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Effects of Feeding Frequency on Reproductive Performance and Stress Responses in Gestating Sows

임신기 사료 급여횟수가 모돈의 번식성적 및 스트레스 반응에 미치는 영향

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이 논문을 농학석사 학위논문으로 제출함

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Summary

In recent years, the negative sides of livestock production caused by intensive production conditions for animal (i.e., livestock epidemics and environmental contamination) have more increased not only the consumer's concerns about product safety and animal welfare, but also the ethical responsibility for livestock producer. So, swine industry is in a difficult situation which has to solve these problems at the same time while seeking the financial efficiency. Gestation is one of the most important period which determines farm productivity. In general, two restrict conditions (i.e., restricted feeding and individual stall) are imposed on gestating sow for successful reproductive performance, but each of these conditions is at the centered on controversial issues. Moreover, swine farm has difficulty to hire employers who take care of swine herd and management. Subsequently, breeding farm needs to find some ways to use labour efficiently or reduce labour. Therefore, this study was conducted to investigate whether once daily feeding (OF) with stall housing system in gestation has effects on sow reproduction and stress responses, compared to twice daily feeding (TF).

A total of 20 sows (parity 2 or 3, Yorkshire × Landrace) were alloted to one of two treatments (OF and TF) in a completely randomized design (CRD) based on their parity, body weight (BW), backfat thickness (BF) and WEI. A gestation diet was fed at 2.4 kg/d for the 3rd parity and 2.2 kg/d for the 2nd parity, while a same lactation diet was provided *ad libitum* regardless of treatment. In gestation, sow BW, BF and BF changes were not affected by feeding frequency (FF), but significantly or numerically higher BW gains of sows from d 35 to 90 ($P<0.05$) and from d 35 to 110 ($P<0.10$) were observed in OF. In lactation, although litter weight at birth was significantly higher in OF ($P<0.05$), sow BW, BFT, ADFI, WEI, litter and piglet performance, milk composition and immune parameters were not affected by FF. The OF had lower water consumption from d 35 to 70 ($P<0.05$), d 70 to 105 ($P<0.10$) and overall period of gestation ($P<0.05$). Stereotypes and salivary cortisol levels in gestation did not differ between treatments. However, when sows were fed once their feed, significantly reduced active behaviors at d 105 of gestation ($P<0.05$) and numerically increased inactive behaviors at d 70 and d 105 ($P<0.10$) were observed. Consequently, OF is regarded as effective feeding method in sow reproduction compared to TF, and positively affects stress-related responses. However, more research for the nutrient digestion and utilization of OF is recommended, considering its higher gestation BW gain. This study demonstrated that OF is more practical alternative feeding method for gestating sows in swine farm, considering both working hour (labor cost) saving and sow welfare in gestation.

Contents

List of Tables

List of Figures

List of Abbreviation

ADG	Average daily gain
ADFI	Average daily feed intake
BF	Backfat thickness
BW	Body weight
CRD	Completely randomized design
ESF	Electric sow feeder
IgG	Immunoglobulin G
LSY	Litter per sow per year
ME	Metabolizable energy
OIE	World animal health organization
WEI	Weaning to estrus interval

Ⅰ. Introduction

Livestock industry positively or negatively affects the natural resource, public health, social equity and economic growth (World Bank, 2009). In recent years, the negative sides of livestock production caused by intensive breeding conditions for animal (i.e., livestock epidemics and environmental contamination) have increased not only the consumer's concerns about product safety and animal welfare, but also the ethical responsibility for livestock producer. So, nowadays livestock producers are in a difficult situation which has to solve these problems while seeking the financial efficiency at the same time .

Although various factors have influences on the farm productivity in swine industry, a lot of farm production indexes are represented by sow's performance (e.g., Litter/Sow/Year; LSY, Piglet weaned/Sow/Year; PSY, Market pig/Sow/Year; MSY). In particular, sow management in gestation is the most important part because conception, implantation and parturition as well as following lactational performance depend upon the management during pregnancy. So, most of the swine farms have used restricted conditions such as stall housing and limited feeding for adequate reproductive performance over the last several decades, but these conditions have been arousing the controversy between pork producer and consumer due to the following positive or negative effects. Firstly, stall housing system during pregnancy has advantages such as individual management and aggression prevention. However, movement and social interaction of sow could be suppressed by the narrow confines of the stall. Secondly, while limited feeding in gestation is easy to control sow body condition and stimulate lactation feed intake, a certain amount of feed at a set time may sustain sow hunger and could increase stereotypic behaviors in gestation. These existing conditions in gestation might also have negative influence on sow welfare, therefore, a practical alternative to achieve both farm economic and animal welfare is being recommended.

Considering previous studies, the adjustment of feeding frequency in gestation can reduce the negative effects associated with stall housing and limited feeding, and improve sow welfare. Robert et al. (2002) reported that once daily feeding reduced the desire for food and negative behaviors than twice daily feeding in primiparous sow. Wittman (1986) also demonstrated that sow reproduction was improved when the feeding number of gestating sow was adjusted. Futhermore, according to the studies of Lawrence and Terlouw (1993) and Rushen (1984), When low level of feed was provided, sow showed more activities after meal and consumed more water for stomach distention.

