A Dissertation

for the Degree of Doctor of Philosophy

Influence of Animal Welfare Management System in Swine on Physiological Responses and Reproductive Performance

동물복지를 적용한 사양방법이 돼지의 생리적 변화 및 번식성적에 미치는 영향

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By

Jang, Jae Cheol

School of Agricultural Biotechnology

Graduate School, Seoul National University

Influence of Animal Welfare Management System in Swine on Physiological Responses and Reproductive Performance

지도교수 김 유 용

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Overall Summary

Influence of Animal Welfare Management System in Swine on Physiological Responses and Reproductive Performance

The objectives of these experiments were 1) to investigate the effects of gilts housed either in group with the electronic sow feeding system or conventional stall, 2) to evaluate the effect of group housing with electric sow feeding system in gestating sows over three consecutive parities, and 3) to investigate the effects of different space allowances on growth performance, blood profile and pork quality in a one site grow-to-finish production system.

Experiment I. The Effects of Gilts Housed Either in Group with the Electronic Sow Feeding System or Conventional Stall

This experiment was conducted to assess the welfare and productivity of gestating gilts in groups with the electronic sow feeding (ESF) system compared to conventional stalls (ST). A total of 83 gilts (Yorkshire×Landrace) were housed into individual stalls to be artificially inseminated. Gilts confirmed pregnant were introduced to treatment, conventional stalls (ST) or groups with the ESF system. All gilts were taken to the farrowing crates one week prior to their expected farrowing date. In the gestation period, there were no significant differences between gilts allocated to ST and ESF on growth performance. However, backfat thickness gain ($P=0.08$) and body condition score (BCS) at 110 days of gestation ($P=0.10$) tended to be higher in ESF gilts than ST. Likewise, gilts housed in group showed significantly higher estimated body muscle contents at 110 days of gestation ($P<0.02$) and body muscle change during gestation ($P<0.01$). There was a trend for a shorter parturition time in ESF gilts ($P=0.07$). Reproductive performance did not differ with the exception of piglet mortality (ST = 0.2 no. of piglets vs ESF = 0.4 no. of piglets; P< 0.01). In blood profiles, ST gilts showed a higher cortisol level at 110 days of gestation (P< 0.01). Weaning to estrus interval was shorter in gilts housed in ESF than ST (P<0.01). In locomotory behaviors, ESF gilts recorded a tendency to elevate locomotion score at 36, 70, and 110 days of gestation (P=0.07, P=0.06, and P=0.06, respectively). Similarly, ESF gilts showed significantly higher incidence of scratches at 36, 70, and 110 days of gestation (P<0.01). Moreover, farrowing rates were higher in stall treatment (97.6%) compare to group housing treatment (95.2%). In conclusion, while group housed gilts with ESF system positively affected welfare status in combination with less physiologically stressful environments and activity, it negatively effects piglet mortality, farrowing rates and injuries of gilts.

Experiment II. Comparing Gestating Sows Housing Between Electronic Sow Feeding System and Conventional Stall over Three Consecutive Parities

This study was conducted to investigate the effects of gestating sows housed in groups with electronic sow feeding (ESF) system over three consecutive parities. A total of 83 pregnant gilts (Yorkshire × Landrace) were housed into 1) ST (n=41): gilts housed in conventional stall, 2) ESF (n=42): gilts housed in groups with ESF system on the basis of body weight (BW) and backfat thickness (BFT) in a completely randomized design. Rice hull was used as bedding material in group housing floor. Same commercial gestating diet was provided daily at 2.0 kg, 2.2 kg and 2.4 kg/day in the first, second and third parity, respectively in both treatment. All sows introduced farrowing crates five days before expected farrowing. BW and BFT of sows were measured at d 35, 110 of gestation as well as at 12 h and d 21 postpartum. Parturition time was recorded during farrowing. Reproductive performance, including total born, stillborn, mummy born alive, mortality, weaning pigs as well as litter and piglet weight were recorded. Scratch incidence, locomotion scores in sows were assessed at d 36, 70, and 110, respectively. Ten sows in each

treatment were randomly selected for blood sampling. Serum samples were analyzed for cortisol and oxytocin levels. In the gestation period, ESF tended to increase BW gain in second parity ($P=0.08$), and consistently showed the significance during third parity ($P<0.01$), resulting in higher BW at d 110 ($P=0.10$, $P<0.03$ in parity 2 and 3, respectively). Similarly, BFT gain tended to be higher in ESF than ST ($P=0.08$, $P= 0.10$ in parity 1 and 2, respectively). Estimated body fat contents changes also higher in ESF regardless of parities ($P<0.01$, $P<0.02$, $P=0.10$ in parities 1, 2, and 3, respectively). However, there were no significant differences on sow BW and BFT changes during lactation. There was a tendency of shorten delivery time in ESF treatment ($P=0.07$, $P=0.09$, and $P=0.10$ in parities 1, 2, and 3, respectively). In reproductive performances, higher piglet stillborn in ST was observed ($P=0.06$, $P=0.07$ in parity 2 and 3, respectively). In endocrinal analysis, ST observed higher serum cortisol at d 110 of gestation ($P<0.01$ in parity 1), whereas no detectable difference was observed in serum oxytocin level. Higher incidence of body scratch was scored in ESF in early gestation in all parities ($P<0.01$), resulting in higher locomotor disorders in middle and late gestating period ($P=0.07$). In conclusion, our result suggested that ESF system showed higher growth performance as well as survival rate of piglets. However, more incidences of body scratch and higher locomotion disorder scores observed in ESF sows due to in combination with persistent fighting around ESF machines and inadequate bedding materials. Consequently, it is necessary to consider the proper bedding materials as well as adequate space divider or barrier for gestating sows to avoid escaping aggression in ESF system.

Experiment III. Effects of Different Space Allowances on Growth Performance, Blood Profile and Pork Quality in a One Site Grow-to-Finish Production System

This experiment was conducted to evaluate the optimal space allowance on growth performance, blood profile and pork quality of growing-finishing pigs. A

total of 90 crossbred pigs ([Yorkshire x Landrace] x Duroc, 30.25 ± 1.13 kg) were allocated into three treatment (0.96: four pigs / pen, 0.96 m^2/pig; 0.80: five pigs / pen, 0.80 m^2/pig; 0.69: six pigs / pen, 0.69 m^2/pig) in a randomized complete block (RCB) design. Pigs were housed in balanced sex and had free access to feed in all phases (growing phase I, growing phase II, finishing phase I, finishing phase II). There was no statistical difference in growing phase, but linear decrease was observed on ADG ($P<0.01$), ADFI ($P<0.01$), and BW ($P<0.01$) with decreasing space allowance in finishing phase. On the other hand, quadratic effect was observed on gain to feed ratio in early finishing phase ($P<0.03$). Consequently, overall ADG, ADFI, and final BW were linearly declined in response to decreased space allowance ($P<0.01$). The pH of pork had no significant difference in 3 hr after slaughter, whereas there was a linear decrease in 24 hr after slaughter with decreasing space allowance. Floor area allowance did not affect pork colors, but shear force linearly increased as floor space decreased ($P<0.01$). There was linear increase in serum cortisol concentration on 14 wk ($P<0.05$) with decreased space allocation. Serum IgG was linearly ameliorated as space allowance increased on 10 week ($P<0.05$) and 14 week ($P<0.01$). Data from current study indicated that stress derived from reduced space allowance deteriorate immune system as well as physical status of pigs, resulting less pork quality. Provision more than 0.80 m^2/pig for space allowance is recommended for maximizing growth performance and production efficiency in a one site grow-to-finish production system.

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List of Abbreviation

ACTH	adrenocorticotropic hormone
ADFI	average daily feed intake
ADG	average daily gain
AI	artificial insemination
ANS	autonomic nervous system
BCS	body condition score
BFT	backfat thickness
BUN	blood urea nitrogen
BW	body weight
CK	creatine kinase
DFD	dark ,firm and dry
ESF	electronic sow feeding
FMD	foot and mouth disease
HPA	hypothalamic-pituitary-adrenocortical
Ig	immunoglobulin
LCT	lower critical temperature
ME	metaboilzable energy
NSP	non-starch polysaccharide
PSE	pale, soft and exudative
SEM	standard error of mean
SNF	solids-not-fat
ST	conventional stall
WEI	weaning to estrus interval

Chapter I. General Introduction

The management of animal production has changed significantly across the European Union (EU) over the last half of the 20th century (Tawse, 2010). Over this time, pork production has intensified, which means that the total number of breeding animals has increased, while the ratio of animal breeding farm has drastically decreased (Blokhuis et al., 2003). The reason for this phenomenon appears to be strongly related to the increased household incomes. With the worldwide economy development, its per capita income has grown rapidly. It led to significant changes in the patterns of food consumption which is shifting from grains to livestock derived products (Huang and Bouis, 2000). To meet the consumer's demand, large numbers of animals have been moved to indoor housing systems with lower space allowances, the use of prophylactic medicines and growth promoters has increased (Fraser, 2003). This intensification of the industry increased productivity, but decreased the monetary value of any given animal (Winter et al., 1998). Widespread concern in farm animal welfare has spotlighted in response to this campaign as evidence has shown that keeping farm animals in intensive condition may lead to a reduction in welfare status of animals (Harper et al., 2002). Pigs are the mostly intensively accommodated mammals in the world (Arey and Brook, 2006), with around 1.3 billion pigs are slaughtered annually for meat worldwide. Although legislation to minimum conditions for the protection for pigs recently goes beyond that required by EU law (e.g. Animal Welfare Act 2006), it does not solve all of the welfare concerns associated with conventional pig production (Tawse, 2010).

In Korea, a total of breeding pigs are gradually increased, while swine farm drastically decreased from 133,000 in 1990 to 4,900 in 2015 (Figure 1). It indicates that swine production is currently undergoing a drastic change from small farms to modern intensive production facilities. On the other hand, the activities of consumer groups, animal protectionists and the media attention to animal health crises such swine fever and foot-and-mouth disease have led to the general public becoming increasingly aware over the years

(Velarde and Dalmau, 2012). Issues such as animal welfare, food safety and the environment have therefore assumed greater importance for the public. Although South Korean government has been moving toward protecting farm animals, compare to European countries (Netherlands, Denmark, United Kingdom etc.), it seems likely to take time and efforts.

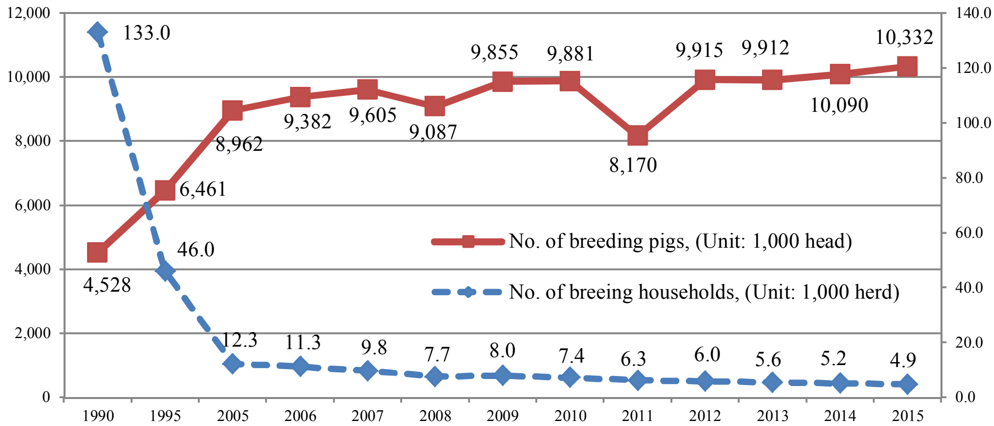

Figure 1. Change in the total breeding pigs and total swine farms in Korea (Ministry of Agriculture, Food and Rural Affairs, Korea, 2016)

Several studies suggested the ways to cope with restricted condition. In growing-finishing pigs, increasing space allowances ameliorated average daily gain and average daily feed intake (Harper and Kornegay, 1983; Meunier-Salaun et al., 1987; Brumm et al., 2001). These studies often found that space allowance reduce overall productivity, but they found it hard to determine the precise point at which crowding and growth depression began. Recently, the allometric space equation suggested by Petherick and Baxter, 1981, enables the use of a broken line analysis to determine the critical k value at which performance is negatively affected by the amount of space provided. According to Gonyou et al. (2006), the critical value at which space allowance begins to negatively affect production is k=0.034, and growth is depressed by approximately 0.5 % for every 1 % reduction in space beneath that value.

In gestating sows, individual stall management was widely used for the ease of artificial insemination, low capital cost and minimize overt aggressive behaviors (Jang et al., 2015). However, the restriction of movement and the impossibility to perform normal feeding and social patterns of behavior cause welfare problems such as development of stereotypies, chronic stress, lameness, and decubital ulcers (Scientific Veterinary Committee, 1997). Several studies have compared different indicators of welfare as well as productivity in stalls and modern commercial group housing system. Group housed sows with the electronic sow feeding (ESF) system have similar or improved productivity than sows housed in stalls (Bates et al., 2003). Moreover, no differences in stress-related serum cortisol concentrations are evident between sows housed in stalls and those housed in groups (Barnett et al., 1989, von Borell et al., 1992).

Consequently, in preparing to face the welfare challenges in swine management in South Korea, three experiments were conducted to investigate 1) the effect of gestating gilts housed in group with the electronic sow feeding system on physiological response and reproductive performance, 2) the effect of gestating sow housing with electronic sow feeding system over three consecutive parities, and 3) effects of different space allowances on growth performance, blood profile and pork quality in a grow-to-finish production system.

Chapter II. Literatures Review

I. Animal welfare

1. General concept

1) Definition

Animal welfare started with the publication of the Brambell report on the welfare of farm animals, and British government issued in 1965 (Brambell report, 1965). Since then, a very large amount of researches has been investigated about animal welfare problems involving very scientific fields of interest, such as the development of welfare assessment in various environmental conditions, as well as more fundamental questions linking to the biological bases of welfare and stress (Carenzi and Verga, 2007). The concept of freedom plays a key role in animal husbandry. In fact, the Farm animal Welfare Council (FAWC) defined the knowledge about the needs of animals which is related to the proposal of giving animals some freedoms (Table 1.).

According to the study of Carenzi and Verga (2007), there are three main approaches to define methodologies of welfare level.

The first approach emphasizes the organism's biological functions, such as growth and reproductive performance, as well as health status and behavioral characteristics. Behavior reflects the foremost response to the environmental stimuli and may give a clear signal of the stressors. Qualitative welfare levels reflect absence of distress or of a large stress response (Broom, 1986; Wiepkema, 1987; Broom and Johnson, 1993). A second approach suggest that the relationship between stress and welfare, which emphasizes much more the welfare in psychological aspects, considering emotional feelings as key elements in determining the quality of life. This is very similar to the one given by WHO (World Health Organization, 1946): "a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity." Thus the second approach includes not only the state of the physical condition of animal, but also its psychological feelings. The third approach emphasizes natural living, insisting that animals should be allowed to live according to their natural attitudes and behavior, mainly developing and using their natural adaptations. However, due to the domestication process, domestic animals differ in many ways from their co-specific as well as hard to assess welfare level in scientific way. More recently, a more comprehensive approach to animal welfare, categorized into four main issues, was proposed by Docks and Kling-Eveillard (2006):

1) Biological and technical definitions, which stress the fundamental needs of animals and the freedoms they should be given, as well as the possibilities to cope with the environmental challenges.
2) Regulation approaches, which recognize the animal as a sensitive being and as such it has to be put in conditions 'compatible with the biological needs of the species'.
3) Philosophical approaches, which consider the "animal's status" and its role in the human society.
4) Communication between man and animal, which give much importance to the farmer-animal interaction and its effects on industrial breeding systems.

Table. 1. The five freedoms as the fundamental experience goals for animals

Freedom	How
1.Freedom from Hunger and Thirst	By ready access to fresh water and a diet to maintain full health and behavior.
2.Freedom from Discomfort	By providing an appropriate environment including shelter and a comfortable resting area.
3.Freedom from Pain, Injury or Disease	By prevention or rapid diagnosis and treatment
4.Freedom to Express Normal Behavior	By providing sufficient space, proper facilities and company of the animal's own kind. Also: Possibility to carry out natural behaviors.
5.Freedom from Fear and Distress	By ensuring conditions and treatment which avoid mental suffering.

(Farm animal welfare council, 1993)

2) Global legislation on the welfare of pigs

The European Union (EU) has detailed legislation on the welfare of pigs which is contained in Council Directive 2008/120/EC laying down minimum standards for the protection of pigs. The key aspects of the EU Pigs Directive are that it prohibits use of sow stalls which are widely regarded as among the most inhumane aspects of industrial livestock production. The Pigs Directive prohibits sow stalls by providing that from 1 January 2013 sows must be kept in groups except for the first four weeks after mating. Following the clear international trends, the use of sow gestation stalls on New Zealand and Australia pig farms are prohibited by the end of 2015 and 2017, respectively. Canada instituted a nationwide ban on gestation crates in 2014. Certain states in the United States also enacted legislative bans of gestation crates.

For growing-finishing pigs, the Pigs Directive in EU and the National Pork Board sets out minimum space allowances for fattening pigs (Table 2).

Table 2. Minimum recommended space allowances for growing-finishing pigs (adopted by Cho et al., 2013)

Country	Live weight, kg	Space allowance, m^2/pig
European Union[1]	<10	0.15
	10-20	0.20
	20-30	0.30
	30-50	0.40
	50-85	0.55
	85-110	0.65
	>110	1.00
United States of America[2]	5.4-13.6	0.15-0.23
	13.6-27.2	0.27-0.37
	27.2-45.6	0.46
	45.6-68.0	0.55
	68.0-market	0.74

[1]Council Directive 2008/120/EC. Official Journal of the European Union.

[2]National Pork Board (NPB). 2002. 2002. Swine Care Handbook

3) Situation of animal welfare in Korea

With the increased global interest in animal welfare, South Korea has implemented laws and policies related to animal production. The animal protection laws and policies include breeding management, transportation management, slaughter methods, animal welfare, prohibition of animal abuse, and farm regulations (MAFRA, 2015).

With an amendment to the Animal Protection Act, the animal welfare farm certification and labeling system, provides legal verification to those farms that comply with the government standard in animal welfare, introduced on August 2011 and implemented on March 2012. The system went into effect in 2012 with the chicken and egg industry. Pigs were included in the system in 2013, and broilers were included in the certification system in 2014. Beginning in 2015, the system will expand annually to include native Korean cattle, beef cattle, dairy cattle and others.

2. Welfare assessment

Assessment of welfare relies upon the analysis of the interaction between the animals and their environment, including behavior, biological between hypothalamic-pituitary-adrenocortical (HPA) axis and the autonomic nervous system (ANS), as well as their consequences on production traits and possibly health status (Ulrich-Lai and Herman, 2009). Due to their ability to produce energetic metabolites, these systems can be activated by stressors. Also, this energy supply is used by the defence mechanism to cope with the stressor, resulting in their involvement in homeostatic metabolic processes.

