there was significant evidence that crushing risk varied between litters more than would be expected by chance. Litters with fewer or greater than expected numbers of deaths were over-represented in the sample. This was true for gilts farrowing in crates ($\chi^2 = 95.2$; $df = 70$; $P = 0.024$; Figure 1a), whilst even stronger evidence of over-dispersion was evident for gilts farrowing in pens ($\chi^2 = 102.9$; $df = 50$; $P < 0.0001$; Figure 1b).

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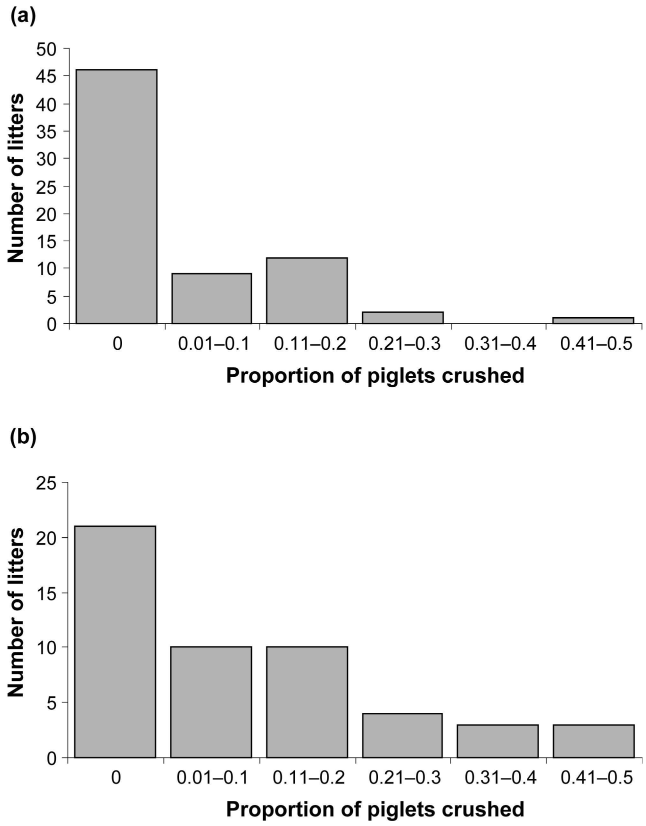
Figure 1



Graph showing the proportion of piglets crushed by gilts farrowing in **(a)** crates (n = 71) and **(b)** pens (n = 51).

Study 2: Consistency of piglet crushing and other causes of death

Materials and methods

Farm production records were analysed retrospectively.

Animals, housing and management

Details were the same as for Study 1, except that records from 125 sows that had farrowed at least four times were used. Sows that savaged piglets in their first and/or second parity were often culled, so savaging sows were under-represented in our study sample. No other forms of mortality were used as criteria for culling sows. There was a total of 793 farrowings between 1990 and 2001. The mean (± SE) final parity number was 6.3 (± 0.14) with 14 sows reaching parity nine. Gilts and newly weaned sows were housed and fed as for Study 1 except that all farrowed in crates with straw. These farrowings were generally unsupervised, and assisted delivery occurred in only 14 cases (10 of which involved oxytocin injection).

Data collection

As for Study 1, the same stockperson was responsible for keeping production records on a litter record card for the farrowing sows. The following data were collected from these litter record cards for analysis:

1. Length of gestation.
2. Year and season of farrowing (Spring = March–May; Summer = June–August; Autumn = September–November; Winter = December–February).
3. Number of piglets born alive.
4. Number of intra-partum stillbirths (excluding mummified piglets).
5. Number of liveborn piglet deaths before weaning, together with the cause and age at death. The cause of death for each piglet was categorised from external observation by the stockperson (see Table 1 for definitions).
6. Litter weight.

Litter weight was measured two days after birth. Fostering of piglets was sometimes practiced on Days 2–3 after farrowing in cases of unusually small or large litters (31% of litters had piglets fostered on or off, or both). However, since a high proportion of piglet mortality occurs within 48 h post partum (English & Smith 1975; Marchant *et al* 2000), we used only the number of piglets in the litter at birth in our analysis. Records that were missing because of lost or blank cards were entered as missing data.