Therefore, it is expected that feeding frequency in gestation, particularly once daily feeding does not only improve sow reproduction and animal welfare, but also add profit on the farm management by improving productivity and saving labor costs compared to twice daily feeding.

Ⅱ. Literature Review

1. Introduction

Over the past few decades, there have been many changes in management of gestating and lactating sow. Sow reproductivity and productivity have remarkably improved with the advance in management methods such as facilities, feeding, ventilation and sanitation as well as genetic improvement, but resulted in the consequential environmental problems. At the same time, the global consumption of pork which is the most popular and excellent protein source for humans has been accelerated by the population explosion in developing countries. However, many of scientific and public concerns about sow welfare have also been greatly increased as the swine production intensified. Thus, this review will address not only the diverse aspects of sow reproduction and productivity, but also factors affecting sow welfare.

1.1. Pork production and sustainability of global swine industry

World pork production and consumption have had a steady increase over the last few decades (Figure 1). This has been promoted by the rise in national income and population of developing countries for example China, Russia, Brasil and so on (Figure 2). As the result, pork has become the most widely eaten meat in the world. According to the 2012 Revision of the official United Nations population estimates and projections (UN World Population Prospects, 2012), the world population will reach approx. 9.7 billion by 2050 (Midium-variant projection, Figure 3), with much of the increase happening in Asia and

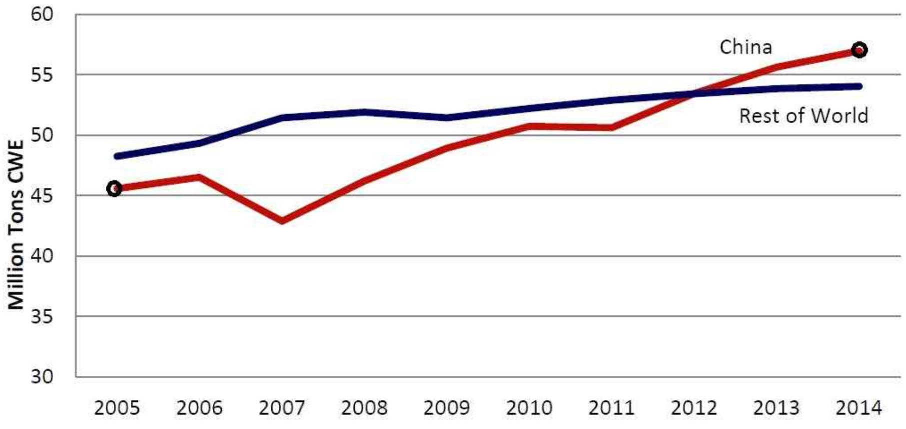

Figure 1. Pork production trends of China and the rest of World (adopted from USDA, 2014)

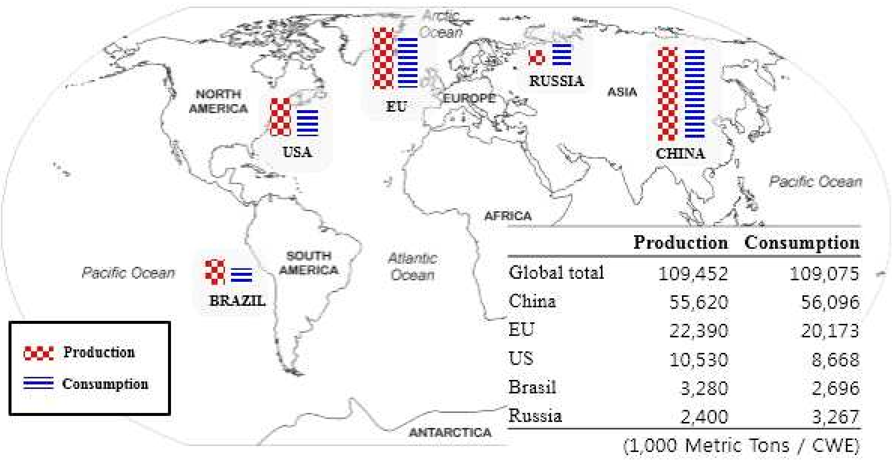

Figure 2. World pork production and consumption by selected country in 2013 (USDA, 2014)

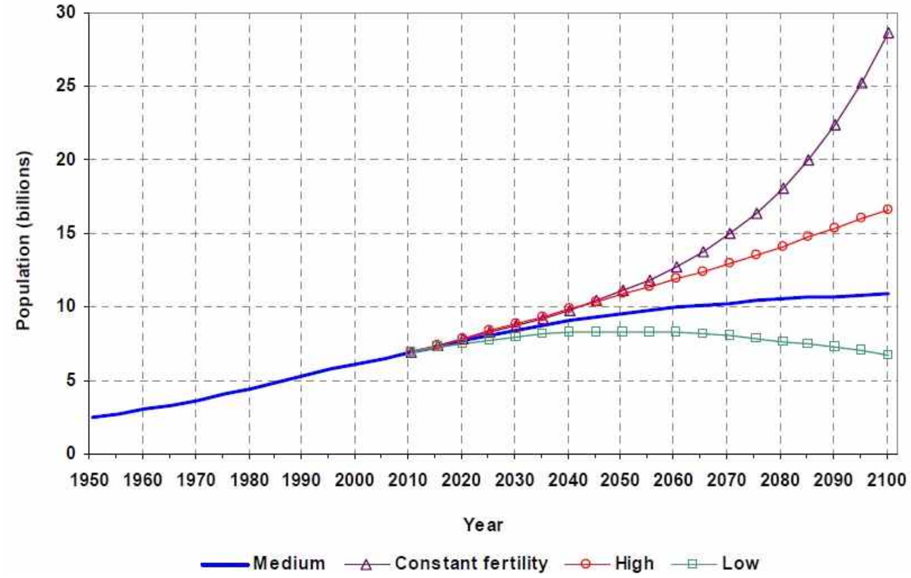

Figure 3. Population of the world (adopted from UN World Population Prospects, 2012)