1) Physiology

A various number of biological systems, such as the cardiovascular system, the gastrointestinal system, the exocrine glands and the adrenal medulla are controlled and influenced by the ANS during stress (Cannon, 1929). However, it is controversial that stress activation of the ANS does not significantly affect an animal's long-term welfare due to the relatively short duration of the biological effect on autonomic responses (Moberg, 1987). In fact, plasma levels of catecholamines are extremely sensitive to handle, so that more surgical blood sampling method such as direct venous puncture or chronic catheter must be considered (Fernández et al., 1994). In addition, Fernández et al. (1995) suggested that this short-term acute response can be diagnosed by various measurements, such as heart rate, blood pressure, plasma glucose and fatty acid levels. Furthermore, the value of monitoring the ANS' activity is subjected to various factors, such as locomotion, physical activity and/or feed intake (Villé et al., 1993; Talling et al., 1996; Webster and Jones, 1998). The concentration of plasma glucose and fatty acids represent the energy balance between the mobilization of energy stores and the use of energetic metabolites, whereas the concentration of serum lactic acid reflect the value of anaerobic metabolism (Guise et al., 1998). These metabolic measurements are frequently connected with the assay for determination of enzyme circulating activity, such as transaminases and creatine kinase (CK) which largely used to detect susceptibility of stress in pigs (Pérez et al., 2002; Foury et al., 2005b).

In contrast, the HPA activity with the release of cortisol, a cholesterol derived steroid synthesize in the fascicular zone of the adrenal cortex under the control of the pituitary hormone ACTH (adrenocorticotropic hormone) and release in the general circulation to reach its receptors in tissues, have a broad and long-lasting effect on the body (Reichlin, 1998; Harris et al., 2003). Cortisol has catabolic activity in peripheral tissues and anabolic activity in liver, including gluconeogenesis and protein synthesis (McMahon et al., 1988). Since cortisol also reduces the entrance of glucose into cells, it increases blood glucose and insulin secretion, resulting in the storage of energy as fat in the adipose tissue. Consequently, this affect increased fat depots at the expense of tissue proteins (Sapolsky et al., 2000). Moreover, cortisol increases appetite for feed by stimulating the arcuate and ventromedial hypothalamus in the brain (Leshin et al., 1994). Thus, it is frequently the case in homeostatic regulations, the increases of energy availability is a coordinated process via peripheral and central mechanism (Tempel and Leibowitz, 1994). Although the feature of HPA axis is not specifically documented in pigs, cortisol is highly susceptible to diurnal cycle that is genetically determined by light (Hay et al., 2000), feed intake (Gervink et al., 2003).

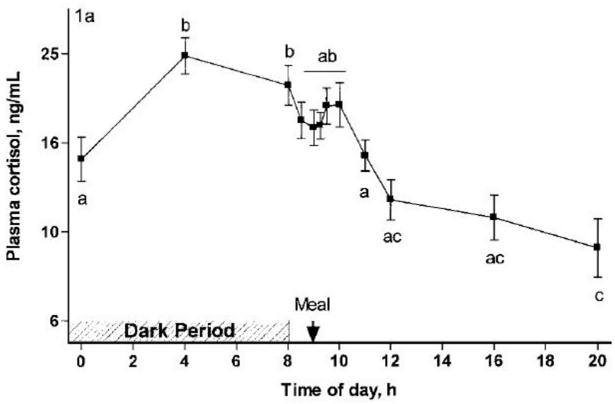

Figure 1. Diurnal changes in plasma cortisol of gestating sows fitted with an indwelling jugular catheter. The meal-induced release of cortisol is clearly visible (Hay et al., 2000).

2) Behavior

Behavior is the primary way of interaction so that it can be a sensitive indicator of the animal's perception of environmental changes (Rushen, 1991). Various behavioral patterns often reflect the first level of response of an animal to a stressful environment. Thus, behavior has been used extensively to analyze environmental needs or preferences (Arey and Edwards, 1998; O'Connell and Beattie, 1999). Moreover, behavior is also classical symptom to the examination of health problems, like the general behavioral depression accompanying fever and known as sickness behavior, or lameness indicative of locomotor problems (Dantzer and Kelly et al., 2007).

In addition to sickness related behavior, other changes in duration and frequency of normal behavior are recognized as indicators of mental suffering (Cook et al., 2000). Moreover, Cook et al. (2000) noted that there are numerous possible signs of stress, including startle or defense response, avoidance, excessive level of aggression, stereotypic behavior, and lack of responsiveness. Although not all these various behavior is the sign of poor welfare, it can be a warning sign if accompanied with other symptoms (Mason and Latham, 2004). Redirected injurious behaviors such as tail biting in pigs correlated with a lack of exploratory activity are clearly abnormal behaviors that may easily lead to pain. So, acceptance of behavioral need for this exploration as well as frequencies of redirected behaviors can be used as indicators of welfare (Day et al., 2002; Guy et al., 2002a).

Aggressive behaviors are the major expression of social interaction of pigs (McGlone, 1986). Most aggressive behavior appears in relation to feed competition or mixing (Ewald & Carpenter, 1978; Armstrong, 1991; Chapman & Kramer, 1996). In intensive commercial pig housing system, such behavior can especially be observed when unknown pigs are mixed into new groups (Meese and Ewank, 1972). The incidence of aggressive behavior occur several circumstances such as body weight difference, various space or group sizes or familiarity (Rushen, 1987; Algers et al., 1990). Aggressive encounters often result in skin injuries and can additionally cause immunosuppressive effects (Tuchscherer and Manteuffel, 2000).

An animal performing a stereotypic behavior repeats a relatively invariant sequence of behaviors, which has purposeless function (Fraser and Broom, 1990). The impossibility to display a behavioral need can also derive to the appearance of stereotypies. Various abnormal behaviors perform in farm animals; bar biting in confined sows, tong-rolling in cows, crib-biting in horses (Bergeron et al., 2006).

3) Performance

Although the relationship between production and welfare is not that simple and difficult to interpret, parameters on performance give an overview of the problems that reflects optimum welfare (Gregory, 1998; Jones and Boissy, 2011). Practices to improve production via the use of growth promoters have been questioned, because they may cause a detrimental impact on welfare or mask the negative impact or poor welfare on production performances (Mormède et al., 1990). Therefore, it is better to approach the welfare assessment of performance in a way of health status, rather than productivity. Representative parameters are mortality in growing-finishing pigs, and reproductive performance of sows (stillborn, mummy, weaned pigs, culling rate, farrowing rate, weaning to estrus interval, etc.). Mortality rate was influenced by various factors such as housing condition, management, group size and stockmanship (Losinger and Heinrichs, 1997). In sows, poor reproductive performance might be related to stress situation. Possible explanation reported by Wan et al. (1994) noted that glucocorticoid hormones reduce the activity of sex neuroendocrine systems and therefore reduce the efficiency of reproductive performance. In finishing pigs, agonistic productivity can lead to detrimental effect on welfare and reduced weight gain (Tan et al., 1991; Stookey and Gonyou, 1994). They also compromise pork quality, giving pork with low pH, pale, soft and exudative (PSE) which affecting the economy crisis of pig production (Sellier, 1998).

II. Group housing in gestating sows

1. Group housing in gestating sows

A major public concern on a farm animal welfare is more focused on gestating sow (Council Directive 91/630/EEC, 1991). In commercial condition, gestating sows are predominantly accommodated in gestation stalls which are both physically and psychologically detrimental to sows (Bracke et al., 2002a, b; McGlone et al., 2004). In fact, so much compelling evidence for this exists that the European Union's (EU) Agriculture Council, consisting of agriculture ministers from the EU's 15 member countries, recently issued a directive addressing gestation stalls (Council Directive 2001/88/EC, herein referred to as the "EU Pigs Directive") that will apply to newly built facilities as of 2003 and all other facilities as of 2013. The directive bans the use of stalls after the fourth week of pregnancy and bans tethering completely in order to, in its own words, "move towards a better standard of animal welfare" (European Commission, 2001). Nevertheless, most Asian countries are still using stall housing because of the ease of artificial insemination, low capital cost, individual feeding and minimize aggressive behavior (Jang et al., 2015). However, stall housing causes a negative effect on muscle weight and bone strength (Marchant and Broom, 1996), decubital ulcers, chronic disease and stereotypes, which probably indicate poor welfare of sow (Scientific Veterinary Committee, 1997).

There are the pros and cons between group housing and individual stall system. Individual stalls can be reduced labor costs, more manageable, earlier morbidity detection, and ability to control feed intake (Barnett et al., 2001; Estienne and Harper, 2003). In addition, stall protects the sow from aggressive encounters that normally occur during regrouping of sows in group-pens, which occurs several times throughout a sow's lifetime (Gonyou, 2005).

In contrast, the major difference of group housing system is to provide freedom of movement by providing enough space to turn around, lie down, stand-up, stretch limbs and groom (Jensen et al., 1995). This is commonly known as dynamic space, or the space necessary to make postural adjustments or turn-around (Gonyou, 2005). Basically, removing the sow's ability to walk and turn-around may affect their health, performance, and overall well-being (Barnett et al., 1985; Jensen et al., 1995).

2. Factors affecting the welfare of group housing system

1) Space allowance

The minimum space requirement for a sow in group housing is still controversial. EFSA (2006) describe the three types of space required in order to aid estimation of what levels of space pigs need; static, behavioral and interaction space. The static space required for pigs to simply lie or stand can be calculated with the equation $A=k*W^{0.666}$, in which A is the area in m^2, W is body weight in kg and k is a constant depending on the posture of the animal. Examples of k=0.019 for sternal lying (and standing) and k=0.047 for fully recumbent pigs (Baxter, 1986).

A lot of scientific literatures relating to space allowance in pigs have measured the occurrence of aggressive interactions as an important outcome within feeding system types (Barnett et al., 1992; Weng et al., 1998; Salak-Johnson et al., 2007; Remience et al., 2008). They concluded that the effect of floor space on aggression is particularly increased early after mixing. In gilts, Barnett et al. (1992) observed that d 2 to 54 after mixing, increasing space reduced aggressive behaviors, such as bites and butts. Likewise, the number of threats, withdrawals, and head interactions, including bites and nose interactions, were reduced with increasing space at d 6 and 7 after mixing in sows (Weng et al., 1998). Furthermore, Remience et al. (2008) found that nonreciprocal aggression at d 3 and 8 after mixing was greater in pregnant sows at a smaller floor space, although reciprocal aggressive behavior (bites or knocks) did not differ. For sows mixed soon after insemination, increasing space reduced feeding aggression at d 2 after mixing but not at d 8 (Hemsworth et al., 2013).

Increased aggressive behavior correlated with decreased space allowance. Weng et al. (1998) indicated that more injuries have been observed at greater space restriction in group housing with individual feeding stalls. Similarly, Remience et al. (2008) noted that more fresh superficial injuries and deep skin injuries were reported when less space (2.25 versus 3.0m^2/sow) was provided in ESF group housing. Moreover, Salak-Johnson et al. (2007) stated that skin injuries increased as floor space decreased. However, Barnett (1977) and Hemsworth et al. (2013) concluded that although space affected aggression and stress, there were no effects of space on skin injuries. These conflict results may be due to different experimental condition, such as floor feeding and electronic sow feeders (ESF) and static and dynamic group etc.

The immune system is one of the mechanisms that organisms have developed to defend against environmental challenges and other perceived threats (Salak-Johnson et al., 2012). Several researches have concluded that chronic stress exerts a general immunosuppressive effect that suppresses or withholds the body's ability to initiate a prompt, efficient immune reaction (Hafen et al., 1991; Huebner, 1992). This has been due to the high levels of corticosteroids production during chronic stress, which produces an imbalance in corticosteroid levels (Salleh, 2008). Plasma cortisol and changes in leukocyte populations are the most common physiological parameters used to measure farm animal welfare (Terlouw et al, 1997; McGlone et al., 2004; Trevisi and Bertoni, 2009). In the study of Salak-Johnson et al. (2012) find the differences in cortisol, neutrophil and lymphocyte populations, and neutrophil : lymphocyte (N:L) ratio, with those sows housed at the greatest floor space allowance having the lowest N:L ratio but the greatest plasma cortisol. In contrast, most studies have found no difference in plasma cortisol (von Borell et al., 1992; Tsuma et al., 1996; Pol et al., 2002; Geverink et al., 2003) or immune activity, more specifically N:L ratio (Von Borell et al., 1992; McGlone et al., 1994; Broom et al., 1995; Hulbert and McGlone, 2006) among sows housed in stalls or pens.

2) Group size

Group size is defined by the number of sows in a pen, rather than by the amount of space allotted to each sow (Bench et al., 2013b). It was previously expected that aggression would increase in large groups due to the more establishment of dominance hierarchy in earlier studies (Taylor et al., 1997; Arey and Edwards, 1998). However, more recent reviews have concluded that there is no evidence to suggest that there is more aggression in large groups of up to 40 sows in experimental settings and up to 300 sows in industrial conditions (Barnett et al., 2001; Spoolder et al., 2009). It also supports the studies of Hemsworth et al. (2013) that there is no statistical difference in the frequency of aggression in group housing sows at early gestation period (d 2 and 8 after mixing) into groups of 10, 30 and 80. The author suggested possible explanation for this result is the social behavior of pigs, which originated from group size. In large groups, where individual recognition becomes less likely, animals use method other than aggression to establish social dominance, such as body size (Rodenburg and Koene, 2007). Group size had no effect on reproductive performance (Taylor et al., 1997; Hemsworth et al., 2013), as well as serum cortisol concentration (Hemsworth et al., 2013). Anil et al. (2007) noted that sows exposed to the aggression associated with mixing and the ESF before implantation might leads to the lack of difference in reproductive performance between different size of groups.

3) Group type

In commercial condition, gestating sows can be managed in either static or dynamic groups. For static groups, all sows in a group are introduced on the same day, and remain until the entire group is moved to the farrowing facility. Static grouping is forming a pen group at one time without adding any more females once the group is established. In dynamic groups, small groups of sows are added to a larger existing group periodically throughout gestation, and groups are also removed periodically as sows move to farrowing. Each time a new group is added a new bout of aggression will occur (Marchant-Forde, 2009). However, it has been shown that sows adopt a more tolerant and passive response to unfamiliar animals in large dynamic groups (Spoolder et al., 1997).

Although few studies have pointed out greater aggressive behavior originated from frequent mixing in dynamic groups (Arey and Edwards, 1998; Barnett et al., 2001), recent findings does not necessarily support this interpretation. According to the studies demonstrated by Van der Mheen et al. (2003), sows in large dynamic groups (50 sows) consumed their individual ratio in smaller portions due to disturbances at the feeders compared to small static groups (13 sows). In addition, sows in dynamic groups recorded more incidences of skin scratches, but no differences between treatments were observed on pregnancy rates, litter size or litter weight. In agreement, Anil et al. (2006) found that although skin injury scores were greatest in the dynamic group both in general and 2 week after mixing, there were no effects on aggression, cortisol concentrations, farrowing performance, and longevity. Moreover, in the studies of Strawford et al. (2008) who found that there were no differences in aggression, skin injuries, and cortisol concentrations between sows in static and dynamic groups with an electronic sow feeding.

4) Feeding regime; feeding level, feeding system

Feeding level. It is generally considered that restricted amount of feed was commonly provided to breeding sows in order to prevent excess BW gain and fat deposition, which can cause farrowing and locomotion problems and subsequently reduce reproductive performance (Meunier-Salaün et al., 2001). In the pork industry, it is generally considered that restricted level of feeding during gestation is sufficient for maintenance and fetal development, suggesting that animals are not in a negative energy balance (Verdon et al., 2015). However, limited feeding resulted in more competition for feed or access to feeding areas (Barnett et al., 2001), and development of stereotypies (Lawrence and Terlouw, 1993). In condition of group housing, there is no clear evidence in the literatures that have been conducted of increased aggression, stress, or injuries in association with restricted feeding level. According to the study of Spoolder at al. (1995), although there were no effects on aggression or skin injuries, grouped sows fed 1.8 kg (23 MJ DE/d) in "lock-in" stalls spent more time standing and manipulating bars and chains after feeding than sows fed 3.2 kg (40 MJ DE/d). It is also of interest that Bergeron and Gonyou (1997) found that sows fed either a high-energy diet (23.7 MJ DE/kg) or a "high-foraging" diet (a standard diet [14.0 MJ DE/kg] but with a device in the feeder that increased the feeding time) spent less time active and less time displaying stereotypies than sows fed a standard diet (14.0 MJ DE/kg). Therefore, the lack of energy in the diet as well as time spent feeding may contribute to the development of stereotypies (Verdon et al., 2015). However, although increased feeding times have been shown to reduce sow hunger, in sequential feeding systems such as the ESF, it can cause crowding, thereby reducing overall feeder capacity (Bench et al., 2013a).

Feeding system. The type of feeding system affects the level of aggression related to competition for feed (Spoolder et al., 2009). There are four representative feeding types in group housing system; floor feeding, partial stalls and ESF. Floor feeding is the most simplest and cheapest among other systems. This system allows sows to feed simultaneously and thus fulfill some element of natural feeding behavior. However, variation in feed consumption between dominant and subordinate sows can also be seen in floor feeding systems, causing subordinates to suffer from undernourishment and low weight gain of sows (Brouns and Edwards, 1994). On the other hand, partial stall reduces aggression and plasma cortisol concentrations in the long term in group-housed gestating gilts (Barnett, 1997; Andersen et al., 1999). The majority of welfare concern in this system is the incidence of vulva biting. Andersen et al. (1999) found that sows housed in pens with full-body feeding stalls increased vulva bites and suggested that feeding arrangement influences the nature as well as the amount of aggression. Indeed, although floor feeding is competitive, gaining access to feeding stalls can also lead to competition and aggression between group-housed sows (Bench et al., 2013b). The most advantageous group housing system dealing with individual feed consumption of sow is ESF. This allows for the greatest possible control over individual sow intake. However, this system forces sows to feed in sequence, and as such, sows queue at the ESF entrance gate. These findings support recent work by Olsson et al. (2011) who observed that approximately 4 to 6 sows often queue at the ESF entrance, although one-third of queued sows having already eaten daily feed ration. Consequently, preventing queuing has been identified as an important development in improving welfare in ESF systems (Anil et al., 2003).

5) Bedding

Although the influence of quality of bedding on welfare, health and performance of the animals has not been extensively studied, the most common enrichment and bedding material for group housed sows reported in the literature is straw (Arey, 1993). In fact, straw offers excellent possibilities for diverse manipulation: to root or scratch in, to chew and eat it. Andersen et al. (1999) found that in group housed sows, the supply of a bedding substrate reduced the frequency of abnormal gait, compared to sows raised on a slatted floor. Bedding also plays an important role in group housing designs as it functions to absorb urine and feces, and is used to enhance sow welfare (Lay et al., 2000). It has been noted that group housing with straw bedding is almost always associated with large, dynamic groups and ESF feeding (Spoolder et al., 2009). This suggests that in large group sizes with a tendency for higher incidences of aggression, enrichment and bedding may be an effective means of improving sow welfare (Bench et al., 2013b). However, the use of straw is not without its disadvantages, mainly due to cost, increased labor, hygiene concerns and, most importantly, incompatibility with manure and drainage systems (Tuyttens, 2005). Bench et al. (2013a) categorized that there are several factors which makes it difficult to evaluate the welfare relevance of straw from the scientific literature: (1) the variation of the composition, structure, quality and quantity of straw; (2) no scientifically authorized or qualified assessment of animal welfare on the effect of straw; (3) lack of specific investigation on the welfare impact of straw; (4) the importance of straw with age of the animal and their housing conditions and management.

III. Space allowance in growing-finishing pigs

1. Effects of space allowance in growing-finishing pigs

1) Growth performance

According to the studies of Petherick (1983), the most common means to express space allowance in as space per animal, but this has the limitation that space requirements increase with body weight (BW). A second option is to express space allowance as weight density (kg/m^2), but space requirements are not directly proportional to body weight. A third means is to express as no allometric relationship between body weight and body dimensions. The equation $A = k * BW^{0.67}$ can be used to express the relationship between space allowance (A) and body weight (BW) (Petherick, 1983). A recent summary of research studies suggests that the maximum growth rate for the entire growing-finishing period will be achieved at a coefficient (k) of 0.0336 (Gonyou et al, 2006) when A is m^2/pig and BW is in kg.