Statistical analysis

GLMs were fitted using the IRREML option of Genstat (Genstat, Version 5, Lawes Agricultural Trust, Rothamsted Experimental Station), using a binomial error structure and a Logit transformation. Different types of piglet mortality were fitted as Y-variates. The number of stillborn piglets was analysed as a proportion of the total number born, and liveborn piglet mortality was analysed as a proportion of the number born alive. Three aspects of liveborn mortality were analysed: mortality resulting from crushing, mortality resulting from low viability, and total liveborn mortality (from any cause). The following factors were fitted as fixed effects in the model: parity number, farrowing season and farrowing year (fitted as factors), number of piglets born alive, litter weight, and gestation length. The effects of each factor were estimated after adjusting for all other model terms.

The direction of effects of the variates (gestation length, number of piglets born and litter weight) and factors (parity, farrowing season and year) were determined using coefficients of effect and predicted means, respectively. Statistical significance was determined using Wald statistics. These approximately follow a Chi-square distribution, and so have been reported as χ^2 in the results, with a subscript to indicate the appropriate degrees of freedom.

Variation between sows and consistency in piglet mortality

The consistency of sows in the different types of piglet mortality was assessed by testing whether there was evidence for between-sow variation. This was investigated by re-running each model with 'sow' left out of the random model, and calculating the change in the deviance explained. To calculate the statistical significance of 'sow', the change in deviance was treated as a Chi-square statistic

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with one degree of freedom. Repeatability (R) was calculated using the following formula:

R = between-sow variation / (between-sow variation + within-sow variation)

Phenotypic variation between sows was characterised by calculating the mean (± SD) percentage of each sow's piglets that died from each cause of mortality.

Results

Sow performance

The mean (± SE) number of piglets born per litter (alive or stillborn) was 12.2 (± 0.13). Of these, the mean (± SE) number born alive was 11.4 (± 0.12), ranging from 0 to 20. The mean litter weight was 15.7 (± 0.16) kg. Gestation length showed a wide range from 111 to 122 days, with a mean (± SE) of 115.1 (± 0.05) days. The number of farrowings per season was as follows: Spring = 204, Summer = 189, Autumn = 205, Winter = 195.

Piglet mortality

Of the 8267 piglets born, 540 (6.5%) were intra-partum stillbirths, leaving 7727 born alive. A further 1185 of these liveborn piglets died before weaning: 559 were crushed, 366 were low viability, 14 were savaged and 246 died from other causes.