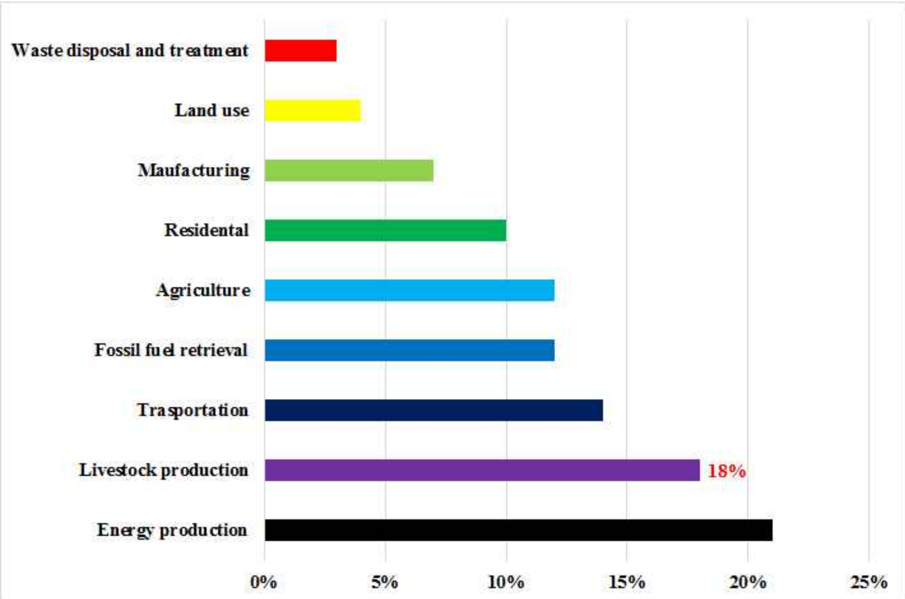

Figure 4. Global industrial greenhouse gas emission (FAO, 2006)

Africa. It is estimated that world consumption of pork, as one of the best protein source for human, will be more increased by the expected population growth. Therefore, improving swine productivity is a sine qua non for the future generation.

However, it is not that everyone agrees with the output rise of swine products because of their harmful effects on environment and public health. Insanitary and overcrowded conditions of the farm area could be one cause of livestock epidemic spread such as foot and mouth disease (FMD), avian influenza (AI) and mad cow disease (BSE). Increasing concentration of greenhouse gases by human activities including livestock industry have been blamed as one of the major causes of global warming. According to the report of UN Food and Agriculture Organization (FAO, 2006), livestock industry including pork, dairy product, beef and chicken across the world have generated about 18 % of greenhouse gas emissions with increasing the consumption of meat and its byproduct in developing countries (Figure 4). What's worse, is that swine has the second largest record of CO_2 emission quantity within agricultural industry. Therefore, it is the time for us to reconsider the seriousness of the existing pork production method and to propose a solution considering both productivity and sustainability of swine industry.

1.2. Animal welfare

Livestock policies in a large number of countries has centered on quality instead of quantity. Recently, public concerns for animal welfare has grown remarkably (Kanis et al., 2004), and is being more extended to livestock products (Thornton, 2010). Although many scientists and organizations are involved with animal welfare, the 'Five Freedoms' for livestock which was defined by Farm Animal Welfare Council (FAWC) in the UK has become the widely accepted definition of animal welfare. The 'Five Freedoms' includes 1) Freedom from hunger and thirst, 2) Freedom from discomfort, 3) Freedom from pain, injury or disease, 4) Freedom to express normal behavior, and 5) Freedom from fear and distress (FAWC, 1992). The council says that animal welfare implies both fitness and a sense of well-being, and should be considered whether on farm, in transit, at market and at slaughterhouse. Besides that, there are a similar approaches and definitions of animal welfare by The World Animal Health Organization (OIE) and Welfare Quality (Table 1).

