Effect of Farrowing Environment on Behaviour and Physiology of Primiparous Sows with 35-day Lactation

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ABSTRACT

Aiming at investigating the effect of farrowing environmental difference on primiparous sows that lactated for 35 days, 16 gilts with closed EPD were reared in straw-bedded farrowing pen or farrowing crate randomly. Nest-building, postures change within 3 days after farrowing, and bahaviour of gilts in 2-5 weeks after farrowing (W2, W3, W4, W5) were observed. Prolactin, cortisol, and IgG were measured at 2 days before EPD, the parturition day, and the weaning day. Results showed that, straw-bedded pen can encourage gilts' nest-building behaviour, and significantly reduced the incidence of abnormal behaviour, and their oral behaviour directed mostly to straw, while gilts in farrowing crate performed more ventral lying and sitting, and less lateral lying, and the frequency of their vacuum-chewing and active behaviour directed to pen were higher; gilts in straw-bedded pen performed more ventral lying and active behaviour in W5, while gilts in farrowing crate performed less behaviour directed to pen in W3 or W4 than in W2 or W5; lower cortisol also showed that straw-bedded pen can reduce gilts' stress. There is no significant difference in IgG between sows in different environment or in different weeks. In conclusion, the straw-bedded farrowing pen reduced stress of gilt, and met the behavioural requirement. Straw stimulated nest-building behaviour, and effectively reduced the sitting, oral behaviour directed to pen and vacuum-chewing.

INTRODUCTION

Farrowing/lactating system is the key of the swine production. A cohort study by Kilbride et al. (2012) showed that the pre-weaning mortality of live born was 12% and crushing was the primary cause of death accounting for 55% of the pre-weaning death. Farrowing crates are widespread used to

protect the piglets, which reduced the risk of pre-weaning death attributable to crushing, but piglets in this system were at increased risk of death from other causes, consequently crates had no significant effect on the mortality of suckling piglets (Kilbride et al., 2012). Gu et al. (2011) reported that there was no difference in crushing to death or mortality between the freedom farrowing pens and crates, and they concluded that with appropriate anti-crushing bars, the freedom farrowing pen was beneficial to reduce the death of piglets caused by crushing.

On the other hand, crate is cruel as it confines the sow or gilt into a small space and constricts their movements. Barren crate hampered in expression of strongly motivated behaviour such as exploring, and can lead to abnormal behaviour (Vanheukelom et al., 2012). Straw is a suitable environmental enrichment for pigs, providing them a stimulus and outlet for exploratory and manipulative oral behaviours (Tuyttens, 2005). "Straw presence" often tends to increase the intuitive welfare score in experts' housing system assessment (Spoolder et al., 2003). Besides, Sows have a strong preference to farrow in a bedded lying place and are prepared to gather large amounts of straw to build a nest before farrowing (Arey et al., 1991; Arey, 1992), along with the rise of PGF2α (Algers et al., 2007). Even in a barren environment, sows have high motivation to build a nest (Andersen et al., 2005)

Confined sows are limited in their selection of nest-site, unable to gather material for nest building and are forced to farrow in an uncompleted nest (Gustafsson et al., 1999). Straw which allows nest building can favourably influence maternal behaviour (Herskin et al., 1998; Ringgenberg et al., 2012; Melišová et al., 2011), and reduce the risk of crushing (Weary et al., 1998; Marchant et al., 2001), while stress weaken the maternal of sows, such as delayed response to screaming of piglets (Ringgenberg et al., 2012). Thus, Straw-bedded pen with anti-crush device is a practicable alternative.

Additionally, Jarvis et al. (2006) investigated whether housing sows in a crate during lactation leads to chronic stress, and found that baseline plasma ACTH and cortisol levels showed no treatment differences during the lactation, and the difference of Cortisol AUC and cortisol/ACTH ratio were only shown on Day 29. So, prolonged confinement in farrowing crates may have a negative impact on sow welfare. However, EU rules prevent weaning before 28 (Council Directive 2008/120/EC), and EU organic rules delay weaning until at least 40 days (CIWF, 2006).

Weaning at 5 weeks of age is thought much better for piglets but not for sows. The aim of this experiment was to investigate the effect of farrowing environmental difference on primiparous sows that lactated for 35 days.

MATERIALS AND METHODS

Animals and care

During pregnancy, gilts were group-housed in a straw-bedded pen (6m × 10m) with a 6m × 10m outdoor area. Seven days before expected parturition day (EPD), 20 gilts with closed pregnancy condition and EPD were randomly moved to either a farrowing crate (Treatment C) or a straw-bedded farrowing pen (Treatment P) in the same room. Because of dystocia or small litter size, 16 primiparous sows were used in the experiment (eight sows in each treatment). Piglets were weaned at 35 days of age by the sows moving out.