Several studies have demonstrated that space allowance has a significant impact on feed intake (Edmonds et al. 1998; Gonyou and Stricklin 1998; Table 3). They concluded that less consumption of feed originated from decreased space allowance detrimentally influenced on average daily gain, resulting in poor growth performance. Brumm and Gonyou (2001) suggested that a major response to space restrictions was a decrease in feed intake. Kerr et al. (2005) demonstrated that growing pigs maintained at higher space allowance had a higher weight gain (8.23 kg) than their high stocking density counterparts (7.42 kg) for five weeks at the same room temperature. White et al. (2008) reported that reducing stocking density from 0.93 to 0.66m^2/pig resulted in 4.0% less body weight, 17.0% less ADG, 10.7% less average daily feed intake (ADFI) and a 7.8% less G/F ratio.

Table 3. The effect of space allocation on feed intake, and gain to feed (G/F) ratio in growing-finishing pigs (Adopted by Nyachoti et al., 2004)

Space (m^2/pig)	Performance variable			% change in ADFI	Reference (BW, kg)
	ADFI(Kg/d)	ADG(g/d)	G/F ratio		
0.560	2.18[a]	876[a]	0.40	-8.3	Hyun et al. (1998)
0.250	2.00[b]	734[b]	0.37		(35)
0.780	2.58	795[a]	0.31[a]	-1.2	Brumm and Miller (1996)
0.560	2.55	765[b]	0.30[b]		(27 to 107)
0.705	2.36[a]	877[a]	0.37	-4.7	Gonyou and Stricklin (1998)
0.436	2.25[b]	832[b]	0.37		(25 to 97)
0.545	2.70[b]	834[a]	0.31	-11.1	Edmonds et al. (1998)
0.345	2.40[a]	688[b]	0.29		(18 to 55)
0.740	2.87[a]	700[a]	0.24	-11.9	McGlone and Newby (1994)
0.560	2.53[b]	600[b]	0.24		(59 to 106)

[a, b] Means within a column and study bearing different letters differ.

2) Behavioral time budget

Few scientific literatures have demonstrated the relationship between space allowance and feeding behavior. Hyun et al. (1998) demonstrated that pigs on the restricted space allowance (k = 0.017) made 29 % fewer feeder visits, but spent 40 % more time at the feeder per visit and consumed 45 % more feed per visit than pigs on the higher space allowance. Other studies also found that crowded pigs (k=0.031, k=0.024, k=0.027, respectively) spent more time feeding (Bryant and Ewbank, 1974 and Meunier-Salaun et al., 1987), while the increased time spent feeding was not correlated by an increase in daily feed intake. These results suggest that feeder occupation is not necessarily linked to ingestion of feed.

According to earlier findings of Meunier-Salaun et al. (1987), behavioral changes are often the first sign of stress due to crowding. Moreover, resting was the main activity observed among uncrowded pigs, occurring at a frequency of over 60 % of the behavioral time budget. When space was restricted below *k*=0.024, pigs were less frequently observed incidences of lying and sleeping (Bryant and Ewbank, 1974; Mogensen et al., 1997; Fisher et al., 1997a, b). The reason for this result can presumably be interpreted that the lower space allowance reduced the lying area so that the animals could not sleep comfortably simultaneously.

Pigs preferred to spend most of their time lying in a fully recumbent, or lateral, postural position as well as this behavior increases as pigs grow, and is especially evident at night (Ekkel et al., 2003). Imposing a space restriction may physically prevent pigs from lying in a fully recumbent position. At space allowances of *k*=0.027 (Meunier-Salaun et al., 1987) and *k*=0.025 (Pearce and Paterson, 1993), pigs were observed lying in a sternal recumbency posture more often than a lateral one.

3) Carcass evaluation

Effects of space allocation on carcass backfat and percentage lean have only been reported in a few trials (Brumm and Miller, 1996; Hamilton et al, 2003; Brumm, 2004; Brumm et al, 2004a). According to studies of Brumm and Miller (1996), pigs with less space allowance from the nursery (*k*=0.021) to the market weight (*k*=0.024) showed a decrease in daily lean gain, while carcass lean percentage was not differ between treatment. Hamilton et al. (2003) studied the correlation between gender and space allowance for leanness, suggesting that gilts showed more carcass leanness in the crowded environment (*k*=0.021) while barrows observed more carcass leanness in the uncrowded environment (*k*>0.035). These results warrant further studies examining the effects of space allowance on carcass lean gain and carcass lean percentage among the genders. Consequently, it is not possible to predict the impact of space allocation on carcass traits, because of lack of data available. However, it is noteworthy that the effect is a numerical improvement in carcass lean and a decrease in carcass backfat depth as space allocation limited with a resulting decrease in daily feed intake (Hamilton et al., 2003).

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Chapter III : The Effects of Gilts Housed Either in Group with the Electronic Sow Feeding System or Conventional Stall

ABSTRACT

This experiment was conducted to assess the status and productivity of gestating gilts in groups with the electronic sow feeding (ESF) system compared to conventional stalls. A total of 83 gilts (Yorkshire×Landrace) were housed into individual stalls to be artificially inseminated. Gilts confirmed pregnant were introduced to their treatment, conventional stalls (ST) or groups with the ESF system. All gilts were taken to the farrowing crates one week prior to their expected farrowing date. In the gestation period, there were no significant differences between gilts allocated to ST and ESF on growth performance. However, backfat thickness gain ($P=0.08$) and body condition score (BCS) at 110 days of gestation ($P=0.10$) tended to be higher in ESF gilts than ST. Likewise, gilts housed in group showed significantly higher estimated body muscle contents at 110 days of gestation ($P<0.02$) and body muscle change during gestation ($P<0.01$). There was a trend for a shorter parturition time in ESF gilts ($P=0.07$). In the lactation period, group housed gilts showed a tendency to increased BCS changes ($P=0.06$). Reproductive performance did not differ with the exception of piglet mortality (ST=0.2 no. of piglets vs ESF=0.4 no. of piglets; $P<0.01$). In blood profiles, ST gilts showed a higher cortisol level at 110 days of gestation ($P<0.01$). Weaning to estrus interval was shorter in gilts housed in ESF than ST ($P<0.01$). In locomotory behaviors, ESF gilts recorded a tendency to elevate locomotion score at 36, 70, and 110 days of gestation ($P=0.07$, $P=0.06$, and $P=0.06$, respectively). Similarly, ESF gilts showed significantly higher incidence of scratches at 36, 70, and 110 days of gestation ($P< 0.01$). Moreover, farrowing rates were higher in stall treatment (97.6%) compare to group housing treatment (95.2%). In conclusion, while group housed gilts with ESF system positively affected welfare status in combination with less physiologically stressful environments and activity, it negatively effects piglet mortality, farrowing rates and injuries of gilts.

Key words: Electronic Sow Feeding, Stall, Gilts, Gestation, Piglets, Group Housing

INTRODUCTION

The European Union legislated to phase out housing pregnant sows in stalls by January 2013 due to animal welfare issues (Council Directives 91/630/EEC and 2001/88/EC, and Commission Directive 2001/93/EF). This ordinance influenced the strategies of management, feeding and sow welfare. The move towards group housing systems has been investigated for the past two decades by European countries. Nevertheless, most Asian countries are still using stall housing because of the ease of artificial insemination, low capital cost, individual feeding and minimize aggressive behavior. However, stall housing causes a negative effect on muscle weight and bone strength (Marchant and Broom, 1996), decubital ulcers, chronic disease and stereotypes, which probably indicate poor welfare of sow (Scientific Veterinary Committee, 1997). Sows housed in groups are known to resolve these problems. Several studies have reported the effects of group housing. In productivity, group housed sows with the electronic sow feeding (ESF) system have similar or improved productivity than sows housed in stalls (Bates et al., 2003). In peripheral physiologic measures, several studies have concluded that no difference in stress-related plasma cortisol concentrations are evident between sows housed in stalls and those housed in groups (Barnett et al., 1989; von Borell et al., 1992; Zanella et al., 1998). However, there is limited data on the effects of group housed gilts on the measurements that are given above. Thus, more studies that compare different indicators of welfare as well as productivity in stalls and modern commercial group housing system of gilts are needed. Therefore, the objective of the study was designed to assess the adequacy of the welfare and productivity of gestating gilts housed in either conventional stalls or group housed with the ESF system.

MATERIALS AND METHODS

Experimental animal management and diets

A total of 83 primiparous sows (Yorkshire×Landrace) with an average 180 d of age and approximately 134.3 kg of body weight (BW) were introduced into stalls to be artificially inseminated. They were given twice daily boar contact. When signs of first estrus were detected, artificial insemination (AI) was served twice a day at 12 hour intervals with fresh diluted semen (Darby A.I. center, Gyeonggi-do, Republic of Korea). Pregnancy diagnoses were done with ultrasound analyzer (Easy Scan, Dong-Jin BLS Co., Ltd., Gyeonggi-do, Republic of Korea) with day 28 and 35 postcoitum. Gilts confirmed pregnant were allotted to their treatment, ST or ESF on the basis of BW and backfat thickness (BFT) in a completely randomized design. Two gilts in ESF and one gilt in ST were excluded in the experiment because of miscarriage and failure in adaptation of feeding station during gestation, respectively. After 110 days of gestation, gilts were all moved to farrowing crate ($2.50 \times 1.80\ m^2$). Physical measures included sow body weight (BW), body length, body condition score (BCS) and BFT, which were measured at mating, 110 d of gestation, farrowing, and 21 d of lactation, respectively. BW was measured by electronic livestock weighing scale for pig (DHG, CAS Co., Ltd., Gyeonggi-do, Republic of Korea). Body length was started at the base of the ear of the gilt and measured to the base of its tail using measuring tape. BCS was scaled in steps of 0.5 from class 1 for very thin to class 5 for fat gilts. BFT was measured at the P_2 position (mean value from both sides of the last rib and 65 mm away from the backbone) using Ultra-sound (Lean-meter, Renco Corp., Minneapolis, MN, USA) at the same time. Muscle and protein composition changes during gestation of primiparous sows were calculated using the equations of Dourmad et al. (1996) and Dourmad et al. (1997), respectively.

$$\text{Muscle (kg)} = -9.2+0.61(\pm 0.052)\ \text{BW} - 0.86(\pm 0.29)\ \text{BFT}$$

$$\text{Protein (kg)} = 2.28+(0.178\times\text{EBW})-(0.333\times\text{BFT})$$

*EBW (kg) = sow empty live weight estimated from the live weight ($= 0.905 \times BW^{1.013}$)

The reproduction traits were recorded within 24 h postpartum, including the number of piglets born alive, stillborn piglets, mummies, and piglet losses. Individual piglet weight of total born was measured at birth and piglets were weighed at 21 d of lactation. Full-HD camcorders (HMX-M20BD, Samsung, Suwon, Korea) were installed to record the duration of parturition which defined as the time between the expulsion of the first and the last born piglet. Average daily feed intake (ADFI) was scored during lactation. Detection of weaning to estrus interval (WEI) of each sow was monitored from 3 to 10 d after weaning.

All experimental gilts were fed daily around 08:00 h with a commercial diet during gestation and lactation and gilts in both treatments were provided 2.0 kg/d during gestation and were *ad libitum* in lactation.

Animal housing

Gilts in stall treatment were housed in individual gestation stall (2.15×0.6 m/head) and an individual feeder with one waterer per sow. Floors were fully slatted concrete with no bedding. A climate computer regulated ventilation and heating in the compartments. Temperatures varied between 15°C and 20°C. Lighting was provided in combination with a several windows and fluorescent lights, which were switched on at 08:00 h and switched off at 20:00 h.

Gilts in ESF treatment were housed in a room (15.2m×10.2m, 3.8 m/head) with full concrete flooring and approximately 10 cm deep rice hull bedding. The Rice hulls were provided around lying area and changed every 2 weeks. Water was provided *ad libitum* by 5 nipple drinkers per pen. The ESF station (Compident VII, Schauer, Prambachkirchen, Austria) was located in the middle of each pen. Gilts were identified by radio-Frequency Identification tag and provided the allocated amount of feed individually. Feed was dispensed with water in the ESF so that gilts finished consuming feed without leaving the ESF to drink water.

Skin injuries and locomotion score

Skin injuries and locomotion scores were assessed in both treatments of all sows on each of d 36, 70, and 110 as described by Karlen et al. (2007). Injuries were categorized according by fresh scratches and partially healed injuries. Each side of the gilt's body was divided into 21 areas for injury scoring. The one experimenter did scoring of all injuries in each experiment. Locomotion score was assessed based on the observation of sows standing and walking. Gilts were observed by two experimenters and given a score of 0 (not lame) to 3 (severely lame, cannot stand) while they walked on the solid concrete floor of the 50 m long central corridor.

Sample collection and chemical analyses

For analyzing plasma cortisol concentration, ten primiparous sows in each treatment were used to collect blood samples at breeding, 110 d of gestation, 24 h of parturition and 21 d postpartum with ethylenediaminetetraacetic acid tubes (BD Vacutainer K2E, Becton Dickinson, Plymouth, UK). Piglet bloods (n: ST = 10, ESF = 10) were also collected from the anterior vena cava at 12 h and 21 d postpartum. All samples were centrifuged at 3,000 g at 4°C for 15 min (Eppendorf centrifuge 5810R, Hamburg, Germany) to separate plasma.

Statistical analysis

The data from two different housing types were compared by Student t-test using PROC TTEST (SAS, 2008). Main effect in the model was different housing system. Individual gilt was considered as the experimental unit and all values are reported as least square means. Differences and suggestive differences between ST and ESF systems were considered at $p \leq 0.05$ and $p \leq 0.10$, respectively. The alpha level used for determination of statistical significance was 0.05.

RESULTS

The effects of different housing systems of gilts on growth performance during gestation are presented in Table 1. There were no significant differences in BW, BFT, body length and BCS. However, ESF treatment tended to gain more BFT (P=0.08) and show higher BCS (P=0.10) at 110 days of gestation. Additionally, there were significant differences on the changes in muscle contents (Table 2). The ESF gilts showed higher weight of muscle in the body (P<0.02) than ST gilts at 110 days, and consequently gained more muscle during gestation (P<0.01). However, no changes in body protein deposition were detected between treatments. During lactation, different housing systems did not affect BW, BFT, and BCS (Table 3). Although there were no significant difference in daily feed intake, ESF gilts tended to lose more BCS (P=0.06) than ST gilts during overall lactation. Reproductive performance of sows such as the number of total born, born alive, stillbirth, mummy, mortality and weaning pigs are presented in Table 4. Mortality was higher in ESF treatments (P<0.01), but there were no significant differences in the other criteria measured during lactation. Litter and piglet weight also were_not affected by different housing systems. Gilts housed in groups tended to shorten parturition time (P=0.07) and significantly shorten the average WEI (P<0.01). Skin injuries and locomotion scores are presented in Table 5. There was a tendency for a higher locomotion score at 36, 70, and 110 days of gestation in group housed gilts (P=0.07, P=0.06, and p=0.06, respectively). Similarly in risk of injury, ESF gilts showed higher incidence of scratches at 36, 70, and 110 days of gestation (p<0.01). In addition, stall housed gilts observed more farrowing rates (97.6%) than ESF gilts (95.2%). In plasma cortisol, ST gilts showed significantly higher levels of cortisol (P<0.01) at 110 days of gestation and a tendency (P=0.08) on 24 hours postpartum (Table 6).

DISCUSSION

Different housing systems did not show any significant differences on growth performance of gilts. However, BFT gain (P=0.08) and BCS at 110 days of gestation (P=0.10) tended to increase in gilts housed in groups. Similar results are shown in several studies. Weng et al. (2009) reported that gilts housed in groups showed significantly higher BTF gain than those housed in stalls due to different thermal environment experienced by animals. Marchant and Broom (1996) reported that although BW and body length are heavier and similar compared to group housed with ESF as gilts, group housed sows show significantly heavier BW and longer body length by the fourth parity. Possible explanations for these results are associated with muscular and skeletal development by activity (Marchant and Broom, 1996), less performing energetically costly stereotypes (Cronin, 1985), and decreasing lower critical temperature (LCT) by providing bedding materials (Geuyen et al., 1984) of group housing sows. Indeed, sows that had a higher LCT require a higher proportion of their energy intake to maintain body temperature (King, 1991). Karlen et al. (2007) suggested that sows confined in stalls show poorer body condition as a consequence of their higher LCT. In agreement with previous studies, our findings indicated that activity and thermoregulation might be attributed to improve BFT and BCS in group housed gilts. Different housing systems significantly influenced the estimated body composition. The lack of exercise in stalls leads to smaller locomotor muscles in proportion to total body weight than group housed sows (Marchant and Broom, 1996). This is consistent with the study of Petersen et al. (1998) who confirmed that sows reared in large pens had an increased total bone mass, most significantly for the leg, compared to that of stall sows. Although our experiment did not conduct a postmortem examination, results of the present study indicated that activity would be a contributing factor affecting the growth of muscle mass in group housed gilts.

There were few differences in BW and BFT changes between the two gestation housing treatments. Our results are in agreement with Bohnenkamp et al. (2013), but differ from Borell et al. (1992) who reported that gilts housed in groups showed significantly less BFT loss during lactation.The sows mobilize their body reserves and enhance their feed intake (Eissen et al., 2000) to increase energy demand during lactation. However, considering there were no statistical differences on ADFI in our results, we could explain that the tendency of poorer BCS in group housed gilts ($P=0.06$) were associated with higher loss of BW and BFT.

In piglet performance, piglet mortality was significantly increased ($p<0.01$) in group housed treatment, which is in agreement with the results of Cronin et al. (1996). A dominant portion of piglet mortality in both treatments was crushing (Stall, 91%; ESF, 89%) in the present experiment. One explanation for this result may be the maladjustment of confinement. Boyle et al. (2002) found that sows group-housed during gestation had more postural changes, more ventral and lateral lying and dog sitting behaviors than sows from stalls. This implies that allowing sows to move restlessly increase the incidence of piglet crushing. This agrees with previous studies that group gestation housing may have a negative influence on sow welfare when these sows are placed in farrowing stalls (Mcglone et al., 2004), resulting in an increased number of stillborn piglets, and an increased risk of pre-weaning mortality (Weary et al., 1996), and possibly a disruption in the nursing cycle between sow and litter (Spinka et al., 1997).

Some previous studies calculated the duration of farrowing in sows and found that the average farrowing period ranged from 156 to 262 minutes (Randall, 1972; Madec and Leon, 1992; Van Dijk et al., 2005). Both treatments recorded in the range of value found in previous studies, but there was a trend towards prolonged parturition length in stall treatment ($P=0.07$). Parturition appears to be dependent on high concentrations of oxytocin, and has been shown to be slowed or prevented when plasma oxytocin concentration is reduced by treatment with opioid (Russell et al., 1989). Chronic environmental stress activates endogenous opioid pathways that inhibit oxytocin secretion and thereby prolong delivery (Lawrence et al., 1994). Likewise, the present result indicates that prolonged delivery in stall housed gilts was caused by a chronic stressful environment, resulting in dysfunction of the endocrine regulation.