Table 1. An operational of animal welfare (Welfare Quality project; adopted from Rushen et al., 2011)

Principle	No.	Welfare criteria	Example of potential measures
Good feeding	1	Absence of prolonged hunger	BCS
	2	Absence of prolonged thirst	Access to water
Good housing	3	Comfort around resting	Frequencies of different lying positions, standing up and lying down behavior
	4	Thermal comfort	Panting, Shivering
	5	Ease of movement	Slipping or falling, Possibility of exercise
Good health	6	Absence of injuries	Clinical scoring of integument, carcass damage, lameness
	7	Absence of disease	Enteric problems, downgrades at slaughter
	8	Absence of pain induced by management procedures	Evidence of routine mutilations such as tail docking and de-horning, stunning effectiveness at slaughter
Appropriate behavior	9	Expression of social behaviors	Social licking, aggression
	10	Expression of other behaviors	Play, abnormal behavior
	11	Good human-animal relationship	Approach or avoidance tests
	12	Positive emotional state	Novel object test

In the aspect of animal welfare, an individual stall for sow is at the center of debate, and a bond of sympathy banning the stall intensive production system during gestation has developed in the advanced countries. So, the stall housing system has not been allowed in the Unite Kingdom since 1999, resulting in legislation banning the system in the EU in 2013 and in a certain states in the US and in New Zealand. Australian swine industry also agreed with phasing out of the use of stall by 2017, even though stall housing is legal in Australia so far.

2. Nutrition and physiological changes of sow

2.1. Nutrient requirement during gestation

The NRC (1998) recommendation for daily energy intake of gestating gilt and sow ranges from 6,015 to 6,395 kcal of ME, and the updated version of NRC in 2012 suggests that daily energy consumption till day 90 of gestation and after day 90 of gestation should range from 6,427 to 6,928 kcal of ME and from 7,775 to 8,182 kcal of ME, respectively. While adequate energy intake during gestation improves sow reproduction (Dyck and Strain, 1983; Cassar and King, 1992), excessive energy level of gestation diet has negative influence on embryo survival in the early stage of gestation and feed intake during lactation (Liao and Vuem, 1994; Dourmad et al., 1999). In addition, energy level of sow diet in gestation should consider the practical situation of each farm because energy utilization of gestating sow is positively or negatively affected by the various factors such as other nutrients, parity, breed, environment, body condition and immune status of the sow.

Each protein source in the diet has different nutritional value owing to the difference in amino acid composition and its availability (Bake, 1997). The NRC (1998) suggested that dietary protein level in gestation diet range from 12 to 13 % under the certain feeding amount. Insufficient protein consumption or protein restriction in gestation causes reduction in piglet birth weight and litter weight gain during lactation (Mahan, 1977; Schoknecht et al., 1993). To meet the nutrient requirement in lactation, sow tends to mobilize protein and fat from her body when lactation feed intake is inadequate (Noblet et al., 1990). Kusina et al. (1995) reported that higher protein level with 16g/d lysine in the diet had positive influence on litter weight gain and sow milk production. However, in the previous study of Mahan (1998), although gilt with 16% protein presented higher litter weight gain and litter weight at weaning when it compared to 13% dietary protein level, backfat thickness of the sow with 16% protein in the diet showed a clear decreasing trend as parity is progressed. Meanwhile, there are several experiments reporting that protein level in gestation had no long term effects on sow milk yield and piglet growth during lactation (Mahan, 1979; Maxwell et al., 1987). In contrast, ARC (1981) reported that protein level in the late stage of gestation could have positive influence on milk production and the survival rate of neonatal piglet. Young et al. (1976) also demonstrated that low protein level in gestation diet lowered the piglet weight at weaning.

In general, non-ruminant animal cannot utilize the fiber sources such as cellulose, hemicellulose and lignin due to the absence of their digestive enzymes (Noblet and Etienne, 1989; Black et al., 1993). Nevertheless, the previous results demonstrate the positive effects of dietary fiber sources on sow physiology and reproduction. Lee and Close (1987) reported that sow stereotypes and activities during gestation were reduced as fiber level in the diet increased, improving the fetal growth and maternal energy availability. Grieshop et al. (2001) also showed the increasing result of litter size at parturition with higher fiber level in gestation diet. However, swine farm has to consider the gains and the losses when fiber source is applied to sow diet because dietary fiber could surge the feed costs and the consequent pork production costs.

2.2. Importance of body weight and backfat of sow

Sow body weight and BF thickness have a co-relationship with their productivity. For milk production and reproductive function, it is important for sow to reserve adequate amounts of energy and protein on her body during pregnancy. The total weight gain and maternal weight gain in gestation up until parity 3 or 4 should be approximately 45 kg and 25 kg, respectively (Aherne and Kirkwood, 1985; Williams et al., 1985; Noblet et al., 1990). Insufficient feed intake during lactation not only cause the excessive loss of backfat and body weight, but also increase the sow culling rate due to the poor reproductive performance (Eissen et al., 2000). Poor energy intake and extreme thinness at weaning could delay the WEI of the sow (Tantasuparuk et al., 2001). Clowes et al. (2003) and Thaker and Bilkei (2005) have observed that when the loss of body weight and body protein in primiparous sow during lactation is more than 10 to 12 %, litter performance and subsequent reproduction of the sow could be adversely affected. Yang et al. (1989) recommended that feeding strategy during gestation target on making backfat thickness be 20 mm at farrowing in primiparous sow because piglet growth in the sow with 20 mm backfat was higher than the sow group with 12 mm of backfat. Researches by Young et al. (1991) and Hughes (1993) presented that when sow backfat thickness at weaning was less than 14 mm, the subsequent reproduction could be deteriorated. However, when sow backfat is thicker than 21 mm at farrowing, sow feed intake during lactation would be reduced (Dourmad, 1991; Revell et al., 1998; Young et al., 2004). Meanwhile, Young et al. (2004) observed that lactation feed intake of gilt (primiprous sow) was 20 % lower than multiparous sow.