They were fed three times per day (06:00, 10:00 and 16:00). The straw-bedded pens were cleaned twice per day at 05:00 and 15:00 and fresh straw (about 5cm deep) were provided after the morning feed, while the crates were cleaned at 06:00 and 16:00. Health inspection and disease treatment were performed at 06:30.

Housing structures

Commercial farrowing crates (2.15m × 1.8m) were 0.3m from above the ground. The width of the sow stall was 0.6m. Two fibre glass thermal creeps (1.0m × 0.6m) were fixed in the mid of pared crates. Iron

Table 1 *Behavioural categories and definitions*

Behavioural categories		Definitions
Lying	*Ventral lying*	Lying down with chest and abdomen making contact with the floor and front legs stretched or folded under the body.
	Lateral lying	Lying down with one shoulder making contact with the floor.
Sitting		Partly erected on stretched front legs with hindquarter contacting the floor.
Oral behaviour	*Pen-directed*	Licking, biting, pawing or nosing trough, bars, walls and floor.
	Straw-directed	Nosing, rooting, pawing, holding, biting, chewing, or ingesting straw. (Only in straw-bedded pen)
	Vacuum-chewing	Chewing with no object in the mouth.
Active		All behaviours, except lying, sitting, or standing without any activity, and sleeping.

slats were applied for sow, and plastic slats for piglets.

The straw-bedded farrowing pen (5.7m × 2.1m) had concrete floor with a slope of 18°. The lying area (2.1m × 2.1m) was separated by a square tube (40 mm×60mm) 50mm from above the floor to keep straw. Anti-crush bars were positioned 0.3 m from above the floor and 0.2 m from the wall or side railing in the lying area. Piglets creep (1m×0.8m) was situated in corner of lying area. (Details as shown in Yin et al., 2013)

Behaviour observation and categorisation

The behaviours of the sows were recorded by Noldus Observer XT system (Noldus Information Technology, Wageningen, Netherlands).

Sows were videotaped continuously from three days before EPD and nest-building behaviour was observed 12-hour before the first birth of piglet. Nest-building behaviour means rooting or pawing floor/straw, and holding, depositing or arranging straw in straw bedded pen, but that's sham nest-building behavior in crate, such as scraping with the front paws, teeth grinding, biting on objects or housing facilities, as reported by Wischner et al. (2009) . These 12 hours were divided into six 2-hour periods, that is, -12h, -10h, -8h, -6h, -4h, and -2h.

From 12 hours after the first birth of piglet, 48-hour continuous videotaping was conducted for observing the posture distribution and frequency of postural change (lateral lying to other posture, ventral lying to lateral lying, sitting to lying, and standing to lying).

From the 2nd to the 5th week of lactation, sows were videotaped continuously from 07:00 to 09:00 and 13:00 to 15:00 on the 3rd and 6th day of each week, with a 2-min instantaneous scan, so there were 120 observations per day. Data of states were converted into percentages of the total observation time and data of oral behaviours were recorded as the number of times they occurred. Definitions of the behaviours can be seen in Table 1.

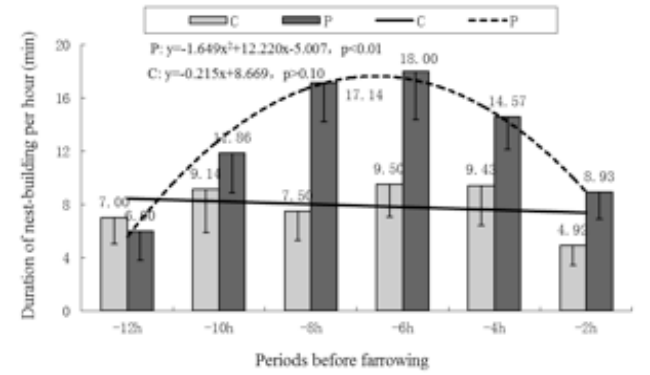
Physiological indicator.

Blood sampling through ear venous was taken in two days before EPD (-2d, taken at 8am), Parturition Day (0d, taken at 6h after the first birth of piglet), and Weaning Day (35d, taken at 8am). The blood was separated after serum separation, and stored in the refrigerator at-20°C until assay. ELISA kits (Rapidbio, the United States) were used to measure cortisol (CORT), prolactin (PRL) and Immunoglobulin G (IgG).

Statistical analysis

IBM SPSS statistics 20 was used for analyses of the experimental data. All dependent

Figure 1. *Nest-building behaviour before farrowing*



variables were checked for normality before being analyzed using One-Sample Kolmogorov-Smirnov Test.

The effect of environment, periods before farrowing on nest-building behaviour was analyzed by Univariate procedure, and Regression analyses were performed using curve estimation. The effect of environment on posture distribution and frequency of postural change in early days after farrowing was analyzed by Multivariate procedure. The effect of environment, periods of lactation on behaviours of sow, and least significant difference (LSD) was used for pairwise comparisons of means among treatments. The effect of environment on PRL, CORT and IgG were analyzed through One-Way ANOVA.