Group housed primiparous sows significantly showed shorter WEI ($P<0.01$). Previous experiments have shown the effects of different housing systems on WEI of sows. However, the results have not always been concordant. Group housing did not affect WEI (Schmidt et al., 1985). In contrast, there was an increase in the number of gilts exhibiting irregular estrus behavior in stalls (Ford and Christenson, 1979; Rampacek et al., 1984). Moreover, Weng et al. (2009) reported that gilts housed in conventional gestating stalls and farrowing crates observed the significantly longest WEI than group housed gilts. This implies that confinement stress in ST is affected negatively on releasing less estrus-stimulating hormones.

In previous studies, aggressive incidents, queuing and many non-feeding visits have been well recognized as being present when using ESF feeders for gestating sows (Jensen et al., 2000). However, few comparative studies have been conducted between stall and group housing on health status. The occurrence of skin injuries in group housed sows is a direct result of aggressive behavior. Previous studies suggest that aggression decreased with less frequent regrouping due to a decreased demand for the establishment of new rank relationships (Hunter et al., 1988). In contrast, individually housed sows can be protected from aggressive physical interactions if partitions are in place (McGlone et al., 2004). In the present study, group housing treatments showed significantly higher skin scratches in all phases ($P<0.01$). This implies that although the static group is well recognized social hierarchy and highly familiar with each of gilts, they encounter higher aggressiveness around feeding machine.

On the other hand, the tendency toward deterioration of locomotion scores in group housed gilts in 35, 70, and 110 days of gestation ($P=0.07$, $P=0.06$, and $P=0.06$, respectively) might be associated with in combination of aggression at every feeding time and floor conditions. Several studies have conducted the effects of beddings in group housing. Andersen et al. (1999) found that in group housed sows, the supply of a bedding substrate reduced the frequency of abnormal gait, compared to sows raised on a slatted floor. Thus, enrichment and bedding may be an effective way in large group sizes to reduce incidences of aggression. However in our experiment, rice hulls were provided only around the lying area, considering slurry systems as well as ease of purchase compared to straw. Therefore, the ESF system would be less advantageous regarding leg injuries and longevity for group housing.

Different housing systems affect farrowing rates, however results are still inconsistent. According to previous studies, farrowing performance and longevity of sows in dynamic and static groups in an ESF system did not differ (Anil et al., 2006). In contrast, farrowing rate was 10% lower in group housing sows compare to stall housing (Karlen et al., 2007). In our findings, Stall housed gilts showed higher farrowing rates (97.6%) than that of ESF gilts (95.2%). Possible reason for this can be explained by attribution of continuous fighting, resulting higher risk of injuries as well as leg problems.

Blood cortisol concentrate has been the most common physiological parameter used to measure farm animal welfare (Terlouw et al., 1997), although the measurement suffers from diurnal variations and sample collection artifacts (McGlone et al., 2004). Barnett et al. (1989) reported that sows housed in stalls had a moderate, but statistically significant increase in cortisol concentrations compared with group-housed sows. In addition, Broom et al. (1995) reported similar concentrations of cortisol for stall-and group-housed sows. Recently, a meta-analysis of 35 refereed journal articles by McGlone et al. (2004) reported that the average stereotypes, cortisol, and immune function are statistically similar between sows in stalls versus group pens. In the present study, stall housed gilts showed significantly higher plasma cortisol concentration in 110 days of gestation ($P<0.01$) and tendency in 24 hours postpartum ($P=0.08$). Possible explanation for this result is that the chronic stress stem from confinement in stalls negatively influenced the growth of gilts in gestation. There was evidence that gilts in stalls showed a trend of less BFT gain and BCS change. Moreover, prolonged parturition length in stall treatment was associated with increased plasma cortisol concentration in 24 hours postpartum.

CONCLUSION

A modern type group housed gilts resulted in several possibilities for welfare parameters. Physiologically, group housed gilts lead to an enhancement of more accumulation of backfat as well as better muscle content in the body during gestation. Advanced management or facilities for reducing piglet mortality are needed in order to ameliorate productivity. Additionally, further investigations in group housing system with ESF are needed for managing aggressive behavior, following an increase of feet and leg problems, which is closely related to longevity of gilts as well as economic losses of the farm.

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Table 1. The effects of different housing system on growth performance of gilts in gestation

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
Gestation				
No. of sows	41	42		
Live body weight, kg				
At mating	136.0	132.4	0.87	0.44
110 days of gestation	185.8	189.6	1.20	0.40
Gain (0-110 d)	49.6	57.2	0.92	0.12
Backfat thickness, mm				
At mating	21.5	18.8	0.45	0.84
110 days of gestation	23.4	22.2	0.40	0.18
Gain (0-110 d)	1.9	3.4	0.38	0.08
Body condition score				
At mating	3.1	3.1	0.04	0.91
110 days of gestation	3.2	3.3	0.03	0.10
Gain (0-110 d)	0.1	0.2	0.05	0.11
Body length, cm				
At mating	114.9	115.0	0.39	0.28
110 days of gestation	122.5	124.3	0.47	0.87
Gain (0-110 d)	7.6	9.3	0.43	0.35

[1] Standard error of the means.

Table 2. The effects of different housing system on estimated body protein and muscle composition

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
Gestation				
No. of sows	41	42		
Body protein contents, kg				
At mating	18.5	18.8	0.19	0.50
110 days of gestation	27.1	27.6	0.23	0.32
Gain (0-110 d)	8.6	8.8	0.17	0.62
Body muscle contents, kg				
At mating	55.4	55.4	0.60	0.96
110 days of gestation	84.0	87.4	0.75	0.02
Gain (0-110 d)	28.6	31.9	0.60	0.01

[1] Standard error of the means.

Table 3. The effects of different housing system on body changes in lactation

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
Lactation				
No. of sows	40	40		
Live body weight, kg				
24 hr postpartum	166.7	174.1	1.21	0.44
21 d of lactation	161.6	162.8	1.13	0.27
Changes (0-21 d)	-5.1	-11.3	0.92	0.25
Backfat thickness, mm				
24 hr postpartum	21.7	22.2	0.41	0.63
21 d of lactation	18.6	19.8	0.37	0.96
Changes (0-21 d)	-3.1	-2.4	0.23	0.97
Body Condition score				
24 hr postpartum	3.0	3.0	0.03	0.76
21 d of lactation	2.8	2.7	0.03	0.96
Changes (0-21 d)	-0.2	-0.3	0.03	0.06
Daily feed intake, kg	5.4	5.5	0.07	0.66

[1] Standard error of the means.

Table 4. The effects of different housing system on reproductive performance

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
No. Sows	40	40		
Litter size, no. of piglets				
Total born	11.4	11.5	0.24	0.86
Stillbirth	0.7	0.6	0.11	0.62
Mummy	0.1	0.1	0.04	0.17
Born alive	10.6	10.8	0.25	0.42
After cross-fostering[2]	10.3	11.0	0.11	0.81
Mortality	0.2	0.4	0.11	0.01
Weaning pigs	10.1	10.6	0.11	0.86
Parturition time, minute	199.5	187.0	5.44	0.07
WEI, day	6.3	6.0	0.15	0.01
Litter weight on lactation, kg				
At birth	15.6	16.3	0.35	0.11
After cross-fostering[2]	14.5	16.2	0.29	0.13
21 d	53.3	54.4	0.90	0.62
Weight gain (0-21 d)	38.8	38.2	0.80	0.99
Piglet weight on lactation, kg				
At birth	1.37	1.44	0.023	0.83
After cross-fostering[2]	1.41	1.49	0.026	0.08
21 d	5.29	5.16	0.078	0.75
Weight gain (0-21 d)	3.88	3.67	0.071	0.82

[1] Standard error of the means.

[2] After cross-fostering day at d1 postpartum.

Table 5. The effects of different housing system on skin injuries and locomotion score

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
Incidence of scratch, No./gilt				
Initial	0.6	0.7	0.09	0.50
d 36	2.9	16.2	0.91	0.01
d 70	2.6	6.2	0.39	0.01
d 110	1.1	4.0	0.26	0.01
Locomotion score				
d 36	0.317	0.595	0.0772	0.07
d 70	0.561	0.810	0.0662	0.06
d 110	0.585	0.857	0.0713	0.06

[1] Standard error of the means.

Table 6. The effects of different housing system on plasma cortisol concentration

Criteria	Treatment		SEM[1]	P-value
	Stall	Group		
Cortisol, µg/dl				
Gilt				
At breeding	2.44	4.75	0.611	0.36
110 days of gestation	4.48	3.00	0.424	0.01
24 hrs. postpartum	5.60	3.78	0.613	0.08
21 days of lactation	2.76	3.86	0.363	0.77
Piglet				
At birth	8.72	5.98	1.018	0.54
21 day	5.38	5.28	0.566	0.17

[1] Standard error of the means.

Chapter IV : Comparing gestating sows housing between electronic sow feeding system and conventional stall over three consecutive parities

ABSTRACT

This study was conducted to investigate the effects of gestating sows housed in groups with electronic sow feeding (ESF) system over three consecutive parities. A total of 83 pregnant gilts [Yorkshire × Landrace] were housed into ST: gilts housed in individual stalls, and ESF: gilts housed in groups with ESF system on the basis of body weight (BW) and backfat thickness (BFT) in a completely randomized design. Rice hulls were used as bedding material on the group housing floor. The same commercial gestating diet was provided daily at 2.0 kg, 2.2 kg and 2.4 kg/day in the first, second and third parity, respectively, in both treatments. All sows introduced farrowing crates five days before expected farrowing. BW and BFT of the sows were measured at d 35, and 110 of gestation as well as at 12 h and d 21 postpartum. Parturition time was recorded during farrowing. Reproductive performance, including total born, stillborn, mummy, born alive, mortality, weaning pigs as well as litter and piglet weight were recorded. Scratch incidence and locomotion scores in sows were assessed at d 36, 70, and 110, respectively. Ten sows in each treatment were randomly selected for blood sampling. Serum samples were analyzed for cortisol and oxytocin levels. In the gestation period, ESF tended to increase BW gain in the second parity ($P=0.08$), and consistently showed significance during the third parity ($P<0.01$), resulting in higher BW at d 110 ($P=0.10$, $P<0.03$ in parities 2 and 3, respectively). Similarly, BFT gain tended to be higher in ESF than ST ($P=0.08$, $P= 0.10$ in parity 1 and 2, respectively). Estimated body fat contents changes are also higher in ESF regardless of the parities ($P<0.01$, $P<0.02$, $P=0.10$ in parities 1, 2, and 3, respectively). However, there were no significant differences on sow BW and BFT changes during lactation. There was a tendency of shorten delivery time in the ESF treatment ($P=0.07$, P=0.09, and P=0.10 in parities 1, 2, and 3, respectively). In reproductive performances, higher piglet stillborn in ST was observed (P=0.06, P=0.07 in parities 2 and 3, respectively). In endocrinal analysis, ST higher serum cortisol was observed at d 110 of gestation (P<0.01 in parity 1), whereas no detectable difference was observed in the serum oxytocin level. Higher incidence of body scratch was scored in ESF in early gestation in all parities (P<0.01), resulting in higher locomotor disorders in the middle and late gestation periods (P=0.07). In conclusion, our results suggested that the ESF system showed higher growth performance and survival rate of piglets. However, more incidences of body scratch and higher locomotion disorder scores observed in the ESF sows was due to the combination of persistent fighting around the ESF machines and inadequate bedding materials. Consequently, it is necessary to consider an adequate space divider or barrier for gestating sows to avoid aggression in the ESF system.

Key words: ESF system, group housing, sow, reproductive performance, parity, stall

INTRODUCTION

The European Union has prohibited the use of gestating crates for pregnant sows (Commission of the European Communities, 2001). Even though keeping pregnant sows in an individual crate is still widely used in the United States and Asia because of the ease of artificial insemination, smaller land requirements, individual feeding and minimize aggressive interactions (Harris et al., 2006). However, as public concerns for animal welfare issues are increasing gradually, group housing systems for most of the gestation sows are attracting an interest from pig producers.

The modern type of group housing for sows with individual feeding is the electronic sow feeding (ESF) system. ESF has been introduced in response to the impact of animal welfare over a decade ago. However, its effect on sow welfare is inconsistent because of the complexity and wide disparity in the design and management of commercial group housing systems, such as space allowance, group type and size, and feeding system (Verdon et al., 2015). Several experimental studies and reviews assessed the effect of the group housing system using multiple welfare indicators (Spoolder et al., 2009; Bench et al., 2013; Verdon et al., 2015). These categories predominantly included physiology, behaviour and health, reproductive performance and productivity (McGlone et al., 2013). Especially, sow injuries caused by aggressive interactions were mostly pronounced in the ESF system, which may negatively affect sow welfare (Jang et al., 2015). However, information is lacking on the long-term and carry-over effects of the static group during gestation to lactation on reproductive performance and body composition of the sows.

Therefore, an experiment was conducted to assess the welfare and productivity of gestating sows in groups with ESF during the first three parities.

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MATERIALS AND METHODS

All experimental procedure performed in this study was approved by the Animal Care and Use Committee of the Seoul National University. The experiment was conducted from January 2013 to May 2014 at the Jacob Experimental Pig Farm, in Eumseong-gun, Chungcheongbuk-do, Korea Republic. Animals, housing conditions, and experimental designs are equal to our previous study (Jang et al., 2015).

Animals, housing and experimental design

Initially at breeding, 90 crossbred gilts (F_1, Yorkshire × Landrace, Darby, Anseong-si, Gyeonggi-do, Korea republic) with an average age of 180 d and about 105 kg of body weight (BW) were housed in groups with an electric sow feeding (ESF) system. During adaptation, five gilts were excluded because of the poor adoptability of the feeding machine. Gilts bred on at least their second estrus were introduced into individual gestation stalls in an environmentally controlled barn. Estrus was diagnosed twice daily in the presence of a mature boar, using the backfat pressure test. Gilts were twice served artificial insemination (AI) with fresh diluted semen (Darby A.I. center, Chungju-si, Chungcheongbuk-do, Korea Republic) at 12 h intervals. Pregnancy of the gilts was diagnosed by an ultrasound analyzer (Easyscan, Dong-jin BLS Co., Ltd., Gwangju-si, Gyeonggi-do, Korea Republic) on d 28 and 35 postcoitum. Two gilts that returned to estrus after the first insemination were not used in this experiment, and pregnant gilts were housed either in ESF (n=42), or ST (n=41) on the basis of BW and backfat thickness (BFT) in a completely randomized design (Figure 1). Both treatments were fed corn-soybean meal based commercial gestation diet containing 3,265 kcal of ME/kg, 12.60 % crude protein, 5.76% crude fat and 4.9% crude ash, respectively. Diets were provided daily at 2.0, 2.2, 2.4 kg/day for the first, second and third parity, respectively.

ST treatment gilts were housed in a gestation barn with an individual crate (2.15×0.6 m) with a fully slatted concrete floor. Beddings were not provided. Air temperatures and ventilation rates were measured and determined with sensors, which were installed near the sows and were manipulated by an automatic climate control system (KO-850, KUN OK Co., Ltd., Nonsan-si, Chungcheongnam-do, Korea Republic). The average temperature during the entire experimental period was 20.4°C, with a range from 13.7°C to 29.2°C. Lights were provided with eight windows and three fluorescent lights, which were switched on at 08:00 and switched off at 20:00. Feed was accurately weighed by a scale (SW-1W, CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea Republic), and was provided twice a day (08:00 and 16:00) by feed buckets through an individual feeder with one waterer per gilt.

ESF treatment gilts were housed in two gestation pens (15.2 m × 10.2 m, 3.8 m^2/ head) with a full concrete floor. As bedding materials, three sacks of rice hulls (120 kg) were provided around the lying area every two weeks. Minimum bedding depth was approximately 10 cm. The same automatic control system for air temperature and ventilation was installed in the barn. The average temperature in the ESF barn during the entire experimental period was 20.9°C, with a range from 14.0°C to 29.5°C. Manure and drains were cleaned every morning (09:00) by same stockperson. Water was provided *ad libitum* by five nipple drinkers per pen. There are four windows on the pen for natural light. Additionally, four fluorescent lights (60W) were supplemented, which were turned on 08:00 to 18:00. The ESF station (Compident VII, Schauer, Prambachkirchen, Austria) was located in the middle of the pen and operated from 08:00 to 18:00. An Expert engineer calibrated the feeders and inspected the computer system every week. Gilts were identified by a radio-frequency identification (RFID) tag and provided an allocated amount of feed individually.

At d 110 of gestation, all sows were moved to the farrowing crates (2.20×0.65 m) with partition walls (2.50×1.80 m) after washing and disinfecting their body. During lactation, the room temperature and air conditioning of the farrowing barn were kept automatically at 25±3°C by heating lamps and ventilation fans. After weaning, sows were moved to the breeding barn again for the next conception. The same treatment was continued on their assigned treatment through three successive reproduction (gestation-lactation) cycles.

Sow and litter performance

In the gestation barn, BW and BFT of sows were measured at days 35, and 110 of gestation and 12 h, 21 d postpartum. BFT was measured at the P_2 position (last rib, 65 mm from the center line of the back) on both sides of the back bone using an electric measuring device (Lean-Meater®, Renco Corp., Minneapolis, MN, USA). Values from the two measurements were averaged to record a single BFT. Muscle and protein composition during gestation of the sows were calculated on the basis of BW and BFT, using the equations adapted from Dourmad et al. (1996) and Dourmad et al. (1997), respectively.

$$\text{Muscle (kg)} = -9.2 + 0.61(\pm 0.052)\text{BW} - 0.86(\pm 0.29)\text{BFT}$$

$$\text{Protein (kg)} = 2.28 + (0.178\times\text{EBW}) - (0.333\times\text{BFT})$$

*EBW (kg) = sow empty live weight estimated from the live weight (= $0.905\times\text{BW}^{1.013}$)

In the lactation barn, total delivery time, which is defined as the interval between the complete expulsion of the first and the last piglet, was recorded by full-high digital camcorders (HMX-M20BD, Samsung, Suwon-si, Gyeonggi-do, Republic of Korea). Litter traits included the number of piglets born alive, stillborn, mummies, and losses. Within 24 h after birth, the litters were weighed individually by scale (SW-1W, CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea Republic), given a gleptoferron injection (463mg/mL equivalent to elemental iron 200mg/mL; Gleptosil, Intervet Korea Ltd., Seoul, Republic of Korea), ear-notched, needle teeth and tails clipped. Male piglets were castrated after the age of three days. Cross-fostering was performed within each treatment when possible. Litter size after fostering for each sow was determined by the number of functional teats. The piglets had no access to creep feed throughout lactation during the entire experimental periods. Litter and mean pig birth BW, weaning BW, and mean BW gain from birth-to-weaning were calculated. All sows were moved to gestation stalls as soon as all piglets were weaned (approximately 21days), and then wean-to-estrus interval (WEI) was scored for the next pregnancy.

Health status

For health descriptors, skin injuries and locomotion scores were recorded in both treatments on each of d 36 (one day after mixing), 70, and 110 as described by Karlen et al. (2007). Both measurements are described in more detail in Jang et al. (2015). Skin injuries were categorized into three regions: front (head, ear, neck, shoulders and front neck), middle (flanks and back) and rear (vulva, rump and hind legs), according by apparently fresh skin scratches. Skin freshness was determined by scratch color and estimated age of scabbing. Locomotion score was assessed based on the observation of sows standing and walking. Sows were observed by two experimenters and given a score of 0 (not lame) to 3 (severely lame, cannot stand). When measure BW and BFT, locomotion was observed and scored for sows in the ST treatment as the sows walked in the central corridor. The same experimenters assessed all health status indicators during the entire experimental period.