2.3. Feeding program in gestating sow

Feeding strategy of the early part of gestation is most important for pregnant sow because ovulation rate, conception rate, fertilization rate and implantation rate of the sow are influenced. Dyck et al. (1980) demonstrated that when daily feed intake in the early stage of gestation was doubled from 1.5 to 3.0 kg, the survival rate of embryo in primiparous sow was reduced by approx. 10 %. Therefore, Pharazyn et al. (1991) reported that 1.8 to 2.0 kg of feed level during early gestation would be safe for pregnant sow. However, on the contrary to this, hughes (1993) reported that increased feed intake in early gestation did not have negative influence on the survival rate of embryo, improving the deposition of maternal tissue. A 30 % higher feed intake in early gestation (from d 3 to 32 of gestation) of young sow improved body weight gain during early gestation and litter size without adverse effects on the piglet birth weight, but only farrowing rate of the sow was reduced.

The feeding strategy in the middle stage of gestation (d 35 to 90 of gestation) is usually focused on making the adequate body condition for farrowing and lactation of the sow because the fetus growth are not remarkable. But, Nissen et al. (2003) could not observed the clear effect of the increase in sow feed intake during the middle stage of gestation. Futhermore, increased feed intake from d 75 to 90 of gestation could have negative influences on the mammary grand development of gestating sow and the milk production of the sow during lactation (Weldon et al., 1991).

Because of the notable progress of fetal growth in the late stage of gestation, the increase in feed intake during pregnancy has been encouraged by some researchers (Whittemore et al., 1984). In addition, Whittemore et al. (1980) reported that the adequate body fat deposition to support the higher fetal growth is recommended. Noblet et al. (1990) also suggested that sow should consume more than 8.33 Mcal DE per day not to lose the fat mass of her body in the late part of gestation. However, overfeeding during the period needs to be prevented for the increase in feed ingestion during lactation (Weldon et al., 1994; Xue et al., 1997). Piao (2010) reported that flat feeding in gestation not only prevent sow fatness at farrowing, but also increase the feed intake in lactation without negative effect on litter performance. Ju and Kim (2010) also found that increased feeding during late gestation has no influence on litter performance during the whole lactation as well as litter size and litter weight at birth.

2.4. Feed intake of lactating sow

Lactation feed intake of the sow is not only stimulated by gestation feed intake, but also affected by various factors such as sow (i.e., body condition, parity, litter size), diet (i.e., nutritional composition, digestion and utilization) and environment (i.e., lactation length, room temperature and management). Dourmad (1991) demonstrated that when sow consumed feed *ad libitum* during gestation, lactation feeding intake was reduced. He explained that a 0.5 kg increase in gestation feed intake resulted in a 0.29 kg decrease in lactation feed intake. Weldon et al. (1994) also reported that although the gilt with *ad libitum* excess to feed during gestation ate approx. two times more than her gestation requirement, their lactation feed intake was only half the feed intake of the gilt with restricted feeding in gestation (Figure 5). In their study, the gilt in *ad libitum* treatment showed significantly higher body weight gain during gestation, but the body weight at weaning was not different when it compared to the gilt with restricted feeding in gestation. During lactation, inappropriate feed intake also causes BW and BF loss, resulting in the increase of sow culling rate because of the poor reproductive performance (Eissen et al., 2000).

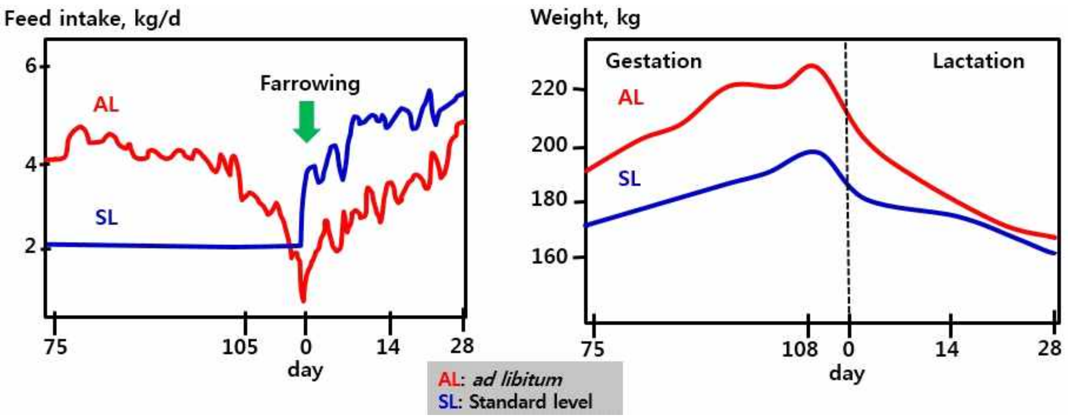

Figure 5. Effects of gestation feed intake on lactation feed intake and BW changes in gilts (Weldon et al., 1994)

Moreover, *ad libitum* feed intake of lactating sow has positive relationship with litter size, litter weight gain (Yang et al., 1989; Koketsu et al., 1996; Eissen et al., 2003), and weaning to estrus interval (WEI) of the sow (Koketsu and Dial, 1998; Koketsu et al., 1997; Eissen et al., 2003).