All the results of the statistical analysis are presented as mean ± s.e.

RESULTS

Nest-building

In 12 hours before farrowing, sows in creates performed less nest-building behaviour than those in straw bedded pen (7.95±2.07min/h vs 12.75±3.90min/h, p=0.002), and there were no peak of nest-building behaviour in sows in creates (p=0.764). In straw bedded pen, as approached farrowing, nest-building behaviour increased from 6.00±2.18 to 18.00±3.64 min/hour at -6h, then decreased to 8.93±2.00 (see Fig.1).

Posture in early days after farrowing

In early days after farrowing, there were no significantly difference in posture distribution, except standing (p=0.017, walking was also concluded in standing for sows in straw pen), between two treatments (Table 2). There were few sitting in both treatments (C: 9 min per hour vs. P: 5 min per hour). There were no significantly difference in frequency of postural change between sows in C and P (Table 3).

As shown in Fig. 2, in each week of lactation, there was no significantly difference in overall lying between sows in C and P (p>0.05), while sows in C performed significantly more ventral lying (p<0.01) and less

Table 2. *Posture distribution of the sows after farrowing (%)*

	Lying	Lateral lying	Ventral lying	Standing	Sitting
C	90.90±1.88	76.67±6.46	14.24±6.88	8.26±1.88	0.63±0.35
P	85.69±6.94	75.21±8.85	10.42±6.04	12.22±3.19	0.35±0.35
p-value	0.102	0.742	0.269	0.017	0.195

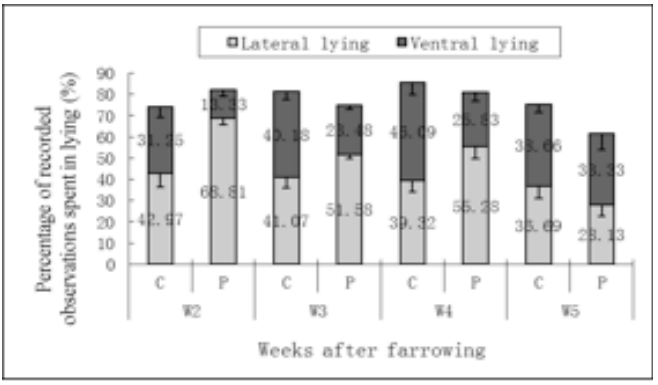
Table 3. *Frequency of postural change of the sows after farrowing (Hrs -1)*

	Lateral lying to other posture	Ventral to	Ventral lying	Standing	Sitting
C	16.86±2.82	11.57±2.53	2.86±1.22	10.00±1.66	0.63±0.35
P	23.50±3.01	13.21±2.13	2.93±0..66	13.14±1.24	0.35±0.35
p-value	0.133	0.629	0.960	0.155	0.195

lateral lying ($p<0.05$), except in W5 ($p=0.49$; $p=0.37$). For sows in P, there were no significantly difference in ventral lying, lateral lying and overall lying between weeks of lactation ($p>0.10$), while sows in P performed more ventral lying in W5 than in any other week ($p<0.05$).

As shown in Fig. 3, in each week of lactation, sows in C performed more sitting ($p<0.05$), and there were no significantly difference in sitting between weeks of lactation for each treatment (C: $p=0.71$, P: $p=0.64$). As shown in Fig. 4, in W2-W4, sows in C were more active ($p<0.01$). For sows in C, there were no significantly difference in active behaviours between weeks of lactation ($p=0.85$), while sows in P performed more active behaviours in W5 than in any other week ($p<0.05$). As shown in Fig. 5, in each week of lactation, sows in C performed more pen-directed oral behaviours ($p<0.05$), vacuum-chewing ($p<0.01$), and overall oral behaviour ($p<0.05$). There were nearly no vacuum-chewing in sows in P (only observed in one sow in W3). And there were no significantly difference in more pen-directed oral behaviours (C: $p=0.13$; P: $p=0.08$), vacuum-chewing (C: $p=0.61$), and overall oral behaviour (C: 0.80; P: $p=0.54$) between weeks of lactation for each treatment.