Sample collection and analysis

Sow blood collection was taken by venipuncture of the jugular vein at the same time of measuring the BW and BFT. Extra sow blood was taken on days -3, -1, +1 and +3 from parturition for oxytocin analysis. After parturition, the piglet's bloods (n: ST = 10, ESF = 10) was collected from the anterior vena cava at 12 h, 21 d postpartum. All samples were enclosed into ethylenediaminetetraacetic acid (EDTA) tubes (BD Vacutainer K2E, Becton Dickinson, Plymouth, UK) and centrifuged at 3,000 rpm and 4°C for 5 min after clotting at room temperature for 30 mins (5810R, Eppendorf, Hamburg, Germany). The upper liquid (serum) of the blood was separated to a microtube (Axygen, Union City, CA, USA) and stored at -20°C until later analysis.

Colostrum samples were taken from functional mammary glands of each treatment at 24 h, whereas milk samples were taken at 21 d postpartum. Colostrum and milk were collected from the first and second teats after an intravascular injection with 5 IU oxytocin (Komi oxytocin inj., Komipharm International Co., Ltd., Siheung-si, Gyeonggi-do, Republic the Korea) in the ear. After collection, samples were stored in a freezer (-20°C) until further analysis. Proximate analysis of colostrum and milk was conducted using Milkoscan FT 120 (FOSS Electric).

Statistical analysis

Sow physiological responses, reproductive performances, and health status were analyzed for their entire productive lifetime from the gilt to the third parity gestation without change. Thus, the experimental unit was the individual sow, because the treatment corresponding to a different housing system was imposed on a particular sow at a particular parity.

Gilts removed before producing one, two, or three litters were considered as missing values for calculating individual parity data. Gilts that were culled before completing three parities were considered to have produced zero pigs in each parity, which was not completed for the calculation of total piglet born, born alive, and net weaned over parities 1, 2, and 3.

Spearman rank correlation coefficients (r_s) were used to assess the associations of the number of stillbirth and parturition time.

Data were subjected to analysis of variance (ANOVA) using the GLM procedure in SAS v9.4 (SAS Inst. Inc., Cary, NC, USA). Repeated measures analysis with an unstructured covariance matrix and housing system was used as the main effect. The significant difference was set at $P<0.05$, and tendencies were determined if $0.05< P<0.10$.

RESULTS

Seventeen sows were culled during the entire experimental period (Table 1). In the ESF treatment, culling rate was recorded at 28.6 % owing to; sudden death by persistent bullying (1), abortion (1), not being pregnant (2), failure to adopt the ESF system at the beginning of the experiment (1), and locomotion disorders (7). In the ST treatment, culling rate was recorded 14.6 % owing to; abortion (3) and not being pregnant (3).

There was a tendency for body weight (BW) gain in the ESF treatment during gestation in the second parity (50.3 vs 52.2; P=0.08, Table 2) as well as BW at d 110 (212.5 vs 216.7; P= 0.10). Similarly in the third parity, ESF sows gained more BW during gestation (45.4 vs 49.9; P<0.01) and showed higher BW at d 110 (242.5 vs 249.4; P<0.03). Backfat thickness (BFT) gain (Table3) tended to be higher in the ESF treatment (1.9 vs 3.4, P=0.08 in parity 2; and 5.8 vs 6.2, P=0.10 in parity 3). In the estimated body contents (Table 4), the ESF treatment showed higher body fat contents gain during gestation (10.7 vs 16.9, P<0.01 in parity 1; and 16.3 vs 17.5, P<0.02 in parity 2) as well as lipid contents at d 110 (48.5 vs 50.8, P<0.02) in parity 2 (Table 4). Likewise, the ESF treatment showed higher estimated muscle contents at d 110 (84.0 vs 87.4, P<0.02) and muscle gain during gestation (28.6 vs 31.9, P<0.01) in parity 1. No detectable treatment effects on BW and BFT were observed during lactation.

There was a tendency of shorten delivery time in the ESF treatment regardless of the parities (199.5 vs 197.0, P=0.07 in parity 1; 238.9 vs 215.0, P=0.09 in parity 2; and 294.4 vs 251.0, P=0.10 in parity 3, Table 5). Stillbirth was higher in the ST treatment (0.8 vs 0.3, P=0.06 in parity 2; and 0.8 vs 0.2, P=0.07 in parity 3). Higher piglet mortality was observed (0.2 vs 0.4, P<0.01 in parity 1) in the ESF treatment. There were no statistical differences on piglet and litter weight (Table 6).

Scratch incidence during the gestation period was significantly higher in the sows housed in groups regardless of the parities (P<0.01, Figure 2). In addition, ESF treatment scored significantly higher skin lesion in all part (front, middle, rear) of the body in comparison to the ST treatment during the entire experimental period (P<0.01, Figure 3).

The most common sites of body lesions in the ESF sows were the front part (38.6%, 35.4%, 37.9% in parities 1, 2 and 3, respectively), while the middle part scored the lowest (32.3%, 30.0%, 28.8% in parity 1, 2 and 3, respectively). However, no treatment effect was observed for the locomotion scores (Table 7).

Figure 4 shows the serum cortisol concentration on d 35, d 110 of gestation, 24 hr postpartum and d 21 of lactation. ESF sows showed higher serum cortisol level on d 110 of gestation (3.00 vs 4.48; $P<0.01$) and tendency on 24 hr postpartum (3. 78 vs 5.60; $P=0.08$) in the first parity. There was no statistical difference on serum oxytocin concentration (Table 8).

Table 9 shows sow milk composition (fat and solid not fat) analysed at 24 hr and d 21 after parturition. No treatment effect was observed in sow colostrum and milk.

DISCUSSION

Although several scientific studies are related to the ESF system of sows and have been published in the past two decades, they focused on welfare indicators (physiology, behaviour or health and reproductive performance), instead of the measurement of growth performance (e.g., BW and BFT). However, these measures are considered as the most objective indicators to precisely assess animal state-of-being (Curtis and Johnson, 2005). The sow performances of welfare from the housing system were reported previously. Chapinal et al. (2010) had previously demonstrated that there were no statistical difference between ESF and stall sows on BW and BFT. In contrast, the results of the current experiment suggested that sows kept in groups with the ESF system over the three consecutive parities showed higher BW and BFT gain in comparison with sows in an individual stall during gestation. This is in agreement with the results of Salak-Johnson et al. (2007) in that sows kept in groups had greater BW throughout gestation than sows kept in conventional gestation stalls. In addition, Weng et al. (2009) stated that sows housed in the ESF system during gestation showed higher BFT gain, presumably due to different environmental temperature. The lower critical temperature (LCT) of a normally fed pregnant sow is between 20°C and 22.8°C for individually crated animals and approximately 13.9°C for group housed sows (Noblet et al., 2001). Provision of bedding materials and huddle with pen mates in an ESF increased LCT, resulting in more probability to maximize energy retention. In the present study, gilts and third parity sows spend the gestation period in winter, which recorded an average of 16.7°C in ST and 17.9°C in the ESF treatment, respectively. Considering the duration of the entire experimental period, prolonged exposure to cold stress affected adversely on BFT and BW gain in the ST treatment.

Likewise, ESF sows showed more estimated body fat and muscle content, which can be explained by behaviour characteristics from different housings. The physical exercise associated with sow movement might result in more accumulation of muscle (Marchant and Broom, 1996). Previous studies indicated that sows confined in stalls spent much time demonstrating agonistic behaviour, sham chewing, and non-feeding oronasofacial behaviour, which are referred to as stereotypic behaviours (Chapinal et al., 2010). This purposeless and repetitive action might lead to an increase in their energy expenditure, resulting in poor body condition. Consequently, although our data did not indicate behavioural observations, it can be assumed that lesser stereotypic behaviours in combination with higher LCT decreased energy expenditure resulted in more accumulation of BW and BFT as well as estimated body contents in ESF treatment.

BW and BFT changes during lactation did not show any difference across the systems. Kim et al. (2016) suggested that group housed sows showed a greater number of weaned piglets and piglet growth rate in comparison with the stall sows. Therefore, ESF sows loss greater BFT and showed higher average daily feed intake (ADFI) during lactation. Similar results were reported by Weng et al. (2009) in that ESF sows gained more body reserves during gestation and mobilized more backfat during lactation because of more litter weight gain. However, the current experiment showed no statistical difference for BW and BFT loss during lactation, which is due to similar reproductive performance and piglet growth between treatments.

It was previously reported that there were no differences for the litter size of sows in groups comparison with stalled sows (Harris et al., 2006; Jansen et al., 2007; Karlen et al., 2007; Salak-Johnson et al., 2007; Chapinal et al., 2010). Similarly, few differences in reproductive performance between treatments were observed in the present study. In the current experiment, whilst piglet mortality was significantly higher on the ESF treatment in parity 1 (0.2 vs 0.4, $P<0.01$), this effect was limited only in parity 1 and did not continue in parities 2 and 3. Our previous study concluded that allowing the movement of gestating sows from group housing to farrowing crates increased piglet mortality due to a confined environment (Jang et al., 2015). This result can be supported by several studies in that the freedom to move in group housed primiparous sows developed more muscle mass in comparison to a stall environment during pregnancy. Hence, this might be compensated for the high level of posture change, increasing the chance of a piglet being crushed (Marchant et al., 2001; Appleyard and Lawrence, 2001). Additionally, Randall (1972) indicated that savage behaviour is more usually seen in gilts than sows due to the lack of maternal experience. On the other hand, the static group sows had the experience of the farrowing process and may be accustomed to the farrowing crates, leading to lesser probability of posture changes, and in turn, resulting in reduced piglet mortality.

In the present study, sows kept in stalls negatively affect piglet stillbirth, which agrees with previous results (Bates et al., 2003; Weng et al., 2009). The likelihood of piglets dying during delivery is greater for sows with longer farrowing duration, which also was supported in the finding by Borges et al. (2005) in which sows that farrow longer than 240 min are at greater risk of delivering stillborn piglets than that of a normal duration. Furthermore, Gu et al. (2011) also suggested that prolonged parturition of farrowing sows increased high stillbirth rate. A possible explanation for the relationship between farrowing duration and stillborn piglets might be the secretion of oxytocin. There is a link between a prolonged parturition time and a lower oxytocin concentration

(Oliveiro et al., 2008). Release of endogenous opoids might inhibit oxytocin release during parturition (van Borrel et al., 2007). Therefore, insufficient oxytocin concentrations could weaken the contractions of the uterus during farrowing, resulting in uterine hypocontractility, prolonged delivery time and, consequently an increased number of stillbirths.

Our results indicated that ESF treatment tended to be reduced on the parturition time, resulting in reduced stillbirth. However, we found no statistical difference on oxytocin concentration as well as correlation between delivery duration and oxytocin concentration (correlation coefficient = -0.005, P=0.96). It could be speculated that there is some problematic aspects of the blood sampling method. For every collected blood sample, we used the snout snare as a temporary restraint device for jugular vein injection. This might be a contributing factor for the lack of increase in the oxytocin level. A possible explanation for our results is that the frequent collection of blood samples may disturb and stress the sows, thereby altering their normal physiological functions (Raud et al., 1971).

In contrast to previous results (Weng et al., 2009; Kim et al., 2016), our results indicated that there was no statistical difference for litter and piglet weight between the ESF and ST treatments. Weng et al. (2009) reported that the ESF treatment showed higher live litter weight at d 14 and 28. In more recently published studies, Kim et al. (2016) noted that sows kept in groups during gestation showed greater litter size and piglet growth rate in comparison to individually confined sows, which reflects greater milk production during lactation. Furthermore, group sows showed more feed intake duing lactation. Our result might be supported by previous reports in that although there is a positive relationship between litter size and milk yield, feed intake is not always linearly associated with litter size in sows (Eissen et al., 2003). Thus, no statistical difference for litter size as well as a similar amount of feed consumption between treatments might lead to similar litter and piglet weight during lactation.

The main factor for sow aggression for group housing is due to the formation of new dominance hierarchies when regrouping. Particularly, competition for access to a limited resource associated with queueing contributed to a greater increase in aggressiveness for ESF (Spoolder et al., 2009). Thus, aggression, injuries and physiological stress has been predominantly used to assess the welfare of sows in most group housing research (Verdon et al., 2015). Previous studies have shown that sows kept in groups observed greater skin injuries on the first day of mixing, then relatively reduced after the first day (Harris et al., 2006; Karlen et al., 2007). In contrast, a current experiment found that skin scratches in the ESF sows were greater during the entire experimental periods. The difference of persistency of skin injuries might be explained in a number of ways.

First, group size could be impacted by increased skin injuries. Tylor et al. (1997) stated that increasing group size (5, 10, 20 and 40) increased aggression for 2 d after mixing. Similarly, Arey and Edwards (1998) found that aggression increased as group size increased. However, recent research by Hemsworth et al. (2013) reported that increasing group size has no effect in aggressive frequency among treatment by sows into groups by 10, 30, and 80. In a current experiment, with relatively large size groups, a possible explanation supported by Greenwood et al. (2014) is that a large group size requires more fighting in order to maintain dominance in hierarchies. Second, a static group with previous experience of aggressiveness might increase skin scratches over three consecutive parities. Although past studies have suggested that sows in static groups showed more familiarities in comparison to dynamic groups, recent published studies do not agree with this interpretation (Verdon et al., 2015). A possible explanation might be the experience associated with aggressive behaviour. A prior experience of social aggression regulates fighting experience, which increases prior winning experiences and diminishes losing experiences as an individual's perceived resource value (Hsu et al., 2006). This might explain why greater skin injuries continued until the end of the experiment. However, it is not easy to say clearly that skin injuries originated from fighting, because we only observed an indirect measurement of behaviour. Further detailed research is required. Third, the nonexistence of partial barriers increased more skin injuries. Partial dividers within lying areas encourage sows to lie against them, which allowed for escape and avoidance of aggressive encounters. According to previous studies, partition of the pen by partial barriers reduced skin injuries (van Putten and van de Burgwal, 1990) and total aggression by 12 h after mixing (Edwards et al., 1993). Consequently, increased skin injuries in the ESF treatment may have been due to the lack of opportunity for these sows to be protected against fighting.

Our previous experiment found that a tendency of lameness in the ESF sows might have resulted in combination with greater and persistent aggressiveness and the misuse of bedding material (Jang et al., 2015). In fact, the most commonly used bedding materials for group housing sow is straw rather than hulls. Previous studies also indicated that the provision of straw resulted better welfare in comparison to other bedding materials (Tuyttens, 2005). In the present study, we used rice hulls rather than straw as beddings because of the ease of purchase and better price competitiveness. However, the floor condition of the ESF barn was rather wet and smooth, mainly due to poor absorptivity of hulls in comparison to straw, which might be one of the reasons why seven sows were culled for locomotary disorder. Consequently, lameness of group housing sow can be ameliorated by managing aggressiveness and floor bedding condition.

CONCLUSION

As discussed, the data of this experiment showed that a long-term effect of a modern type group housing system resulted in better possibilities for overall welfare assessments. Overall, ESF sows showed a tendency towards more BFT gain and BW gain. Likewise, estimated body fat content in the body and body muscle were greater in the ESF sows. Blood levels of cortisol, used as an indication of stress, are significantly higher in ST gilts at d 110 of gestation and at 24 hr postpartum, which is possibly due to environmental change. Reproductive performance is also rather difficult to interpret. Gilts housed in groups with ESF showed greater piglet mortality, whereas sows (second to third parity) housed in a stall showed more stillborn piglets. However, ST sows showed a tendency to more parturition time in comparison with the ESF. However, there was no difference on serum oxytocin concentration. ESF sows showed a greater incidence of skin injuries caused by aggressive encounters over the entire experimental period, resulting in higher locomotor disorders in the middle and late gestation periods. Moreover, poor floor condition due to the misuse of bedding materials might be a contributing factors affecting sow lameness. Much sophisticated research for enhancing the soundness of sows both systemic and mechanic should be considered in order to increase sow welfare.

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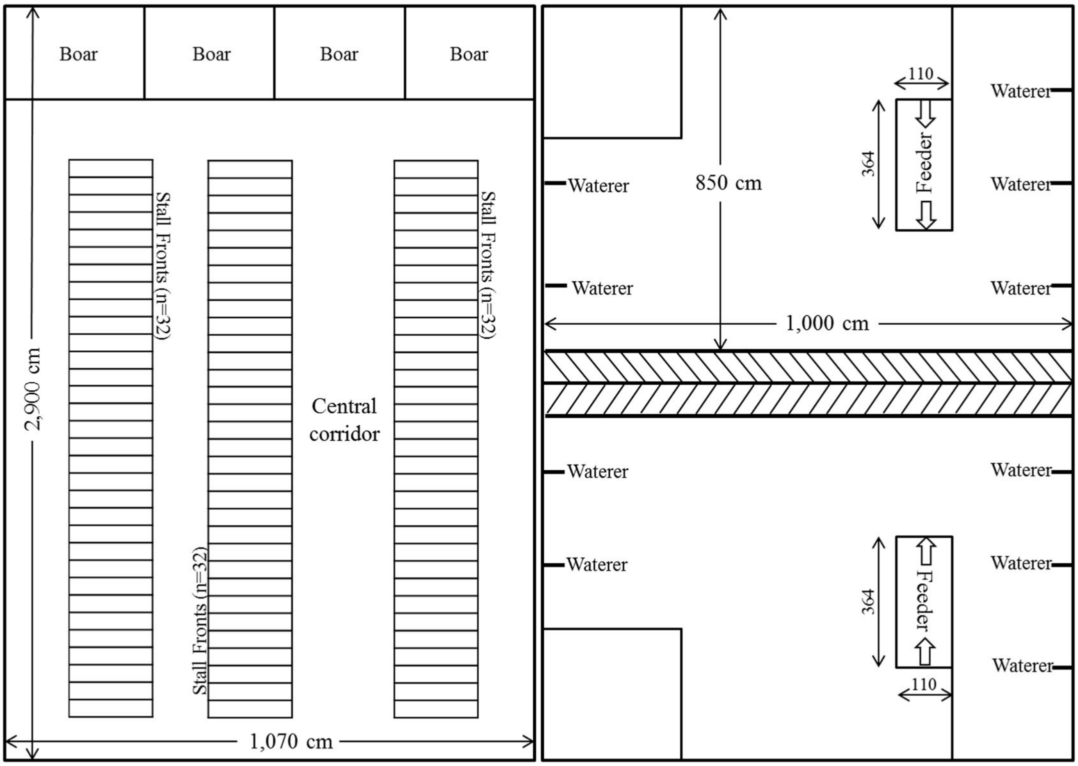

Figure 1. Diagram of the housing pens with individual stall (1 pen, 40 sows) and group housing with ESF system (2 pens, 20 sows each).

Table 1. The effects of different housing systems on lactation feed intake, weaning to estus interval and culling rate over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
No. of sows				
Parity 1	41	42	-	-
Parity 2	38	34	-	-
Parity 3	35	30	-	-
Daily feed intake, kg/d				
Parity 1	5.4	5.5	0.07	0.66
Parity 2	6.0	6.2	0.11	0.39
Parity 3	6.3	6.5	0.10	0.44
WEI[3], d				
Parity 1	6.3	6.0	0.15	0.01
Parity 2	5.9	5.7	0.17	0.48
Parity 3	5.7	5.5	0.20	0.65
Sow removals, head				
Death	-	1.0	-	-
Reproductive failure	6.0	3.0	-	-
Failure to feeder	-	1.0	-	-
Locomotor disorders	-	7.0	-	-
Total culling rate,	14.6	28.6		

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

[3]Weaning to estrus intervals.