2.5. Milk production and piglet growth

The composition and production of sow milk were first investigated by von Gohren (1865). Sow milk composition and its quantity play an important role in her litter performance as milk is the main nutrient source for piglets during lactation (Onderscheka, 1969). Milk composition is changed as the lactation progresses (Jenness, 1974), and colostrum which is accumulated from mammary grand during the late stage of gestation is secreted during 24 to 36 hours after farrowing. Colostrum not only provides energy source to neonate, but also contains rich amounts of immunity substance. Neonatal piglet need to consume the colostrum immediately within the first day of lactation because the absorption of immunoglobulins in sow colostrum is terminated by gut closure (Klobasa et al., 1981; Werhahn et al., 1981). Edwards (2002) has demonstrated that piglet mortality during lactation would be increased if colostrum consumption of neonatal piglet is insufficient. Colostrum and milk are classified by their composition difference. In contrast with low level in lactose and fat, total protein and total solid containing immunity substances tend to be high in colostrum. On the other hand, lactose in milk which is increased during the first week of lactation could be the signal for the conversion of colostrum into milk (Klobasa et al., 1987; Darragh and Moughan, 1998). Fat in sow milk shows a declining tendency during lactation (Klobasa et al., 1987; Kusina et al., 1999; Hansen et al., 2012). Fat reserve for sow milk production could be limited in the late of lactation (Kusina et al., 1999), and BF and body weight loss of lactating sow can be aggravated when she raises a large number of piglets (Eissen et al., 2003). Litter size and Litter gain have a correlation because sow with larger litter size tends to produce more milk than smaller size (Toner et al., 1996; Auldist et al., 1998; Nielsen et al., 2002). However, piglet weight gain in the large litter may have limit because the sow ability to produce milk is not infinite (Zijlstra et al., 1996).

3. Factors affecting reproductivity and longevity of sow

Longevity of sow means constantly and repeatedly keeping sow reproduction cycle combining mating, pregnancy, farrowing, lactating and weaning without illness, abortion, non-pregnancy, culling and mortality. Sow longevity in swine farm is lated to farm economic efficiency and/or animal welfare, and could be evaluated by removal rate, culling rate, replacement rate, average parity and sow-to-gilt ratio of sow in the farm. However, swine farm generally tends to focus on culling rate and replacement rate of the sow as the measurement of the farm longevity. The factors affecting sow longevity can be summarized by a couple of things such as heredity, nutrition, gilt development and management.

3.1. Gilt and heritability

The prenatal and postnatal environment can affect the gilt growth and their reproductive performance. Although the litter size of sows is affected by diverse factors of their environment, the gilts which were chosen from the progeny of sows with higher ovulation rate, higher embryo survival rate and larger uterine size also tends to have larger litter size (Tummaruk et al., 2000). Tummaruk et al. (2001) also reported that gilts with higher litter size were influenced by their mother who used to have higher litter size. Falconer and Mackay (1996) demonstrated that the heritability of litter size is about 0.2. However, the study of Johansson (1981) indicates that the gilt born in smaller litter showed higher body weight at 3 week of lactation and younger at 90kg of body weight than the gilt born in larger litter. Nelson and Robinson (1976) also reported that gilt who has reared with 6 piglet during lactation showed higher ovulation rate, higher embryo survival rate at 25 days of gestation and larger litter size than gilt reared with 14 piglet during gestation. The growing rate of gilts also can affect their own reproduction in the future. Gilts in the group of higher growing rate presented a larger litter size, shorter WEI and higher farrowing rate than the gilts in the group of lower growing rate (Tummaruk et al., 2001). Futhermore, the first mating age is depended on the growing rate of gilt. Because the puberty of gilt is determined by her age, the gilt with higher growing rate could have higher body weight at puberty. Backfat thickness of gilt could be the factors affecting sow reproduction. The previous research of Tummaruk et al. (2001) demonstrated that the gilt with thicker BF tended to show shortened WEI after the fist parity and increase her farrowing rate and litter size during the second parity. Ten Napel and Johnson (1997) have reported that the interval between weaning and the subsequent farrowing of the gilt with thinner BF was also delayed.

3.2. Litter size and lactation length

Sow rearing a large number of piglets has stronger stimulation by suckling, resulting in the increased milk production (Auldist et al., 1998). According to Toner et al. (1996), the sow milk production was linearly increased when the number of suckling piglet was increased by 10. O'Grady et al. (1985) observed that the feed intake of lactating sow was increased with the increment of her litter size. These previous results implied the lactating sow with larger litter size and the consequent higher milk yield requires voluntary feed intake including greater amount of energy for her successful reproductive performance.

During the last several decades, weaning at younger age have been the common practice for swine farmers because they had believed that earlier weaning does not only maximize the facility availability of the farm, but also improve the piglet health after weaning. However, these beliefs were revealed to be false by several researchers. Koketsu et al. (1995) demonstrated that when lactation length was 7 days or less than 7 days, the weaned sow showed the irregularity in weaning to estrus interval. Xue and Dial (1995) and Xue et al. (1997) also reported that the sow with shorter lactation length had higher removal rate. Svajgr et al. (1974) illustrated that when the piglets were weaned at d 2, 13, 24 and 35 of lactation, weaning to estrus intervals of the sows were 10.1, 8.2, 7.1 and 6.8, respectively, and the subsequent conception rates of the sows were 68, 92, 100 and 100%, respectively.