Figure 2. *Lying behaviour in 2-5 week of lactation*



Physiological indicator

In -2d, there were lower PRL level in C sow ($p = 0.09$). There were significantly lower PRL levels in 35d than in -2d or 0d for sows in both treatments ($p < 0.01$). In -2d and 35d, there were significantly higher CORT level in C sow ($p < 0.05$). The CORT level of sows in C was significantly higher in -2d than in 0d or 35d ($p < 0.05$), while there were no significantly difference in the CORT level of sows indifferent stage ($p = 0.27$). There is no significant difference in IgG between sows in different environment or in different weeks ($p > 0.10$). Table 4 Level of PRL and CORT in different stage

DISCUSSION

Maternity

In natural condition, sows usually start looking for nesting sites and collecting nesting material before farrowing. Domestic sows still possess maternal behaviour which has developed during a life in the wild and seems to be hardwired into the nervous system (Gustafsson et al., 1999), and domestication has not given rise to major changes in the performance of nest-building behaviour (Wischner et al., 2009). Generally, the sow starts to build the nest at approximately 24 h before farrowing, showing most intensive activity 12 to

Figure 3. *Sitting in 2-5 week of lactation*

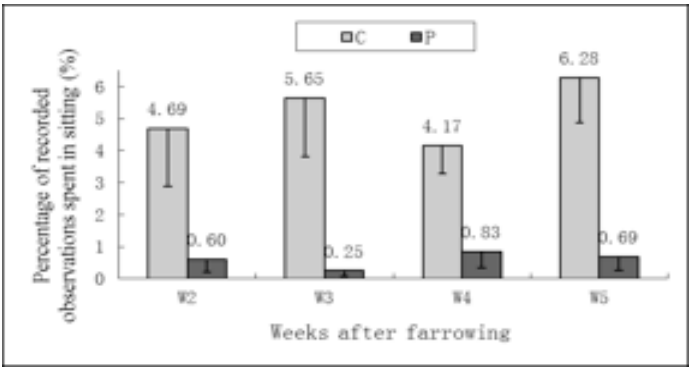
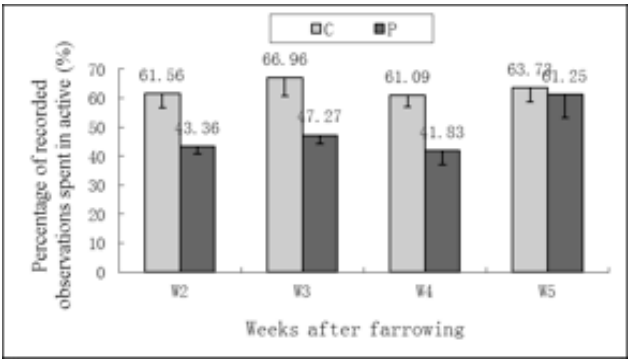


Figure 4. *Active behaviours in 2-5 week of lactation*



6 h before farrowing (Cronin et al., 1994; Haskell and Hutson, 1996; Algers et al., 2007; Cui, 2006).

In present study, primiparous sows in P also showed a nest-building peak 8-5 h before farrowing while sows in C maintained nesting behavior at a low level. That's because of the strong motivation of sows to building a nest (Arey, 1992), which is result of physiological state (such as Prolactin) (Lawrence et al., 1994, Wischner et al., 2009). Even in absence of exogenous stimuli, nest-building like behaviour is shown, such as biting and rooting at the rails in the crates (Wischner et al., 2009). Damm et al. (2003) also reported that compared to sows housed in pens, nest-building in crates is performed only in a small variation and in more fragmented and longer phases.

Suitable nesting material can stimulate the nesting behavior of sows, then regulate hormone to improve maternal (Cronin et al., 1993; Cronin, et al., 1994; Herskin et al., 1998; Herskin et al., 1999). Sows with more nest building activity performed a better maternal (Andersen et al., 2005). Environmental stress of sows inhibits oxytocin, and then influences the maternal behaviour. Jarvis et al. (2004) found a positive relationship between oxytocin and unresponsiveness to piglets. In present experiment, attacking piglets by sows in P when farrowing was found and a piglet was death of that. Ahlstrom (1997) also reported a higher probability of crated gilts to savage their piglets during early stages of farrowing. Thus, providing material of nest has a certain impact on improving maternal behavior, and reduces anxiety of farrowing.

Piglets' death of crushing mostly occurred in the first few days postpartum (Lay, 2002), because at the first five days postpartum sows spent most time together with their offsprings except excretion basically have to stay, lying area ,even for sows in straw pen (Bohnenkampa et al., 2013).