Table 2. The effects of different housing systems on changes in sow body weight during gestation and lactation over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Gestation				
Initial Body weight (BW), Kg				
Parity 1	136.0	132.4	0.87	0.44
Parity 2	162.4	164.5	1.14	0.36
Parity 3	197.1	199.5	1.41	0.40
110 day BW, kg				
Parity 1	185.8	189.6	1.20	0.40
Parity 2	212.5	216.7	1.95	0.10
Parity 3	242.5	249.4	1.57	0.03
Total BW gain, kg				
Parity 1	49.6	57.2	0.92	0.12
Parity 2	50.3	52.2	0.53	0.08
Parity 3	45.4	49.9	1.35	0.01
Lactation				
Farrowing BW, kg				
Parity 1	166.7	174.1	1.21	0.44
Parity 2	199.5	201.4	1.15	0.43
Parity 3	225.2	222.5	1.48	0.36
Weaning BW, kg				
Parity 1	161.6	162.8	1.13	0.27
Parity 2	198.1	199.0	1.11	0.70
Parity 3	221.9	218.4	1.62	0.28
Total BW gain (farrowing to weaning), kg				
Parity 1	-5.1	-11.3	0.92	0.25
Parity 2	-1.3	-2.3	0.49	0.32
Parity 3	-3.3	-4.1	0.67	0.56

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

Table 3. The effects of different housing systems on changes in sow backfat thickness (BFT) during gestation and lactation over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Backfat thickness (BFT) in gestation, mm				
35 day				
Parity 1	21.5	18.8	0.45	0.84
Parity 2	18.0	18.4	0.25	0.37
Parity 3	18.3	18.7	0.29	0.10
110 day				
Parity 1	23.4	22.2	0.40	0.18
Parity 2	22.0	23.0	0.46	0.06
Parity 3	22.4	23.1	0.34	0.32
Total BFT change				
Parity 1	1.9	3.4	0.38	0.08
Parity 2	5.8	6.2	0.20	0.10
Parity 3	4.1	4.4	0.19	0.57
BFT in Lactation, mm				
24 hr postpartum				
Parity 1	21.7	22.2	0.41	0.63
Parity 2	20.5	20.6	0.30	0.85
Parity 3	20.0	19.2	0.28	0.19
21 day				
Parity 1	18.6	19.8	0.37	0.96
Parity 2	19.6	19.4	0.31	0.86
Parity 3	18.6	17.8	0.31	0.18
Total BFT change (farrowing to weaning)				
Parity 1	-3.1	-2.4	0.23	0.97
Parity 2	-0.9	-2.1	0.15	0.46
Parity 3	-1.3	-1.4	0.21	0.89

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

Table 4. The effects of different housing systems on estimated lipid and muscle contents of sows during gestation over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Estimated body lipid contents, kg				
35 days of gestation				
Parity 1	31.3	26.8	0.65	0.01
Parity 2	32.2	33.3	0.47	0.27
Parity 3	40.1	43.0	0.55	0.30
110 day of gestation				
Parity 1	42.0	43.7	0.61	0.17
Parity 2	48.5	50.8	0.51	0.02
Parity 3	55.5	56.8	0.64	0.06
Changes (initial to 110day)				
Parity 1	10.7	16.9	0.56	0.01
Parity 2	16.3	17.5	0.28	0.02
Parity 3	15.4	16.7	0.38	0.10
Estimated body muscle contents, kg				
35 days of gestation				
Parity 1	55.4	55.4	0.60	0.96
Parity 2	74.4	75.3	0.67	0.51
Parity 3	95.3	96.4	0.84	0.52
110 days of gestation				
Parity 1	84.0	87.4	0.75	0.02
Parity 2	101.6	103.1	0.74	0.32
Parity 3	119.4	123.0	0.94	0.06
Changes (initial to 110day)				
Parity 1	28.6	31.9	0.60	0.01
Parity 2	27.2	27.8	0.38	0.44
Parity 3	24.1	26.7	0.85	0.13

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

Table 5. The effects of different housing systems on parturition time and reproductive performance

Criteria	Treatment[2] ST	Treatment[2] ESF	SEM[1]	P-value
Parturition time, min				
Parity 1	199.5	187.0	5.44	0.07
Parity 2	238.9	215.0	7.27	0.09
Parity 3	294.4	251.0	13.04	0.10
Total born/litter				
Parity 1	11.4	11.5	0.24	0.86
Parity 2	11.7	11.3	0.39	0.61
Parity 3	13.6	13.0	0.33	0.37
Stillbirth				
Parity 1	0.7	0.6	0.11	0.62
Parity 2	0.8	0.3	0.14	0.06
Parity 3	0.8	0.2	0.11	0.07
Mummy				
Parity 1	0.1	0.1	0.04	0.17
Parity 2	0.1	0.0	0.02	0.62
Parity 3	0.2	0.4	0.09	0.16
Born alive				
Parity 1	10.6	10.8	0.25	0.42
Parity 2	10.8	11.0	0.38	0.86
Parity 3	12.9	12.3	0.31	0.41
After cross-fostering				
Parity 1	10.3	11.0	0.11	0.81
Parity 2	10.8	11.0	0.20	0.56
Parity 3	12.2	12.0	0.18	0.63
Mortality				
Parity 1	0.2	0.4	0.11	0.01
Parity 2	0.8	0.4	0.12	0.13
Parity 3	0.8	0.7	0.15	0.74
Weaning pigs				
Parity 1	10.1	10.6	0.11	0.86
Parity 2	10.0	10.6	0.20	0.13
Parity 3	11.4	11.3	0.12	0.78

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

Table 6. The effects of different housing systems on progeny growth performance over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Average litter weight, kg				
Litter at birth				
Parity 1	15.6	16.3	0.35	0.11
Parity 2	17.8	17.3	0.45	0.58
Parity 3	19.7	19.2	0.45	0.58
After cross-fostering				
Parity 1	14.5	16.2	0.29	0.13
Parity 2	16.8	17.1	0.33	0.59
Parity 3	18.2	18.1	0.33	0.78
21 day				
Parity 1	53.3	54.4	0.90	0.62
Parity 2	60.2	62.4	0.92	0.23
Parity 3	68.7	66.8	0.98	0.30
Litter weight gain (d 1 to d 21 postpartum)				
Parity 1	38.8	38.2	0.80	0.99
Parity 2	43.4	45.3	0.80	0.25
Parity 3	50.5	48.7	0.93	0.32
Average piglet weight, kg				
Piglet at birth				
Parity 1	1.37	1.44	0.02	0.83
Parity 2	1.58	1.60	0.03	0.86
Parity 3	1.47	1.49	0.03	0.60
After cross-fostering				
Parity 1	1.41	1.49	0.03	0.08
Parity 2	1.56	1.56	0.02	0.92
Parity 3	1.50	1.51	0.02	0.87
21 day				
Parity 1	5.29	5.16	0.08	0.75
Parity 2	6.05	5.97	0.07	0.59
Parity 3	6.04	5.91	0.07	0.40
Piglet weight gain (d 1 to d 21 postpartum)				
Parity 1	3.88	3.67	0.07	0.82
Parity 2	4.49	4.40	0.07	0.54
Parity 3	4.54	4.40	0.07	0.35

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

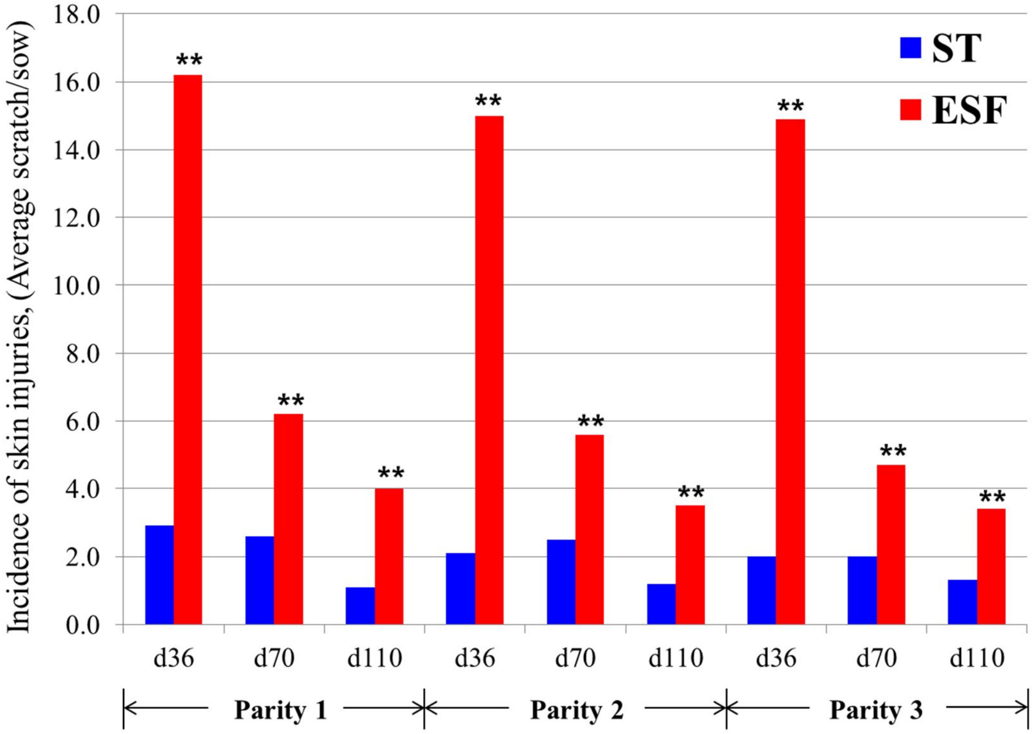

Figure 2. The effect of different housing system on incidence of injuries over three consecutive parities (**P<0.01)

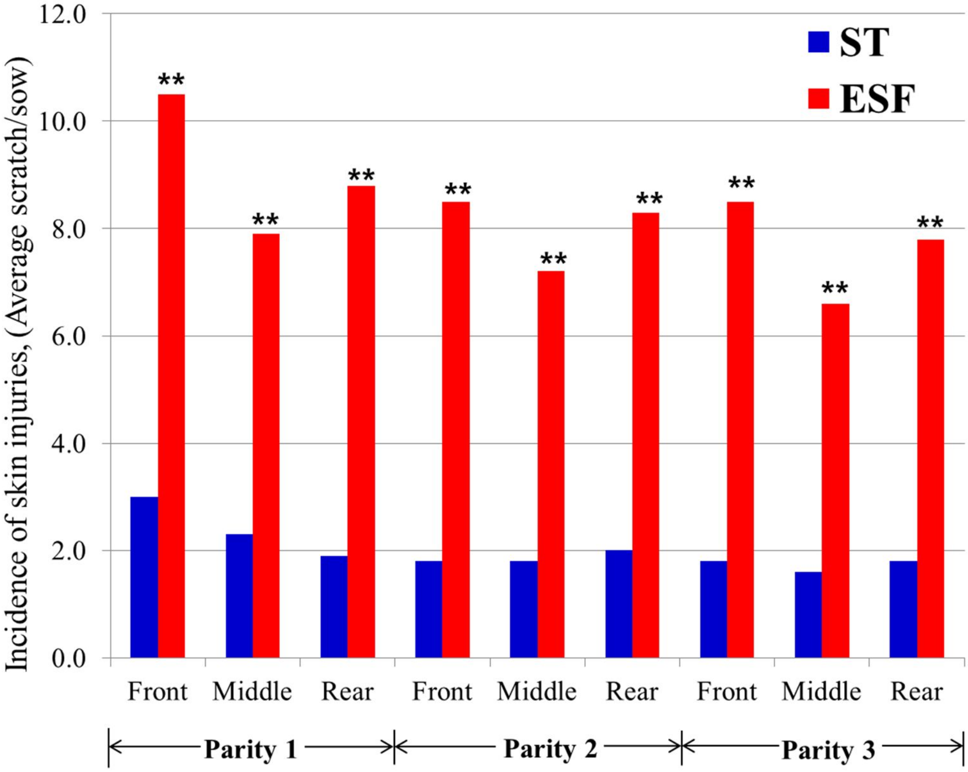

Figure 3. The effect of different housing system on distribution of skin lesions over three consecutive parities (**P<0.01). Skin injuries were categorized into three regions: front (head, ear, neck, shoulders and front neck), middle (flanks and back) and rear (vulva, rump and hind legs).

Table 7. The effects of different housing systems on locomotion score over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Locomotion scores				
36 days of gestation				
Parity 1	0.371	0.595	0.0772	0.07
Parity 2	0.348	0.609	0.1064	0.22
Parity 3	0.368	0.667	0.1056	0.16
70 days of gestation				
Parity 1	0.561	0.810	0.0662	0.06
Parity 2	0.478	0.783	0.0843	0.07
Parity 3	0.474	0.800	0.0945	0.09
110 days of gestation				
Parity 1	0.585	0.857	0.0713	0.06
Parity 2	0.522	0.870	0.0977	0.07
Parity 3	0.526	0.933	0.1079	0.07

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

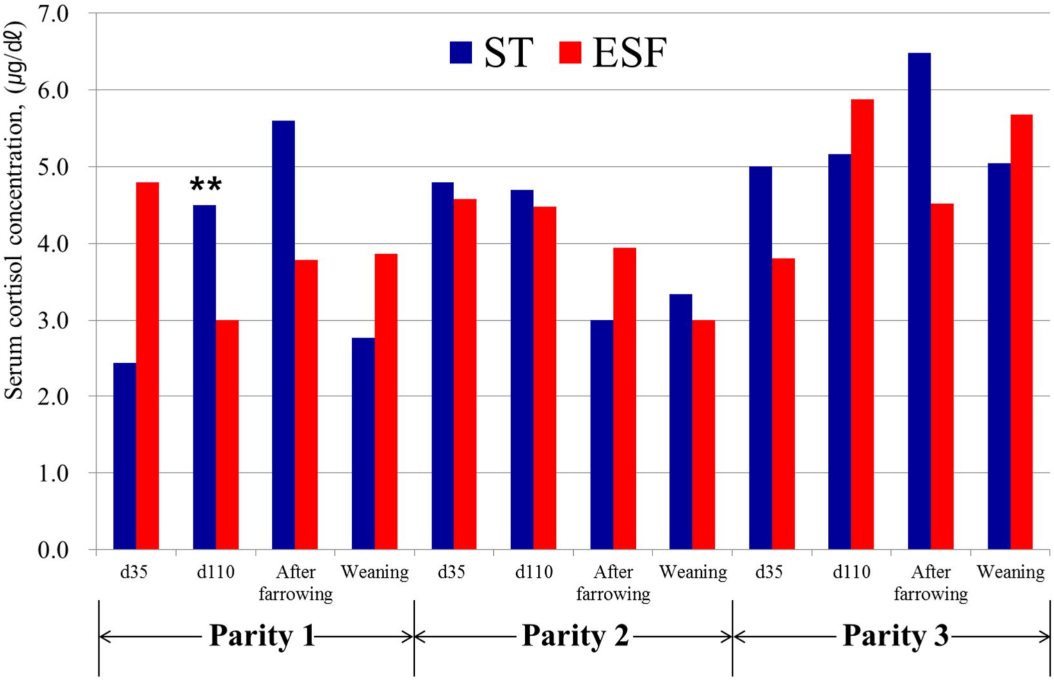

Figure 4. The effect of different housing system on cortisol level of sows over three consecutive parities (**P<0.01).

Table 8. The effects of different housing system on plasma oxytocin concentration of sows over three consecutive parities

Criteria	Treatment[2] ST	Treatment[2] ESF	SEM[1]	P-value
Oxytocin, pg/ml				
D-3				
Parity 1	15.8	17.1	0.77	0.42
Parity 2	16.6	17.7	0.70	0.46
Parity 3	15.4	18.2	0.96	0.18
D-1				
Parity 1	18.7	20.6	0.64	0.15
Parity 2	17.8	20.5	0.85	0.12
Parity 3	18.5	19.9	0.59	0.26
D+1				
Parity 1	12.0	12.5	0.81	0.77
Parity 2	11.9	10.1	0.98	0.39
Parity 3	17.4	13.6	1.39	0.19
D+3				
Parity 1	8.1	8.1	0.67	0.98
Parity 2	6.0	6.0	0.67	0.52
Parity 3	8.9	7.5	0.73	0.38

[1]Standard error of the means.

[2]Treatment were; ST(sows housed in gestating stalls, n=40), ESF(sows housed in groups with ESF, n=40).

Table 9. The effects of different housing system on milk composition of sows over three consecutive parities

Criteria	Treatment[2]		SEM[1]	P-value
	ST	ESF		
Fat, %				
Parity 1				
Colostrum	7.94	8.88	0.547	0.11
d 21	6.08	5.83	0.372	0.37
Parity 2				
Colostrum	7.57	7.69	0.215	0.80
d 21	6.05	6.40	0.206	0.43
Parity 3				
Colostrum	7.25	7.01	0.170	0.50
d 21	6.26	6.43	0.210	0.72
Solid not fat (SNF)				
Parity 1				
Colostrum	10.05	10.60	0.260	0.28
d 21	10.76	10.36	0.083	0.18
Parity 2				
Colostrum	10.23	10.45	0.095	0.28
d 21	10.15	10.24	0.086	0.64
Parity 3				
Colostrum	10.45	10.50	0.290	0.94
d 21	10.52	10.73	0.200	0.61

[1]Standard error of the means

[2]Treatment were; ST(sows housed in gestating stalls), ESF(sows housed in groups with ESF).

Chapter V : Effects of Different Space Allowances on Growth Performance, Blood Profile and Pork Quality in a One Site Grow-to-Finish Production System

ABSTRACT

This experiment was conducted to evaluate the optimal space allowance on growth performance, blood profile and pork quality of growing-finishing pigs. A total of 90 crossbred pigs ([Yorkshire x Landrace] x Duroc, 30.25 ± 1.13 kg) were allocated into three treatment (0.96: four pigs / pen, 0.96 m^2/pig; 0.80: five pigs / pen, 0.80 m^2/pig; 0.69: six pigs / pen, 0.69 m^2/pig) in a randomized complete block (RCB) design. Pigs were housed in balanced sex and had free access to feed in all phases for 14 weeks (growing phase I, growing phase II, finishing phase I and finishing phase II). There was no statistical difference in growing phase, but linear decrease was observed on ADG ($P<0.01$), ADFI ($P<0.01$), and BW ($P<0.01$) with decreasing space allowance in finishing phase. On the other hand, quadratic effect was observed on gain to feed ratio in early finishing phase ($P<0.03$). Consequently, overall ADG, ADFI, and final BW were linearly declined in response to decreased space allowance ($P<0.01$). The pH of pork had no significant difference in 3 hr after slaughter, whereas there was a linear decrease in 24 h after slaughter with decreasing space allowance. Floor area allowance did not affect pork colors, but shear force linearly increased as floor space decreased ($P<0.01$). There was a linear increase in plasma cortisol concentration on 14 week ($P<0.05$) with decreased space allocation. Plasma IgG was linearly ameliorated as space allowance increased on 10 week ($P<0.05$) and 14 week ($P<0.01$). Data from current study indicated that stress derived from reduced space allowance deteriorate immune system as well as growth performance of pigs, resulting in poor pork quality. Recommended adequate space allowance in a grow-to-finish production system is more than 0.80 m^2/pig for maximizing growth performance and production efficiency.