3.3. WEI and flush feeding in post-weaning period

Weaning to estrus interval (WEI) of sow is one of the important factors determining litter per sow per year (LSY) because WEI is the main component of non-productive day of the sow. With the swine production improvement, sow is usually at heat within 3 to 5 days after weaning (Vesseur, 1997), with more than 90% presenting estrus within 7 days post-weaning (Belstra et al., 2004; Behan and Watson, 2005). Weaning to estrus interval of the sow regardless of parity and breed has negative relationship with her fertilization rate, the consequent farrowing rate and litter size at parturition (Leman, 1990; Dewey et al., 1994; Vesseur et al., 1994) because the estrus length and ovulation time tend to get shorter with delayed WEI (Rojkittikhum et al., 1992; Weitze et al., 1994). Wilson an Dewey (1993) demonstrated that the sow with WEI of 7 to 10 days showed a lower number of piglets at birth and farrowing rate than the sow with WEI of 3 to 6 days. Therefore, WEI of sow should be controlled properly for her successful reproductive performance.

However, these can bring us to ask what causes the WEI to be delayed. According to the study of Shaw and Foxcroft (1985), the sow with WEI of 6 days presented a low LH pulse at weaning than the sow with WEI of 4 days. This delayed WEI of sow makes the follicular development slower and has a slower onset of the follicular phase after weaning. Soede et al. (1994) presented that LH surge in the pre-ovulatory stage, ovulation and an increase in progesterone have a strong relationship with each other, regardless of WEI of the sow. By the study of Rojkittikhun et al. (1992), the interval between the estradiol-17b increase and the estrus initiation of sow tended to be long when WEI of the was delayed, implying that this sow was more insensitive to estrogen as the leading cause of estrous behavior.

The term 'flush feeding' means giving sow (or gilt) extra feed including an increase in both quantity and quality of the sow diet just before mating, and stimulates ovulation of the sow, resulting in the shortened WEI in the post-weaning period. Fahmy and Dufor (1976) observed that feeding sow ad libitum after weaning increased the ovulation rate within 7 days after weaning from 52 to 62%, compare to limited feeding. Van Den Brand et al. (2001) also reported that carbohydrate fortification in the diet after weaning resulted in the shortened WEI of sow when it compared to the fat rich feed, increasing the average ovulation rate of primiparous sow in estrus within 9 days after weaning from 52 to 67%. Recently, Van Den Brand et al. (2006) reported that adding dextrose to the sow diet during post-weaning period did not have any positive effect on WEI, the numerical improvement was observed in the piglet weight at birth with the addition of dextrose. Providing additional soluble non-starch polysaccharide (NSP) such as sugar beet pulp to the sow diet during the post-weaning period increases the total born and born alive of her piglets (Sorensen, 1994; Van der Peet et al., 2004). The effects of these dietary supplements would be related to the increased secretion of insulin and IGF-1 which supports the follicle development, resulting in the bomogenization of follicle size and the consequent reduced variation of fetal development.

4. Stress responses by breeding conditions in gestating sow

4.1. Restricted feeding

During pregnancy, it is important for sow to maintain a adequate body condition for her successful reproductive performance (Dourmad et al., 1994). Feeding strategy in gestation could positively or negatively influence on her following reproduction, sometimes causing her locomotion problems. Feeding small and concentrated meal once or twice daily has advantages of both providing the exact quantity of nutrients and saving the operating costs, but consequently sow hunger and the frustration for feed could be sustained (Rushen et al., 1993). Feed restriction deeply has relevance to the occurrence of stereotypic behaviors. These behaviors reach its peak immediately after meal, and occurs when the limited nutrient intake of sow is combined with the restricted access to feed (Rushen, 1985; Appleby and Lawrence, 1987; Spoolder et al., 1995). Therefore, sow stereotypic behaviors which are involved with feed are regarded as the indicator of both satiety and welfare (Wiepkema et al., 1983).

Group housing with restricted feeding could bring about feeding competition of sows, resulting in injured sow as well as feed intake imbalance within the sow group. (Edwards, 1993; Brouns and Edwards, 1994). This is one of the reasons why the stall housing system has come into wide use, but the stall, as mentioned above, also has many problems. Although ESF system has been suggested as the alternative to stall housing recently, this system still have the risk of body damage of the sow by feeding competition near the feeder during mealtime (Van Putten and Van de Burgwal, 1990).

Low density gestation diet, that is bulky diet with fiber sources, has positive effects on extending feeding time, reducing feeding rate and feeding motivation, and decreasing aggression and stereotypes (Meunier-Salaun et al., 2001). However, we must remind that increasing fiber sources in diet causes the cost rising.

4.2. Housing system and sow welfare

Along with the development of livestock industry, domestic animal has been raised on the farm with intensive facilities which has benefits in terms of working efficiency, herd management and land cost saving. In most countries, the swine accommodations are mainly slurry based, with slatted floors and without bedding, and sows are housed in individual stalls (also called a crate) for better productivity during most of their life. But, the system has been at the center of controversy among farmers, consumers and scientists due to the poor sow welfare.