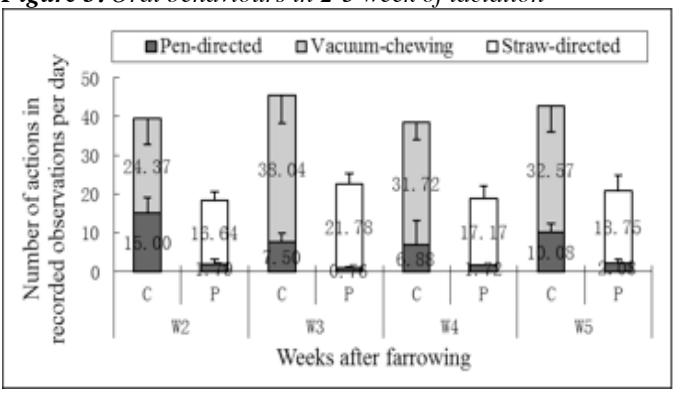
General behavior can be negatively influenced when sows do not have access to nesting material, which can result in more changes in position during the first 24 hours postpartum (Herskin et al., 1998). Frequently changing position of sows have a higher risk of crushing piglets, especially rolling behaviour (Danholt et al., 2011). Csermely (1994) showed that sows in intensive hous-

Table 4 *.Level of PRL and CORT in different stage*

		-2d	0d	35d
PRL ($ng \cdot ml^{-1}$)	C	$1.342^{Ax}\pm0.139$	$1.498^{Ax}\pm0.208$	$0.945^{Bx}\pm0.155$
	P	$1.504^{Ax}\pm0.199$	$1.529^{Ax}\pm0.222$	$0.972^{Bx}\pm0.156$
CROT ($ng \cdot ml^{-1}$)	C	$193.87^{ax}\pm22.67$	$142.26^{bx}\pm15.12$	$144.12^{bx}\pm18.85$
	P	$165.19^{ay}\pm16.67$	$132.26^{ax}\pm14.68$	$117.08^{ay}\pm10.83$
IgG ($mg \cdot ml^{-1}$)	C	$56.24^{ax}\pm4.35$	$59.66^{ax}\pm3.69$	$57.60^{ax}\pm4.47$
		$57.71_{ax}\pm3.32$	$60.87^{ax}\pm2.69$	$60.61^{ax}\pm3.70$

Note: Means with different superscripts are significantly different (capital letters means p<0.01 and lowercase letters means p<0.05; XxYy for column and AaBb for row.)

Figure 5. *Oral behaviours in 2-5 week of lactation*



ing facilities change position more often than free-range sows.

The number of changes among different positions did not show significant differences between the two treatments in this study. Since sows' activities are influenced by the size of space, more changes of different positions occurred in straw-bedded pen due to their more standing position caused by relatively free space. However, gilts in C changed position more often than those in P when farrowing, and some of them attacked the offsprings. There is a high risk of crushing piglets in this period, but behaviours were not analyzed because of the interference of aids to deliver. Fraser et al. (1995) also considered that the stress of gilts in crate may increase the probabilities of attacking and crushing piglets when farrowing.

It is also regarded that the time of sows' sitting are related to number of the crushing on piglets (McGlone and Morrow-Tesh, 1990) and there is frequently sitting of gilts in crate. However, gilts in C showed rare sitting behaviour (9 minutes per day) in present study, which may due to their straw-bedded group pen before farrowing, and the short-period in C had little impacted on them. Besides, gilts' unfamiliarity with the crate affected their behaviours.

Physiological indicator showed that PRL is high before and after farrowing, which is determined by sows' physiological condition, because PRL is closely related to the maternal behaviour (Cui, 2006). The PRL of sows in C were a little bit lower than that of sows in P, however, it only showed significant difference in the day before farrowing which may be caused by crated gilts' high hypothalamus-pituitary-adrenal axis (HPA axis) before farrowing. Study of Ruis et al., (2001) on sows' social attack also showed that the increased activity of HPA axis under the stress can directly lead to the increased PRL, which may be the result of the inadaptation of the sows to the nesting environment. However, the closely PRL after farrowing indicated that simulation of farrowing and piglets can lead to a standard level of PRL secreting. Therefore, the effect of environment on maternity was exerted mainly before farrowing and at the beginning of farrowing.

Behaviours in 2-5 week of lactation

The result of present experiment showed that, the ventral lying of gilts in C was more than that of sows in P in W2 - W5, while lateral lying was significantly less. Lying time showed no significant differences between the two treatments, which indicated that gilts in C perform more ventral lying. Generally, sows adopt lateral lying more when resting, while ventral lying represents a more alert and active behavior (Jarvis et al.,2002). Therefore, more ventral lying of gilts in C was active, which is in line with the result that the activity of gilts in C was higher than that of sows in P. However, Jarvis et al., (2006) found that sows in pen were more active, with more ventral lying and less lateral lying. This is because no obvious vacuum-chewing was found in their study, while gilts in crate showed vacuum-chewing in ventral lying in present experiment. The ventral lying of sows increased as lactation in P, and lateral lying and total lying decreased in W5. This is in accordance with biological nature of pig, as lateral lying is the position

for suckling as well as for sows to initiate lactating. From 3rd or 4th week during lactation, sows stopped initiating lactating (Bøe, 1991), and the frequency of lactating declined (Tuchscherer et al., 2000). Sows limit the suckling then the massaging after suckling, thus sows adopted more and more ventral lying position to end lactating.