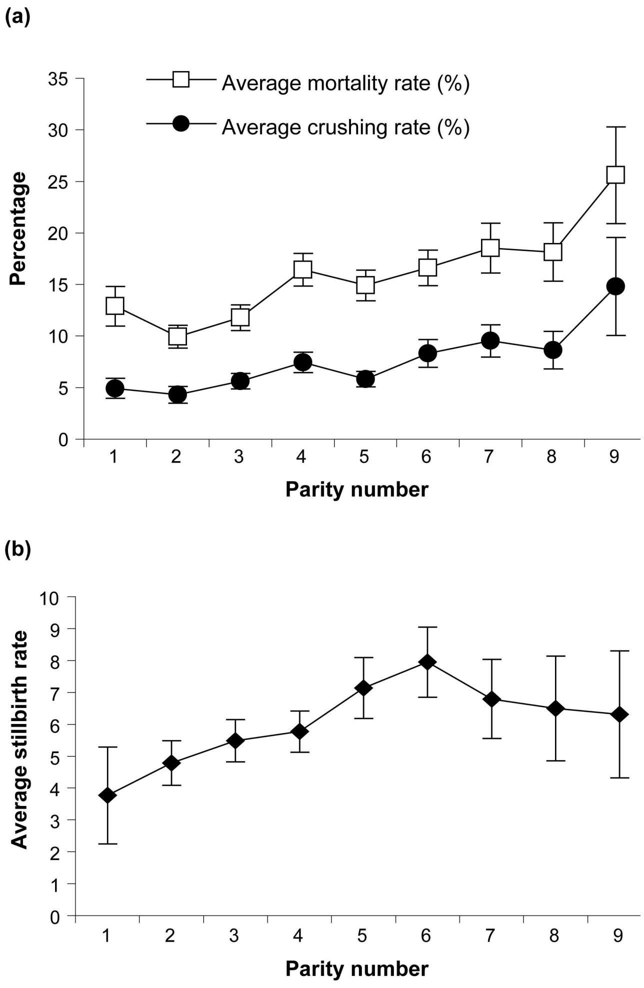
Factors affecting piglet mortality

Increasing number of piglets born, having accounted for all other factors, was associated with a higher mortality for all causes examined, as was lower litter weight (Table 2). Mortality resulting from crushing increased with parity, and total liveborn mortality increased after Parity 2, with a higher mortality in Parity 1 (Figure 2a). Higher parity number was also associated with an increasing proportion of stillborn piglets, with the highest stillbirth rate occurring in Parities 5 and 6 (Figure 2b). Gestation length and farrowing season had no significant effect on any cause of piglet mortality. Farrowing year affected stillborns (χ^2_1 = 18.6; P < 0.0001) and total deaths (χ^2_1 = 17.3; P < 0.0001). Inspection of the data suggested that the effect of year on stillbirths was due to a higher frequency during 2000. This may have been a result of disruption to pregnant sow housing during a disease eradication programme.

Variation between sows and consistency in piglet mortality

Each sow's overall piglet mortality resulting from the different causes was calculated. Means (± SD) and ranges are illustrated in Table 2. As can be seen from the size of the standard deviations relative to the mean, phenotypic variation between individual sows was high. Evidence was found for between-sow variation in the proportion of crushed piglets, indicating that individual sows showed some consistency across parities in crushing of piglets (Table 3). Individual sows also showed significant evidence of consistency in stillborn piglets, deaths as a result of low viability and total liveborn deaths across parities. To quantify consistency, estimates were made of repeatability for the different causes of mortality (Table 3).

Figure 2



The effect of parity on piglet mortality. **(a)** Percentage of liveborn deaths from any cause (total liveborn deaths; χ^2_8 = 27.9, P = 0.0005) and from crushing (χ^2_8 = 20.0; P = 0.0103). **(b)** Percentage of stillborn piglets (expressed as a percentage of total born alive or dead; χ^2_8 = 18.6; P = 0.0172).

Discussion

In Study 1, crushing risk was not uniform across the litters of different gilts. Instead, piglets in certain litters had a higher or lower risk of being crushed than would be expected by chance. Differences between litters were more clear-cut in the loose-housing environment (pens) than in crates. This difference between environments is likely to be due to the crate's restriction of both good and bad maternal behaviour by the sow, reducing the range of variation in crushing deaths. For example, turning around and performing piglet-directed investigations before lying down is a natural behaviour (Frädrich 1974) known to reduce the risk of crushing by loose-housed sows (Marchant *et al*

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Table 2 Coefficients of effect for the effects of litter size and litter birth weight on mortality and percentage of piglets dying per sow (mean, standard deviation [SD] and range), for each of the causes of death analysed (* indicates $P < 0.001$).**

Cause of death (coefficients)	Effects on mortality		Percentage of piglets dying per sow			
	Litter size	Litter birth weight	Mean	SD	Minimum	Maximum
Crushing	0.298***	–0.222***	6.5	5.0	0	30.8
Low viability	0.215***	0.157***	4.5	4.5	0	32.5
Stillborn	0.248***	–0.177***	6.0	4.1	0	17.7
Total liveborn deaths	0.238***	–0.181***	14.4	8.0	0	45.8

Table 3 Variation between and within sows in piglet mortality, and estimates of repeatability. χ^2 and *P* values are calculated from the change in deviance when sow is removed from the model.