Key words: Space allowance, growing-finishing pigs, Growth performance, Immune assay, Plasma cortisol, Pork quality

INTRODUCTION

Large-scale intensive pig farming system has been rising globally due to increase of market demands of pork products since the last two decades (Delgado et al., 1999). Ministry of Agriculture, Food and Rural Affairs (2016) reported that the number of breeding pigs per farm increased by 5,600 % from 1990 to 2014. However, as public interests of animal welfare increases to the livestock animals, pork producers are confronted with both production efficiency and welfare issues, although these seem inversely related (Rossi et al., 2008).

Operation of intensive pig production causes various problems, such as growth disturbance (Hyun et al., 1998; Brumm et al., 2001), immune dysfunction (McGlone and Curtis, 1985), risk of exposure to respiratory disease (Christensen et al., 1999) and pork quality deterioration (Hamilton et al., 2003). Several studies have conducted to establish the appropriate space allowance for pigs. National Research Council (2012) recommended the minimum space for maximum ME intake as reported by Gonyou et al. (2006). The European Union (EU) also established space requirements and mandated by law (Council Directive 2001/88/EC). Korean Government also legislated the space requirement with 0.45 m^2/pig in growing phase (30 to 60 kg) and 0.8 m^2/pig in finishing phase (>80 kg). However, this regulation is only applicable in traditional three stage management system (weaning, growing and finishing barn), not the grow-to-finish production systems which are getting popular because of the ease of management in large-scale farming. However, there are few scientific data available to evaluate of the effects of different space allowance on growth performance and pork quality in a grow-to-finish production system.

Therefore, this study was conducted to evaluate the effect of different space allowance in growing-finishing pigs housed in grow-to-finish production system on productivity as well as economic efficiency.

MATERIALS AND METHODS

The protocol for this experiment was approved by the Ethical Committee for Institutional Animal Use and Care of the Seoul National University. The experiment was conducted at the facility of Seoul National University farm located in Suwon-si, Gyeonggi-do, Republic of Korea.

Animals, experimental designs, diets and housing

A total of 90 crossbred([Yorkshire×Landrace]×Duroc) pigs, averaging 30.3±1.13 kg initial body weight (BW), were randomly allocated based on initial BW and sex according to randomized complete block (RCB) design with six replicates. Pen size was 1.60 × 3.00 m, with space allocation achieved by varying the number of pigs per pen. Treatments were 1) 0.96 (0.96m^2/pig, 4pigs/pen); 2) 0.80 (0.80m^2/pig, 5pigs/pen); and 3) 0.69 (0.69m^2/pig, 6 pigs/pen).

A corn-soybean meal based commercial feed were used for 3 phases, including growing (0 to 6 weeks), early finishing (7 to 10 weeks) and late finishing period (10 to 14 weeks). All nutrients of experimental diets were met or exceed the nutrient requirement of NRC (1998). Calculated nutrient contents of the experimental diets were presented in Table 1.

Floor were partially slatted, and a climate computer regulated ventilation and heating in the compartments. Temperatures varied between 15 and 20 °C. Lighting was provided in combination with a several windows and fluorescent lights. Each pen had one nipple drinkers and feeder. Animals were fed diet and water ad libitum during the whole experimental period. BW and feed consumption were recorded at initial, 3, 6, 10 and 14 weeks to calculate average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G/F ratio).

Sampling measurements

A 10 ml blood samples was collected from jugular vein from six randomly selected pigs in each treatment. Blood samples were collected in a disposable vacutainer tube without anticoagulant (BD Vacutainer K2E, Becton Dickinson, Plymouth, UK), and centrifuged at 3000 rpm at 4℃ for 15 min (Eppendorf centrifuge 5810R, Hamburg, Germany) to separate plasma. Samples were stored at -20°C and analyzed for determination of plasma urea nitrogen (PUN), cortisol, Immunoglobulin A (IgA) and G (IgG).

Total PUN concentration was analyzed using a blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co., Messachusetts, USA).

For cortisol analysis, samples were analyzed in duplicate within a single assay. Cortisol concentrations were measured using a Coat-a-Count™ assay kit (Diagnostic Products, Los Angele, CA).

For immunological parameters, plasma IgG and IgA of pigs were determined by ELISA assay according to the manufacture's protocols (Bethyl Laboratories Inc., USA). The assay was analyzed in duplicate on plasma sample. The assay dynamic range of IgA and IgG were both 15.6 to 10,000 ng/ml.

Pork quality

At the end of experiment, 6 pigs from each treatment were randomly selected and slaughtered at average 115.98 ± 0.84 kg for the carcass analysis. Pork samples were collected from nearby 10th rib on right side of carcass. After chilling, 1 hour after slaughter was regarded as initial time. The pH and pork color of longissimus muscle were measured 2 times 1 h and 24 h after slaughter, respectively. The pH was measured using a pH meter (Φ 500 Series, Bechman Coulter, USA) and pork color was measured by CIE color L*, a*, and b* values using a chroma meter (CR-300, Konica Minolta Co., Osaka, Japan). Water holding capacity of pork was measured by centrifuge method (Kauffman et al., 1986). To calculate the cooking loss, longissimus muscles were packed with polyethylene bag and heated in water bath until core temperature reached 72°C. Weight difference, before and after roasting, was regarded as cooking loss. For shear force analysis, samples are cored (0.5 inch in diameter) parallel to muscle fiber and the cores were used to measure the shear force using a tabletop Warner-Bratzler Shear Force Machine (Saltner Brecknell, Model 235 6X: Motor for Shearer: Bodine Electric Company, Small Motor S/N 0291KUIL 0009 Chicago, IL).

Mortality and economic analyses

A total of 12 pigs were excluded from the experiment (Table 6.). Data correction for the ADFI for replication with excluded pigs was adjusted considering feed intake for maintenance and feed intake for growth for each pig within the pen (Lindemann and Kim, 2007). Pen size was not corrected in the event of pig death or removal. For economic analysis, the days to market weight (115 kg) was calculated from the final body weight and overall ADG (0 to 14 week).

Statistical analysis

The experimental data were analyzed using PDIFF option with General Linear Model procedures of SAS 9.3 (SAS Inst.,Inc., Cary, NC). The pen of pigs was the experimental unit for growth performance (BW, ADG, ADFI, and G/F ratio), and individual pig was used as the experimental unit in hematological analysis and pork quality evaluation. Orthogonal polynomial contrasts were used to test for linear and quadratic responses to increasing levels of space allowance on growth performance, hematological analysis, immune status and pork quality. Statistical differences were considered significant at the level of $P<0.05$ and highly significant at the level of $P<0.01$, with a trend between $P\geq0.05$ and $P\leq0.10$.

RESULTS

The effect of different space allowance on growth performance was presented in Table 2. There were no significant differences in body weight (BW), average daily gain (ADG), average daily feed intake (ADFI) and gain to feed (G/F) ratio in growing phase (0 to 6 week). However, BW was linearly increased ($P<0.01$) as space allowance increased in both early (10 week) and late (14 week) finishing phase, respectively. In addition, there were linear increase in ADG ($P<0.01$) and ADFI ($P<0.01$) as stocking density decreased from 0.69 to 0.96 m^2/pig in finishing periods and over the entire experimental period. On the other hand, quadratic response was observed on G/F ratio in late finishing period ($P<0.03$) and overall period ($P=0.07$).

Space allocation did not affect PUN concentration in growing-finishing pigs (Figure 1.). However, plasma cortisol level linearly elevated with space allowance decreased ($P<0.05$) in 14 week (Figure 2).

The effect of different space allowance on immunological parameter was shown in Table 3. There were no detectible observations in plasma IgG concentration on 3, 6, 10 and 14 week, whereas IgG was linearly increased as space allocation increased on 10 and 14 week ($P<0.01$ and $P<0.02$, respectively).

The more pigs accommodated intensively, the less pH of pork on 24 hour postmortem of carcass ($P<0.01$, Table 4.). Moreover, there was linear increase of shear force with decreased space allowance ($P<0.01$, Table. 5).

The effect of different space allowance on mortality and days to market weight were presented in Table 6. Whilst the pigs reared in 0.96m^2 showed the shortest day (176.0 day), pigs in 0.69 m^2 recorded the longest days to market weight (207.8 day). Similarly, one pig (1 in growing phase) were dead in 0.96 treatment, but seven pigs (2 in growing, and 5 in finishing phase, respectively) were dead in 0.69 treatment during the overall experimental period.

DISCUSSION

The data from the current experiment showed that there was no effect of space allocation on average daily feed intake (ADFI), average daily gain (ADG), and body weight (BW) in growing phase. Previous studies have insisted that there are various reasons for the effect of space allowance on growth performance in growing-finishing pigs; reduction in feed intake (Petherick et al., 1989; Gonyou et al., 1992) and changes of behavioral requirement (Pearson and Paterson, 1993). Brumm et al. (2001) stated that growing-finishing pigs reared less than optimal space diminished feed intake, resulting in a reduction in ADG. More recently, White et al. (2008) reported that reducing stocking density from 0.93 to 0.66 m^2/pig resulted in 4.0% less BW, 17.0% less ADG, and 10.7% less ADFI. This finding is in agreement with our study that reduced space allowance from 0.96 to 0.69 m^2/pig resulted in less ADG and BW (17.0% and 12.1%, respectively) which might be associated with 14.7% less ADFI.

The coefficient value (k) of space allowance (A, m^2/pig) can be expressed using the equation reported by Petherick (1983): $A = k \times BW^{0.667}$. Several countries legislated or recommended minimum space requirement for pigs using this formula, varied from 0.028 (The European Community, 2001) to 0.034 (NPB, 2003) for growing-finishing pigs. Moreover, recent study of Gonyou et al. (2006) demonstrated the relationship between space allowance and ADFI using broken-line analysis. Additionally, the range of critical coefficient value (k) determined by nonlinear analysis for growing-finishing pigs on partial slat was from 0.0357 to 0.0358 ($P<0.03$ and $P<0.01$, respectively). Our analysis resulted in an approximate of the critical value of k =0.045 for 0.69 treatment (0.69m^2/pigs) in growing phase, whereas critical value of k =0.033 in finishing phase. We assumed that growing pigs occupied in 0.69m^2 was large enough to grow without detrimental effects. This is also supported by the finding that the higher lipid accretion of pigs reared in the spacious pen is due to their higher feed intake, which, when in excess of the energy requirement for protein deposition and maximal lean gain, results in increased accretion ratio of lipid : protein (Schinckel, 1999).

Cortisol is a steroid hormone or glucocorticoid produced by the adrenal gland and released in response to stress. Generally, a poor welfare situation could lead to extreme stress to animals. Blood cortisol concentration has been the most common physiological parameter used to measure farm animal welfare (Terlouw et al., 1997), although the measurement suffers from diurnal variations and sample collection artifacts (McGlone et al., 2004). The current study showed that space allowance significantly influenced concentration of plasma cortisol. This is consistent with the study of Zhang et al. (2013) who confirmed that the linearly increased cortisol concentration was related to higher stress in the pigs of 0.38 m^2 than that of 0.64 m^2. These results suggest that a chronic stress response as implied by the linear increase of cortisol concentrations with the higher stocking density may have a detrimental effect on growth performance.

The immune system serves the defense against the stress response in order to maintain homeostasis (Bohus et al., 1993). Plasma IgG and IgA, widely used as an index of humoral immune parameters, are the major immunoglobulin that the extravascular compartment against pathogenic viruses and microorganisms (Li et al., 2007). Recent studies by Woof et al. (2006) have concluded that where there is limited antigen, IgA is able to trigger effector functions that have the potential to destroy micro-organisms and mammalian cells by inhibiting complement activation. Considering our experimental condition, it seems likely that there are enough antigens, so that IgA properly activated in both treatment. IgG, however, it can be interpreted by the study of Tuchscherer et al. (1998) that complement activation of IgG effectively provides the organism with a first line of nonspecific humoral defense against infections before the immune response. Several studies noted that the psychological stress can modulate the activation of complement system (Coe et al., 1988; Stefanski et al., 1996). Consequently, chronic stress derived from declined space allowance might lead nutritional disruption, resulting in the suppression of the IgG function in the present study.

Previous studies on the influence of space allowance on pork quality characteristics are prone to conflict, because most of studies compared different production systems rather than different environments with in the same system (Liorancas et al., 2005). Brumm et al. (2001) found that different space allowance did not influenced on carcass yield in grow to finish production system. In contrast, earlier studies of Wariss et al. (1983) who reported that pigs housed with higher density were more likely to produce paler meat than that of lesser density. Enfält et al. (1997) found a lower ultimate pH, higher drip loss, increased shear force values, and reduced intramuscular fat for outdoor compared to indoor reared pigs. Recent findings of Liorancas et al. (2006) reported that offering spacious conditions compared to commercial conditions resulted in higher muscle pH 24 hours postmortem, which is concordant with our result. The pH change is a very critical factor to determine pork quality. It has been acknowledged that initial pH is regarded as an indicator of PSE (pale, soft and exudative) and the final pH is regarded as an estimation of DFD (dark, firm and dry) pork (Maganhini et al., 2007). The data from our result suggest that decreased special allocation increased carcass pH changes. One possible explanation is due to higher blood cortisol level. Higher levels of blood cortisol were associated with higher pork temperatures, resulting in significantly lower ultimate pH values (Dokmanovic et al., 2015). Thus, it is more susceptible to develop rapid rigor mortis (Warriss et al., 2003). In carcasses with rapid development of rigor mortis, higher cooking loss (Huff-Lonergan et al., 2002; Hambrecht et al., 2003) and more water holding capacity (Hambrecht et al., 2003) were observed. In agreement with those findings, in this study, decreasing muscle glycolytic potential (Hambrechet et al., 2005) originated from chronic stress negatively influenced on the rate of pH decline, resulting more detrimental effect on pork quality.

In the present study, higher mortality was observed in the pigs occupied in 0.69m^2, whereas 0.96 m^2 was the lowest. In agreement, numerous studies have shown that morbidity levels increase with a decrease in floor space (Brumm and Miller, 1996; Wolter et al., 2002). More recently, Hamilton et al. (2003) stated that there was a trend for the mortality to be higher for pigs reared in the restricted than the unrestricted floor space.

Although we did not analyze statistically, days to market weight per pig was numerically shortest in the pigs reared in the largest (0.96 m^2) space allowance, but longest in the pigs reared in the small (0.69 m^2) space allowance. This finding is rather different from previous studies that the production and economic measures per pig improve with increased space allowance, the production per unit area or at a system level often still declines (Edwards et al., 1988; Gonyou et al., 2006), which implies that the optimum from the pig and producers' perspective are different (Jensen et al., 2012). If policy makers make changes that benefit pig welfare for example by increasing space allowance, this can result in reduced margins for producers, unless they can obtain a price premium (Bornett et al., 2003). We cannot define that space allowance did increased total marginal profits, because we only measured days to market weight. Thus, multi-dimensional analysis is required to understand of the better production system in order to reduce economic loss of the farm.

CONCLUSION

Swine industry has been changing on a large scale during the last two decades. Reduced floor space affect negatively on the welfare of pigs. Numerous results of researches show that the negative effects on performance were associated with large groups and the reduced floor-space allowance. The data of current experiment showed that space allowance more than 0.80 m^2/pig resulted in better possibilities for maximizing growth performance, humoral functions of immune system, pork qualities and reducing days to market weight. This finding is consistent from previous studies, suggesting that the space allocation coefficient, *k*, above 0.033 guarantee the growth and overall welfare for growing-finishing pigs.

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Table 1. Calculated nutrient contents of experimental diets

Chemical composition	Growing phase (0-6 week)	Early finishing phase (7-10 week)	Late finishing phase (11-14 week)
ME, kcal/kg	3,650.00	3,650.00	3,650.00
Crude protein, %	18.50	15.50	14.00
Crude fat, %	4.00	4.00	4.00
Crude ash, %	8.00	8.00	8.00
Lysine, %	1.10	0.70	0.65
Ca, %	0.60	0.40	0.35
P, %	1.30	0.80	0.75

Table 2. Effect of different space allowance on growth performance in growing-finishing pigs

Items	Treatment[1]			SEM[2]	P-value	
	0.96	0.80	0.69		Lin.	Quad.
Body weight, kg						
Initial	30.14	30.43	30.18	1.23	0.74	0.64
3 week	43.78	42.95	42.05	1.79	0.17	0.97
6 week	60.70	59.82	59.51	2.10	0.24	0.72
10 week	80.15	76.08	73.89	2.05	0.01	0.48
14 week	103.94	98.88	91.40	2.79	0.01	0.64
ADG, g						
0-3 week	650	596	565	30.73	0.13	0.80
3-6 week	806	790	831	23.42	0.60	0.51
6-10 week	695	581	514	27.53	0.01	0.45
10-14 week	850	814	625	37.95	0.01	0.14
0-6 week (Growing)	728	700	698	21.80	0.17	0.45
6-14 week (Finishing)	772	697	569	28.23	0.01	0.47
Overall	753	698	625	20.32	0.01	0.71
ADFI, g						
0-3 week	1,524	1,408	1,446	59.86	0.38	0.32
3-6 week	2,082	1,919	1,966	59.77	0.30	0.27
6-10 week	2,216	1,885	1,722	69.20	0.01	0.22
10-14 week	2,575	2,275	2,116	73.88	0.01	0.42
0-6 week (Growing)	1,803	1,663	1,706	57.74	0.27	0.23
6-14 week (Finishing)	2,398	2,072	1,919	68.60	0.01	0.22
Overall	2,143	1,876	1,828	55.90	0.01	0.09
G/F ratio						
0-3 week	0.426	0.424	0.391	0.011	0.28	0.52
3-6 week	0.387	0.412	0.423	0.010	0.16	0.74
6-10 week	0.313	0.308	0.298	0.011	0.60	0.91
10-14 week	0.330	0.358	0.295	0.011	0.12	0.03
0-6 week (Growing)	0.404	0.421	0.409	0.005	0.77	0.23
6-14 week (Finishing)	0.322	0.337	0.297	0.008	0.28	0.18
Overall	0.351	0.372	0.342	0.006	0.50	0.07

[1] 0.96 : 4 growing-finishing pigs/pen (0.96 m^2/pig).
0.80 : 5 growing-finishing pigs/pen (0.80 m^2/pig).
0.69 : 6 growing-finishing pigs/pen (0.69 m^2/pig).
[2] Standard error of the means.

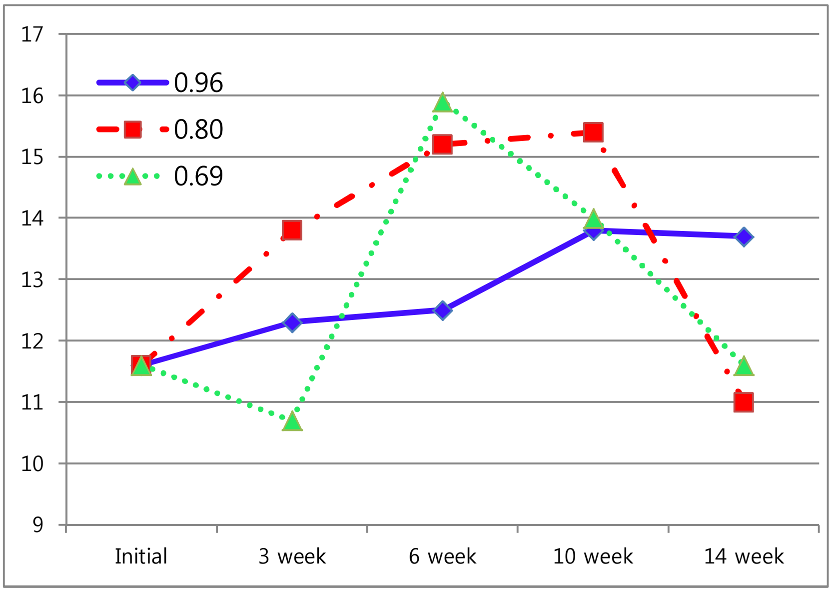

Figure 1. The effect of different space allowance on PUN in growing-finishing pigs.