The activities of sows in P increased significantly from W5 after farrowing, which reflected the sows' refusing and escaping from suckling. When sows are free to spend time keeping away from their piglets, they usually completed the process gradually through manipulating lactating time before the 28th day after farrowing (Pajor et al., 2000). Because sows in C could not walk in this experiment, the activity did not change in W5.

Sows in P performed few sitting behaviour, however, the gilts in C showed longer time of sitting from W2 to W5, which is in accordance with the result of Jarvis et al. (2006). But the sitting of gilts in crate occurred more at the end of lactation in their research, while sitting increased significantly along with lactation proceeding in present study, which may be affected by the spacious feeding environment with straw during gestation.

The activity of gilts in C was higher than that of sows in P throughout the period, which is mainly because they performed more oral behavior, mostly vacuum-chewing when ventral lying. This can serve as an explanation for the longer time of ventral lying and active time. The total oral behavior of gilts in C showed no significant differences among weeks, however, their pen-directed oral behavior occurred less in W3 and W4. The reason may be that the sows' abnormal oral behavior was mostly shown as vacuum-chewing with the prolonging confinement. And the increased pen-directed oral behavior may be caused by the stress of sows' not being able to escape from suckling. Because if sows are forced to be with piglets after 28 days since farrowing, it becomes stress for sows (Jarvis et al., 2006). Although weaning later is more natural for piglets, and causes less stress (Worobec et al., 1999; Gonyou et al., 1998), confinement may do harm to the sows in a relatively long lactation period, since they showed symptom of chronic stress.

Having no access to nesting material for sows can result in more oral-nasal stereotypies (Damm et al., 2003), and many studies (Whittaker et al., 1998; De Leeuw et al., 2003) showed that providing straw can reduce stereotypies. Sows in P nearly show no vacuum-chewing in this experiment, and their oral behaviours are mostly straw-directed which showed no significant difference between weeks after farrowing. This indicated that straw remained attractive to sows. Although there showed some pen-directed behavior in P, it is not stereotypies as showed by rooting the pen. This may be a good exploration to environment. However, results of Jarvis et al. (2006) showed that pen-directed behaviours of sows in straw-bedded pens were less than that in crates. Stewart et al. (2008) found that straw in racks led to a reduction in pen-directed exploratory behaviour in group housed sows. In present experiment, gilts in C performed vacuum-chewing frequently, then more pen-directed behaviour, because most of the pen-directed behaviours observed were mingled with vacuum-chewing. Besides, the differences among sows' behaviors may be mainly caused by available space rather than the straw provided. Space has been proved to be the most important element around parturition period (Jarvis et al., 2002).

Stress and immunity

De Leeuw and Ekkel (2004) found that providing straw can reduce cortisol. Present experiment also showed that cortisol of gilts in C are higher than that of sows in P through all stages, with significant difference only shown in the day before farrowing and weaning day. And cortisol of gilts in C was significantly higher in the day before farrowing than that in the farrowing day or weaning day. The increase of plasma cortisol, as stress indictor, in crated sows was

related to the interruption of pre-parturient behaviour like nest-building (Lawrence et al., 1997), and the absence of nesting material elevated cortisol concentrations before farrowing (Lawrence et al., 1994). However, during the farrowing period, crate did not seem to affect the activity of HPA axis (Jarvis et al., 1998). Cronin et al. (1991) also found that compared to the sows in straw pen, cortisol concentrations of sows in crate increase since the 28th day of lactation, which indicated that crate can be a chronic stressor, which is consistent with the result of present experiment. However, Jarvis et al. (2006) did not find the increase of cortisol in their research.

Whether the sows in crates show chronic stress depends on many factors (the previous feeding environment, nutrition level, equipment in the pen, and so on), which may cause different results of cortisol concentrations among studies. Furthermore, HPA axis may adapt to the continuous stress, thus cortisol and ACTH may back to the standard level before stress (Pignatelli et al., 2000).

In present study, although IgG of gilts in P was a little bit higher than that of gilts in C, there was no significant difference at different stages between the two environments. This indicated that short-time environmental confinement during lactation exerted not significant influence on gilts' humoral immune system.

CONCLUSION

The straw-bedded farrowing pen reduced stress of primiparous sows, and met the behavioral requirement. Straw stimulated nest-building behavior, and effectively reduced the sitting, pen-directed oral behavior and vacuum-chewing. To some extent, straw-bedded farrowing pen can improve maternal behavior, reduce anxiety and fear in farrowing.