	Between-sow variance component	Within-sow variance component	χ^2 (1 df)	*P* value	Repeatability (R)
Crushing	0.167	1.022	69.6	0.0001	0.14
Low viability	0.095	1.622	204.0	0.0001	0.06
Stillborn	0.196	0.898	53.8	0.0001	0.18
Total liveborn deaths	0.065	1.315	26.4	0.0001	0.05

2001), which is restricted by crates (Rudd & Marchant 1995; Jarvis *et al* 2004).

In Study 2 we found significant evidence for repeatability in crushing by individual sows across parities, suggesting that some sows consistently crush more piglets, while others crush few. This estimate was made after adjusting for factors thought likely to influence crushing risk. Our results agreed with previous reports. We found that piglets in larger, lighter litters and in later parities were at greater risk of death from crushing (Weary *et al* 1998; Marchant *et al* 2000; Roehe & Kalm 2000; Tuchscherer *et al* 2000).

Consistency of crushing deaths across parities of the same sow could occur in a number of ways. The sow has a direct influence on crushing through her behaviour and lactational output, both of which are partly controlled by genotype. In addition, the sow's contribution to the genes of her offspring may affect their chances of avoiding being crushed. The relative importance of maternal genotype and the maternal contribution to piglet genotype on piglet survival were estimated to be approximately equal by Van Arendonk *et al* (1996) (heritabilities: 0.09 and 0.11 respectively), while Grandinson *et al* (2002) found the piglet's own genetics to be of negligible importance. The ways in which sow and piglet factors influence mortality are discussed below.

Consistent individual differences in maternal behaviour are one explanation for consistency in crushing across parities and these occur both during the course of one lactation (Pitts *et al* 2002; Valros *et al* 2003) and across lactations (Thodberg *et al* 2002). Sow behaviours that influence crushing are the performance of piglet-directed pre-lying behaviour (Marchant *et al* 2001), posture changes that put piglets at risk (Weary *et al* 1996a; Marchant *et al* 2001), and the likelihood of getting up to free a trapped piglet (Weary *et al* 1996a; Wechsler & Hegglin 1997). Rate of posture changing by sows shows both inter-individual variation (Lammers & De Lange 1986; Meunier-Salaün *et al* 1991; Špinka *et al* 2000) and consistency during a lactation (Valros *et al* 2003). Posture changes with a high crushing risk (rolling over or lying down) have a repeatability of 0.52 between the first and second parity (Thodberg *et al* 2002). Responsiveness to tactile piglet stimuli (Cronin & Cropley 1991; Hutson *et al* 1991) and to piglet distress calls (Cronin & Cropley 1991; Hutson *et al* 1991, 1992, 1993) is also variable between sows.

Consistent differences between sows in piglet crushing may also be due to consistent influences on piglets, either through the maternal genetic contribution to the piglet's genotype or through various influences of the sow. Several aspects of piglet phenotype affect the risk of mortality from a variety of causes including crushing. These include physical, physiological and behavioural features, which interact with one another such that many piglet deaths have a multi-factorial causation (English & Smith 1975; Fraser 1990; Fraser *et al* 1995; Edwards 2002; Lay *et al* 2002). For example, hypoxia, starvation and hypothermia may cause deaths directly or may increase piglet lethargy, which increases crushing risk. Small piglets (Fraser *et al* 1995; Quiniou *et al* 2002), especially in large litters (Dyck & Swierstra 1987; Roehe & Kalm 2000; Tuchscherer *et al* 2000), and piglets in litters with greater weight variability (Fraser *et al* 1995; Marchant *et al* 2000; Knol *et al* 2002; Milligan *et al* 2002) are at greater risk of starvation and also

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spend more time in proximity to the udder, putting themselves at greater risk of crushing (Weary *et al* 1996b, 1998). An additional problem here is that selection for increased lean tissue growth rate has led to piglets with reduced physiological maturity for their size at birth (Herpin *et al* 1993, 2002; Rydhmer 2000; Leenhouwers *et al* 2002), which has exacerbated the problem of poor control of body temperature, with negative consequences for piglet survival.