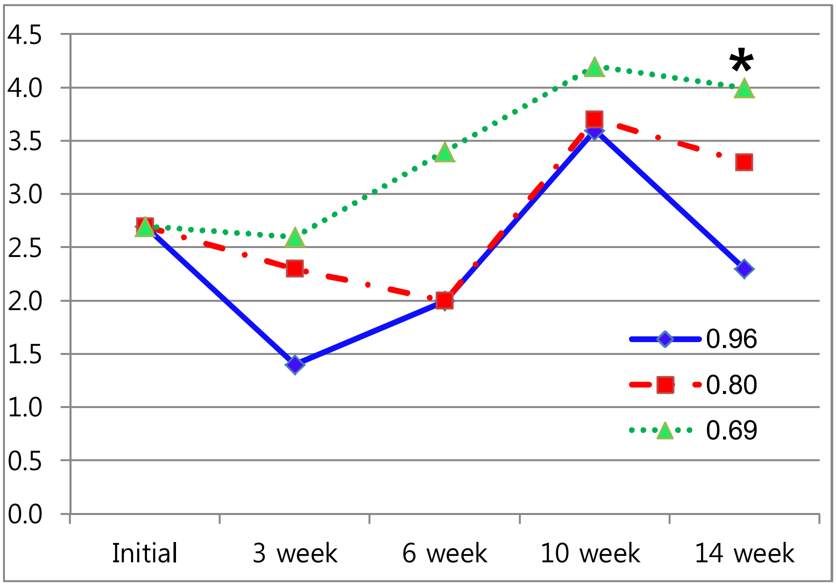

Figure 2. The effect of different space allowance on plasma cortisol in growing-finishing pigs (* Linear effect, P<0.05).

Table 3. Effect of different space allowance on immunological response in growing-finishing pigs

Criteria	Treatment[1]			SEM[2]	P-value	
	0.96	0.80	0.69		Linear	Quadratic
IgG (mg/dL)						
Initial	2.12	2.12	2.12	-	-	-
03 week	2.61	4.34	2.60	0.605	0.98	0.16
06 week	2.52	5.25	4.24	0.570	0.16	0.12
10 week	5.27	4.22	2.27	0.414	0.01	0.52
14 week	4.04	4.03	2.56	0.266	0.02	0.12
IgA (mg/dL)						
Initial	2.12	2.12	2.12	-	-	-
03 week	2.52	2.31	2.21	0.253	0.65	0.93
06 week	2.84	4.87	3.41	0.360	0.54	0.45
10 week	5.06	3.25	3.87	0.423	0.25	0.11
14 week	4.82	5.52	5.09	0.385	0.50	0.55

[1]0.96 : 4 growing-finishing pigs/pen (0.96 m^2/pig).
0.80 : 5 growing-finishing pigs/pen (0.80 m^2/pig).
0.69 : 6 growing-finishing pigs/pen (0.69 m^2/pig).
[2] Standard error of the means.

Table 4. Effect of different space allowance on pork pH and lightness

Items	Treatment[1]			SEM[2]	P-value	
	0.96	0.80	0.69		Linear	Quadratic
pH						
01 hr	5.87	5.87	5.88	0.02	0.85	0.92
24 hr	5.68	5.67	5.62	0.01	0.01	0.09
CIE value L*						
01 hr	40.19	39.76	40.79	40.25	0.85	0.79
24 hr	48.02	45.83	46.50	46.78	0.67	0.29
CIE value a*						
01 hr	1.54	1.56	1.70	1.60	0.23	0.81
24 hr	4.00	3.51	4.10	3.87	0.28	0.86
CIE value b*						
01 hr	3.93	3.82	3.94	3.90	0.23	0.98
24 hr	6.54	5.86	6.27	6.23	0.23	0.48

[1]0.96 : 4 growing-finishing pigs/pen (0.96 m^2/pig).
0.80 : 5 growing-finishing pigs/pen (0.80 m^2/pig).
0.69 : 6 growing-finishing pigs/pen (0.69 m^2/pig).
[2] Standard error of the means.

Table 5. Effect of different space allowance on proximate analysis and physiochemical properties of pork

Items	Treatment[1]			SEM[2]	P-value	
	0.96	0.80	0.69		Linear	Quadratic
Proximate analysis of loin meat						
Dry matter, %	72.12	71.57	71.33	0.18	0.49	0.32
Crude protein, %	23.23	23.15	24.11	0.24	0.07	0.50
Crude fat, %	2.37	3.24	3.06	0.16	0.41	0.65
Crude ash, %	1.34	1.46	1.39	0.11	0.39	0.19
Physiochemical property						
Cooking loss, %	33.89	32.09	33.30	0.10	0.46	0.48
WBS[3], kg/0.5inch^2	4.72	5.16	5.38	0.33	0.01	0.49
WHC[4] , %	57.03	56.48	55.26	0.41	0.87	0.69

[1]0.96 : 4 growing-finishing pigs/pen (0.96 m^2/pig).
0.80 : 5 growing-finishing pigs/pen (0.80 m^2/pig).
0.69 : 6 growing-finishing pigs/pen (0.69 m^2/pig).

[2] Standard error of the means.

[3]Wamer-Bratzler shear force.

[4] Water holding capacity.

Table 6. Effect of different space allowance on mortality and days to market weight

Items	Treatment[1]		
	0.96	0.80	0.69
Final body weight, kg	103.94	98.88	91.40
Overall ADG (0-14 week), g	753	698	625
Days to market weight (110 kg)	176.04	183.93	207.78
Mortality, % (head)			
Growing phase	0.0 (0)	6.7 (2)	5.5 (2)
Finishing phase	4.1 (1)	7.1 (2)	14.7 (5)
Overall phase	4.1 (1)	13.3 (4)	19.4 (7)

[1]0.96 : 4 growing-finishing pigs/pen (0.96 m^2/pig).
0.80 : 5 growing-finishing pigs/pen (0.80 m^2/pig).
0.69 : 6 growing-finishing pigs/pen (0.69 m^2/pig).

Chapter VI. Overall conclusion

Widespread concern in farm animal welfare has spotlighted globally. Numerous scientific researches which relating to farm animal welfare has been conducted with various multi-dimensional assessments from three decades age by welfare leading countries. Most oriental countries including Korea however, little scientific evidences have been investigated in response to this change. Therefore, in preparing to face the welfare challenges in Korean swine industry, three experiments were conducted to investigate 1) the effect of gestating gilts housed in group with the electronic sow feeding system on physiological response and reproductive performance, 2) the effect of gestating sow housing with electronic sow feeding system over three consecutive parities, and 3) effects of different space allowances on growth performance, blood profile and pork quality in a one site grow-to-finish production system.

Group housing gilts showed the higher trends in backfat thickness gain (P=0.08) and body condition score (BCS) at 110 days of gestation (P=0.10) compare to confined gilts. Additionally, they showed significantly higher estimated body muscle contents at 110 days of gestation (P<0.02) and body muscle change during gestation (P<0.01). There was a trend for a shorter parturition time in ESF gilts (P=0.07). In blood profiles, ST gilts showed a higher cortisol level at 110 days of gestation (P<0.01). Weaning to estrus interval was shorter in gilts housed in ESF than ST (P<0.01). In locomotory behaviors, ESF gilts recorded a tendency to elevate locomotion score at 36, 70, and 110 days of gestation (P=0.07, P=0.06, and P=0.06, respectively). Similarly, ESF gilts showed significantly higher incidence of scratches at 36, 70, and 110 days of gestation (P<0.01).

In the experiment of group housing over three consecutive parities of sows, group housing sows tended to increase BW gain in second parity (P=0.08), and consistently showed the significance during third parity (P<0.01), resulting in higher BW at d 110 (P=0.10, P<0.03 in parity 2 and 3, respectively). Similarly, BFT gain tended to be higher in ESF than ST (P=0.08, P= 0.10 in parity 1 and 2, respectively). There was a tendency of shorten delivery time in ESF treatment (P=0.07, P=0.09, and P=0.10 in parities 1, 2, and 3, respectively). Higher incidence of body scratch was scored in ESF in early gestation in all parities (P<0.01), resulting in higher locomotor disorders in middle and late gestating period (P=0.07).

The effect of space allowance in growing-finishing pigs showed no statistical difference in growing phase, but linear decrease was observed on ADG (P<0.01), ADFI (P<0.01), and BW (P<0.01) with decreasing space allowance in finishing phase. Consequently, overall ADG, ADFI, and final BW were linearly declined in response to decreased space allowance (P<0.01). The pH of pork had no significant difference in 3 hr after slaughter, whereas there was a linear decrease in 24 hrs after slaughter with decreasing space allowance. Shear force linearly increased as floor space decreased (P<0.01). There was linear increase in plasma cortisol concentration on 14 wk (P<0.05) with decreased space allocation. IgG was linearly ameliorated as space allowance increased on 10 week (P<0.05) and 14 week (P<0.01).

Data from our result indicated that group housing management with electronic sow feeding system showed higher growth performance as well as survival rate of piglets. However, more investigation for managing aggressive behavior is needed to for the sake of the sow welfare as well as economic profitability. For growing-finishing pigs, the stress, derived from reduced space allowance, deteriorated immune system as well as physical status of pigs, resulting less pork quality. Provision more than 0.80 m^2/pig for space allowance is recommended for maximizing growth performance and production efficiency in a one site grow-to-finish production system.

Chapter VII. Summary in Korean

본 실험은 동물복지의 일환으로 모돈 자동급이 시스템이 적용된 군사 시설에서 임신 모돈을 1 산부터 3 산까지 사육하였을 때 모돈의 생리적 변화, 번식성적 및 연산성에 미치는 영향을 스톨사육과 비교하여 보고, 육성 비육돈의 밀사사육이 성장성적과 면역성상 및 돈육품질에 미치는 영향을 검증하여 국내 양돈 농가에 동물 복지 적용 가능성을 제시하고자 수행하였다.

Experiment I. The Effects of Gilts Housed Either in Group with the Electronic Sow Feeding System or Conventional Stall

본 실험은 후보돈의 군사사육이 후보돈의 생리적 변화, 번식성적, 건강성 및 번식 성적에 미치는 영향을 검증하기 위해 수행되었다. 총 83두의 F1 임신모돈 (Yorkshire × Landrace)을 2처리에 완전임의배치법 (completely randomized design; CRD)으로 공시하였다. 인공수정 후 임신이 확인 된 실험돈들은 임신기 사양 방식에 따라 각각 스톨 (ST) 및 군사 (Group) 처리구로 나뉘어 110일 간 사육되었으며, 동일한 시설의 포유돈사로 이동하여 분만 후 포유능력 및 재귀발정일을 측정하였다. 실험 결과, 군사 사육방식은 임신기 모돈의 성장에 유의적인 영향을 나타내진 않았으나, 등지방 축적량(P=0.08) 및 체충실지수(BCS, P=0.10)에서 스톨사육보다 높은 경향을 나타내었다. 또한, 유의적으로 높은 체내 근육량이 임신 110일령(P<0.02) 및 전체 임신기간(P<0.01)에서 나타났다. 분만율은 스톨사육이 군사사육보다 높았으나 (97.5% vs 95.2%), 군사사육 모돈이 스톨사육 모돈보다 분만시간을 단축시키는 경향을 보였다(P=0.07). 분만성적에서는 두 처리구간 총 산자수, 총 생존산자수,

포유 자돈수 및 생시 체중 및 증체량에 있어 유의적인 차이가 나타나지 않았으나, 군사사육 처리구의 포유자돈 폐사율이 스톨사육 처리구보다 유의적으로 높았다($P<0.01$). 포유기 동안의 모돈의 일당 사료섭취량 (ADFI)에서도 유의적인 차이가 나타나지 않았다. 혈액 분석 결과 임신 110일령 스톨사육 모돈의 혈중 코르티졸 (cortisol) 농도가 군사사육 모돈보다 유의적으로 높았다 ($P<0.01$). 이유 후 재귀 발정일(weaning to estrus interval; WEI) 측정결과 군사사육 처리구가 유의적으로 재귀발정일을 앞당기는 효과가 나타났다 ($P<0.01$). 모돈의 지제능력 및 체표면의 상처빈도 측정 결과 임신기 전 구간에 걸쳐 스톨사육보다 군사사육 모돈에서 유의적으로 많은 상처가 측정되었고 ($P<0.01$), 이는 모돈의 지제능력에도 부정적인 경향을 보였다 ($p = 0.07$ in d 36; $p = 0.06$ in d 70; and $p = 0.06$ in d 110, respectively). 결론적으로, 모돈 자동 급이 시스템을 적용한 군사 사육은 모돈의 활동제약을 없애고 social interaction을 통하여 임신말기 스트레스를 완화해 주는 효과가 있지만, 임신기와 포유기의 체형변화 및 산자수, 그리고 포유자돈의 성장에 있어 스톨사육과 별다른 차이점이 없어, 분만성적의 향상까지는 이어지지 않는 것으로 나타났다. 하지만, 공격성 증가로 인한 부상 및 유산 비율의 증가가 분만율에 부정적으로 작용하여 스톨사육에 비하여 분만율이 9% 이상 감소되는 결과를 보았을 때, 공격성 제어를 위한 다각적인 연구가 필요할 것이라 생각된다.

Experiment II. Comparing Gestating Sows Housing Between Electronic Sow Feeding System and Conventional Stall over Three Consecutive Parities

본 실험은 모돈자동급이 시스템을 적용한 군사사육이 1산에서 3산차

까지모돈의 생리적 변화 및 번식능력에 미치는 영향을 스톨사육과 비교하여 한국형 모돈 복지 적용 가능성을 검증하기 위하여 수행되었다. 총 84두의 미경산 모돈 84두를 완전임의배치법(completely randomized design; CRD)으로 공시하여 각각 스톨 사육(ST)과 군사 사육(ESF)으로 배치하였다. 사양실험은 총 3산 동안의 성장성적, 분만성적 및 연산성을 측정하였으며, 임신기간동안 실험사료는 1산차는 2kg/일, 2산차는 2.2kg/일, 그리고 3산차는 2.4kg/일로 증량 급여되었으며, 포유기 동안에는 동일한 사료가 제공되었다. 본 실험 결과, 2산차 군사 모돈의 임신기 체중 변화(P=0.08) 및 110일령 체중(P=0.10)이 스톨 사육보다 높은 경향을 보였으며, 3산차에서도 임신기 체중변화(P<0.01) 및 110일령 체중에서도(P<0.03) 유의적으로 높게 나타났다. 등지방 측정에서도 1산차(P=0.08)와 2산차(P=0.10) 군사사육 처리구의 임신기 등지방 두께 변화량이 스톨 처리구보다 높은 경향을 나타내었다. 또한, 군사사육은 전 산차에 걸쳐 체내 추정 지방 함량이 군사사육보다 높은 것으로 나타났다 (P<0.01, P<0.02, P=0.10 in parities 1, 2, and 3, respectively). 하지만, 포유기 모돈의 등지방 및 체중 감소량에서는 처리구간 차이가 나타나지 않았다. 분만시간 측정 결과 군사처리구의 분만시간이 스톨처리구에 비해 단축되는 경향을 보였다(P=0.07, P=0.09, and P=0.10 in parities 1, 2, and 3, respectively). 분만성적에서는 2산차(P=0.06)와 3산차(P=0.07)에서 스톨 모돈의 사산돈이 증가하는 경향을 나타냈다. 코르티졸 분석 결과 1산차에서는 임신 110일령 스톨 처리구의 코르티졸 수준이 유의적으로 높게 나타났으나, 2, 3산차에서 연속적인 처리구간 유의적 차이는 발생하지 않았다. 혈중 옥시토신(oxytocin) 분석 측정에서도 실험 전 기간 동안 유의차는 나타나지 않았다. 모돈 체표면의 상처빈도 측정 결과 실험 전

구간에 걸쳐 스톨사육보다 군사사육 모돈에서 유의적으로 많은 상처가 측정되었고($P<0.01$), 이는 임신 중기(d 70)와 후기(d 110)의 지제능력 저하에 영향을 미친 것으로 사료된다 ($P=0.07$). 본 실험결과 임신기 모돈의 군사사육에 대한 long-term effect는 모돈 자체의 성장과 자돈의 생존률에 긍정적으로 작용하였다. 하지만 급이기 주변에서의 계속적인 투쟁과 부적절한 깔짚의 제공으로 인하여 체표면 상처 증가 및 지제능력 저하를 야기하였고, 이는 모돈의 연산성 및 농가의 경제성에 치명적 요소로 작용함을 확인하였다. 따라서, 이를 해결하기 위한 조건으로 적절한 투쟁 회피 공간의 제공과 깔짚의 선정(hull 종류가 아닌 straw)이 고려되어야 한다고 사료된다.

Experiment III. Effects of Different Space Allowances on Growth Performance, Blood Profile and Pork Quality in a Grow-To-Finish Production System

본 실험은 두당 사육면적이 육성-비육돈의 성장, 면역반응 및 돈육품질에 미치는 영향을 규명하고자 수행하였다. 30.25±1.23 kg의 삼원 교잡([Yorkshire x Landrace] x Duroc) 육성돈(70±3일령) 144두를 공시하여 육성기 6주, 비육기 8주간 총 14주간 사양실험을 진행하였다. 실험은 총 3처리 4반복으로 성별과 체중에 따라 난괴법(RCBD; Randomized complete block design)으로 배치하였다. 처리구는 펜 당 사육두수를 다르게 하여 0.96($0.96m^2$/pigs), 0.80($0.80m^2$/pigs), 0.69($0.69m^2$/pigs)로 진행하였다. 성장성적 실험결과 육성기에는 사육면적에 따른 체중, 일당 사료섭취량, 일당 증체량 및 사료 효율의 효과는 나타나지 않았다. 그러나 비육기에는 사육면적이 증가함에

따라 일당 증체량(P<001), 일당 사료섭취량(P<001), 및 체중(P<001)이 linear 하게 증가하는 것으로 나타났다. 따라서, 실험 전 기간의 일당 증체량, 일당사료섭취량 및 체중에서도 위와 같은 효과가 나타났다. 돈육 pH 변화 측정결과 도축 후 3시간에서는 처리구간 차이가 발견되지 않았으나, 24시간 에서 사육면적이 감소할수록 linear하게 pH값이 감소하는 효과를 보였다(P<0.01). 돈육색 분석에서는 처리구간 유의차이가 없었으나, 사육면적이 감소함에 따라 등심전단력이 증가하는 효과를 보였다(P<0.01). 혈액 분석에서는 사육 면적이 감소할수록 혈중 cortisol 농도가 linear 하게 증가하였으며(P<0.01), 혈중 IgG는 10주와 14주에서 linear하게 개선되는 결과를 나타냈다(P<0.01). 실험 결과, 사육면적이 감소할수록 돼지는 지속적으로 스트레스를 받게 되며, 이는 결과적으로 사양성적, 돈육의 품질 및 경제성에 부정적인 영향을 미치는 것으로 사료된다. 따라서, 육성-비육돈을 출하 시까지 한 돈방에서 사육할 경우, 돼지 한 두당 0.80m^2 이상의 바닥면적이 제공되어야 비육돈의 성장과 건강성에 부정적인 영향을 미치지 않을 것이라 생각된다.