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REFERENCES

1. Algers B, Uvnäs-Moberg K. 2007. Maternal behavior in pigs. *Hormones and behavior*, 52(1): 78-85.
2. Andersen I L, Berg S, Boe K E. 2005. Crushing of piglets by the mother sow (Sus scrofa) - purely accidental or a poor mother? *Applied Animal Behaviour Science*, 93, 229-243.
3. Arey D S, Petchey A M, Fowler V R. 1991. The preparturient behaviour of sows in enriched pens and the effect of pre-formed nests. *Applied Animal Behaviour Science*, 31(1): 61-68.
4. Arey D S. 1992. Straw and food as reinforcers for prepartal sows. *Applied Animal Behaviour Science*, 33(2): 217-226.
5. Bøe K. 1991. The process of weaning in pigs: when the sow decides. *Applied Animal Behaviour Science*, 30(1): 47-59.
6. Bohnenkamp A L, Meyer C, Müller K, et al. 2013. Group housing with electronically controlled crates for lactating sows. Effect on farrowing, suckling and activity behavior of sows and piglets. *Applied Animal Behaviour Science*, 145(1-2): 37–43
7. Cronin G M, Barnett J L, Hodge F M, et al. 1991. The welfare of pigs in two farrowing/lactation environments: cortisol responses of sows. *Applied Animal Behaviour Science*, 32(2): 117-127.
8. Cronin G M, Schirmer B N, McCallum T H, et al. 1993. The effects of providing sawdust to preparturient sows in farrowing crates on sow behaviour, the duration of parturition and the occurrence of intra-partum stillborn piglets. *Applied Animal Behaviour Science*, 36(4): 301-315.
9. Cronin G M, Smith J A, Hodge F M, et al. 1994. The behaviour of primiparous sows around farrowing in response to restraint and straw bedding. *Applied Animal Behaviour Science*, 39(3): 269-280.
10. Csermely D, 1994. Maternal behaviour of free-ranging sows during the first 8 days after farrowing. *Journal of Ethology*, 12(1): 53-62.
11. Cui S. 2006. Study on maternal behaviour of sows and its relationship with prolactin receptor gene. Northeast agricultural university.
12. Damm B I, Pedersen L J, Marchant-Forde J N, Gilbert C L. 2003. Does feed-back from a nest affect periparturient behaviour, heart rate and circulatory cortisol and oxytocin in gilts? *Applied Animal Behaviour Science*, 83, 55-76.
13. Danholt L, Moustsen V A, Nielsen M B F, et al. 2011. Rolling behaviour of sows in relation to piglet crushing on sloped versus level floor pens. *Livestock Science*, 141(1): 59-68.
14. De Leeuw J A, Ekkel E D, Jongbloed A W, et al. 2003. Effects of floor-feeding and the presence of a foraging substrate on the behaviour and stress physiological response of individually housed gilts. *Applied Animal Behaviour Science*, 80(4): 297-310.
15. De Leeuw J A, Ekkel E D. 2004. Effects of feeding level and the presence of a foraging substrate on the behaviour and stress physiological response of individually housed gilts. *Applied Animal Behaviour Science*, 86(1): 15-25.