Although not the main aim of this work, Study 2 also identified consistent differences between sows in the number of piglets born dead (stillborn). This is in accordance with a genetic study of piglet mortality in crated gilts (Grandinson *et al* 2002), which showed that the tendency for stillbirths was heritable (reviewed by Knol *et al* 2002). Deaths resulting from low viability and total pre-weaning deaths from any cause were also consistent across parities. Total liveborn deaths had a lower repeatability than deaths by crushing, suggesting that the various causes are unrelated and that an analysis of separate causes is more likely to yield positive results in any selection programme for reduced piglet mortality (Grandinson *et al* 2002; Knol *et al* 2002).

Sow consistency over parities in piglet mortality may be useful to pig farmers. A sow with high piglet mortality in early parities is likely to have similar problems in later parities, and this may contribute to decisions about which sows to cull and which to keep (along with other aspects of reproductive performance). Evidence of consistency also suggests that further investigation into the effect of sow genetics on piglet mortality is worthwhile. Repeatability (R) represents an upper limit to heritability, since R also includes variation resulting from permanent environmental effects in the numerator. Heritability would give a better indication of the likelihood of success in a selection programme for reduced piglet mortality. Our estimate of repeatability (R = 0.14) for crushing is consistent with reported heritability estimates for piglet survival to weaning (0.11, Yorkshire Large White, Pietrain [Van Arendonk *et al* 1996]) and for crushing (0.06, Yorkshire [Grandinson *et al* 2002]). Although low, these levels of heritability are typical for reproductive traits (eg litter size: R between 0.122 and 0.241; Ferraz & Duarte 1991; Siewerdt & Cardellino 1995, 1998; Skorupski *et al* 1996). When repeatability is this low, it is more likely that genetic selection will be successful if measurements are made over several parities for each sow (Simm 1998). Indeed, research in mice has shown that selection for litter size based only on the first parity does not improve lifetime reproductive performance (Luxford *et al* 1990). Finally, it should be noted that our use of Logit transformations leads to a relatively conservative estimate of repeatability, since variance components and standard error may be underestimated (Waddington *et al* 1995).

Although repeatability and heritability for crushing appear to be quite low, crushing mortality for individual sows ranged from 0 to 30.8% in Study 2 (Table 2). This represents considerable phenotypic variability (in contrast with traits that have been subjected to heavy selection pressure, such as litter size). If a good proportion of this phenotypic variation is genetic, then rapid genetic progress could be made towards reducing piglet mortality (Knol *et al* 2002). This is unknown and would require a genetic study. Study 1 showed that phenotypic variability in crushing mortality was even higher in loose-housed (pen) systems. Thus, it is possible that genetic progress in reducing piglet mortality might be even more rapid in a population of loose-housed sows. In the dairy sector, it is now recognised that selection for production traits has begun to compromise health and fertility (Pryce *et al* 1998), both of which have an impact on the welfare of the animals and on the profitability of the system; this recognition has led to a broadening of breeding goals (Christensen 1998). A similar line of thinking could be applied to pigs in order to reduce piglet mortality.

Animal welfare implications

Choosing a farrowing system for modern breeds of sow is an animal welfare dilemma. Confinement systems such as crates cause stress by thwarting the sow's strong motivation to build a nest, and interfere with maternal behaviour. However, crates benefit piglets by reducing crushing mortality. This study provides evidence (i) that sows show large differences between individuals in their propensity to crush piglets, (ii) that these individual differences have been partially masked by the use of farrowing crates, and (iii) that individual differences show some consistency over parities. Selection based solely on numbers of piglets born in crate systems (Avalos & Smith 1987; Rydhmer 2000) may have relaxed selection on good maternal behaviour. Other studies suggest that sow and piglet contributions to piglet survival are heritable (Grandinson *et al* 2002; Knol *et al* 2002). We propose that a broadening of breeding goals to include increased piglet survival rates would be positive for both sow and piglet welfare, and in the longer term might also facilitate the adoption of loose-housed farrowing systems.

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