16. Fraser D, Kramer D L, Pajor E A, et al. 1995. Conflict and cooperation: sociobiological principles and the behaviour of pigs. *Applied Animal Behaviour Science*, 44(2): 139-157.
17. Gonyou H W, Beltranena E, Whittington D L, et al. 1998. The behaviour of pigs weaned at 12 and 21 days of age from weaning to market. *Canadian Journal of Animal Science*, 78(4): 517-523.
18. Gu Z, Gao Y, Lin B, et al. 2011. Impacts of a freedom farrowing pen design on sow behaviours and performance. *Preventive veterinary medicine*, 102(4): 296-303.
19. Gustafsson M, Jensen P, de Jonge F H, et al. 1999. Maternal behaviour of domestic sows and crosses between domestic sows and wild boar. *Applied Animal Behaviour Science*, 65(1): 29-42.
20. Haskell M J, Hutson G D. The pre-farrowing behaviour of sows with access to straw and space for locomotion. *Applied Animal Behaviour Science*, 1996, 49(4): 375-387.
21. Herskin M S, Jensen K H, Thodberg K. 1998. Influence of environmental stimuli on maternal behaviour related to bonding, reactivity and crushing of piglets in domestic sows. *Applied Animal Behaviour Science*, 58(3): 241-254.
22. Herskin M S, Jensen K H, Thodberg K. 1999. Influence of environmental stimuli on nursing and suckling behaviour in domestic sows and piglets. *Animal Science*, 68: 27-34.
23. Jarvis S, Calvert S K, Stevenson J, et al. 2002. Pituitary-adrenal activation in pre-parturient pigs (Sus scrofa) is associated with behavioural restriction due to lack of space rather than nesting substrate. *Animal Welfare*, 11(4): 371-384.
24. Jarvis S, D'Eath R B, Robson S K, et al. 2006. The effect of confinement during lactation on the hypothalamic–pituitary–adrenal axis and behaviour of primiparous sows. *Physiology & behavior*, 87(2): 345-352.
25. Jarvis S, Lawrence A B, McLean K A, et al. 1998. The effect of environment on plasma cortisol and beta-endorphin in the parturient pig and the involvement of endogenous opioids. *Animal Reproduction Science*, 52(2): 139-151.
26. Jarvis S, Reed B T, Lawrence A B, et al. 2004. Perinatal environmental effects on maternal behaviour, pituitary and adrenal activation, and the progress of parturition in the primiparous sow. *Animal Welfare*, 13 (2): 171–181
27. Kilbride A L, Mendl M, Statham P, et al. 2012. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. *Preventive Veterinary Medicine*, 104(3): 281-291.
28. Lawrence A B, McLean K A, Jarvis S, et al. 1997. Review. Stress and parturition in the pig. reproduction in domestic animals, 32: 231-236
29. Lawrence A B, Petherick J C, McLean K A, et al. 1994. The effect of environment on behaviour, plasma cortisol and prolactin in parturient sows. *Applied Animal Behaviour Science*, 39(3): 313-330.
30. Lay D C. 2002. Management tips to reduce preweaning mortality. Forty-Sixth North Carolina Pork Conference. Http://mark.asci.ncsu.edu/NCPorkConf/2002/lay.htm.
31. Marchant J N, Broom D M, 2001. Corning S. Non-ruminant nutrition, behaviour and production-The influence of sow behaviour on piglet mortality due to crushing in an open farrowing system. *Animal Science*, 72(1): 19-28.
32. McGlone J J, Morrow-Tesch J. 1990. Productivity and behavior of sows in level vs. sloped farrowing pens and crates. *Journal of animal science*, 68(1): 82-87.
33. Melišová M, Illmann G, Andersen I L, et al. 2011. Can sow pre-lying communication or good piglet condition prevent piglets from getting crushed? *Applied Animal Behaviour Science*, 134(3): 121-129.
34. Pajor E A, Kramer D L, Fraser D. 2000. Regulation of contact with offspring by domestic sows: temporal patterns and individual variation. *Ethology*, 106(1): 37-51.
35. Pignatelli D, Maia M, Castro A R, et al. 2000. Chronic stress effects on the rat adrenal cortex. *Endocrine Research*, 26(4): 537-544.
36. Ringgenberg N, Bergeron R, Meunier-Salaün M C, et al. 2012. Impact of social stress during gestation and environmental enrichment during lactation on the maternal behavior of sows. *Applied Animal Behaviour Science*, 136(2): 126-135.
37. Ruis M A W, Te Brake J H A, Engel B, et al. 2001. Adaptation to social isolation: acute and long-term stress responses of growing gilts with different coping characteristics. *Physiology & behavior,* 73(4): 541-551.
38. Spoolder H A M, De Bree J, Van der Mheen H W, et al. 2003. Not animal related but housing parameters determine an expert's intuitive welfare assessment of pig farms. Proceedings of the 37th International congress of the ISAE, Abano Terme, Italy, 24-28.
39. Stewart C L, O'Connell N E, & Boyle L. 2008. Influence of access to straw provided in racks on the welfare of sows in large dynamic groups. *Applied Animal Behaviour Science*, 112(3), 235-247.
40. Tuchscherer M, Puppe B, Tuchscherer A, et al. Early identification of neonates at risk: traits of newborn piglets with respect to survival. *Theriogenology*, 2000, 54(3): 371-388.
41. Tuyttens F A M. 2005. The importance of straw for pig and cattle welfare: A review. *Applied Animal Behaviour Science*, 92(3): 261-282.
42. Vanheukelom V, Driessen B, Geers R. 2012. The effects of environmental enrichment on the behaviour of suckling piglets and lactating sows: A review. *Livestock Science*, 143(2): 116-131.
43. Weary D M, Phillips P A, Pajor E A, et al. 1998. Crushing of piglets by sows: effects of litter features, pen features and sow behaviour. *Applied Animal Behaviour Science*, 61(2): 103-111.

44. Whittaker X, Spoolder H A M, Edwards S A, et al. 1998. The influence of dietary fibre and the provision of straw on the development of stereotypic behaviour in food restricted pregnant sows. *Applied Animal Behaviour Science*, 61(2): 89-102.

45. Wischner D, Kemper N, Stamer E, et al. Characterisation of sows' postures and posture changes with regard to crushing piglets. *Applied animal behaviour science*, 2009, 119(1): 49-55.

46. Worobec E K, Duncan I J H, Widowski T M. 1999. The effects of weaning at 7, 14 and 28 days on piglet behaviour. *Applied Animal Behaviour Science*, 62(2): 173-182.

47. Yin G, Sun G, Li X, et al. 2013. Effect of Straw-Bedded Farrowing Environment on Welfare of Suckling Piglets. *International Journal of Applied Environmental Sciences,* 8(5): 591-599.