Besides management advantages, stall housing system enable individual control for the aspects of feeding, controlling body condition and detecting estrus. However in respect of animal welfare, the stall is far from optimal. The stall during gestation and lactation suppresses sow freedom of movement, resulting in increased skin wounds because of sustained contact with hard floor (Bonde et al. 2004; KilBride et al. 2009). Although farrowing crates have the merit of protecting piglets from being crushed by their sows, the crates tend to increase the sow stress responses such as heart rate and cortisol level around parturition, compared to loose housing system (Cronin et al. 1991; Jarvis et al. 2001; Oliviero et al. 2008). In nature, the antepartum behavior of sow such as nest building has an important influence on her farrowing process and the consequent increase in neonatal mortality (Wischner et al. 2009), and suckling piglet has many chances to learn from their mother how to adapt to solid feed, showing better adaptation to the post-weaning environment. But, the farrowing crate and pen (for piglets) may disturb these natural behavior. Similar to nature condition, according to Munsterhjelm et al. (2010) and Oostindjer et al. (2010, 2011), growth performance and feed intake after weaning could be improved in the piglets with enriched environment (e.g. loosening the room, providing straw and branches) during lactation, and this resulted in better adaptability to their post-weaning environment.

In this context, the loose housing systems for sow such as group housing with Electronic Sow Feeder (ESF) or open stalls are being suggested as the alternative to individual stall housing system. However, the group housing system also has disadvantages because the sows in a group tends to get aggressive to determine a dominator within their group, causing the injured sows (McGlone et al., 2004). Moreover, the sows with group housing system could show poor reproductive performance and lower litter size, compared to the sows with individual stall (McGlone et al., 2004; Kongsted, 2004). And, the increase in investment costs (i.e. land cost, facilities cost) of group housing system would not be no longer in question.

4.3. Water intake and hunger

In general, sow receives water ad libitum through a nipple in the farm, however, with restricted feeding, sow hunger in pregnancy could cause excessive water consumption due to the persistent feeding motivation (Rushen, 1984). So some farmers tend to water their sow at a particular time a day to prevent her from consuming excessive water. Robert et al. (1993) reported that excessive water intake of gestating sow would be related to her stomach distention. The intake of dry matter lead primiparous sow to consume more water (Friend, 1971), and the intake of feed and water in gilt tends to reduced at heat (Friend, 1973; Friend and Wolynetz, 1981). Unmatured gilt intakes 11.5 liter of water per day, while gilt in gestation intakes 20 liter per day (Bauer, 1982). These data are similar to the results of 10 liter by Lightfoot and Armsby (1984) and 11 to 15 liter by Klopfenstein (1994).

According to the study of Madec (1984), urinary disorder which is common in sow is strongly related to low water intake, and sow with feed restriction in gestation tends to overcompensate for the insufficient gut fill by drinking excessive water. For lactating sow, high quantity of water consumption is recommended to meet the water requirement for milk production. Even though water supplier such as a

nipple and bite provides adequate amount of water for sow, lactating sow tends to stop drinking and become frustrated prior to drinking the sufficient amount of water. The recent study of Gadd (1996) demonstrated that providing water by a trough which is located next to the feeder makes her drink more water rather than a drinker, resulting in increased feed intake and the consequential improvement of the piglet weight at weaning.

Table 2. Water consumptions (L/day) and flow rates (L/minute) of sow in gestation and lactation (adopted from Swine nutrition, 2001)

<table>
<tr><th rowspan="3">Water consumption</th><th></th><th>Cleary (1983)</th><th>Anderson et al. (1984)</th><th>Pederson (1994)</th><th colspan="2">Lumb (1998)</th></tr>
<tr><td>Gestating sow</td><td>12-15</td><td>13-17</td><td>12-20</td><td colspan="2">5-8</td></tr>
<tr><td>Lactating sow</td><td>18-23</td><td>18-23</td><td>25-35</td><td colspan="2">15-30</td></tr>
<tr><th rowspan="3">Flow rates</th><th></th><th colspan="2">Agriculture and Agri-food Canada (1993)</th><th>Carr (1993)</th><th>Gadd (1998)</th><th>Lumb (1998)</th></tr>
<tr><td>Gestating sow</td><td>2.0</td><td>1.5-2.0</td><td>1.5-2.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td>Lactating sow</td><td>2.0</td><td>1.5-2.0</td><td>4.0</td><td>1.0</td><td>1.5</td></tr>
</table>

4.4. Stereotypic behaviors

Stereotypic behaviors of animal means repetitive and sustained behaviors without specific function and aim (Fox, 1965; Odberg, 1978; Wiepkema et al., 1983). The bouts of remarkable movement may be sustained by animal (Odberg 1986), and the animal could have trouble stopping its behaviors (Feldman and Green, 1967; Cronin and Wiepkema, 1984). The bouts of those abnormal behaviors may be happened certainly and predictably in a time or place (Berkson, 1967; Hinde, 1970). The repeatability of stereotypic behaviors depends partially on the specific external stimulus (Berkson, 1967), especially when performed at a rapid pace (Fentress 1977). But, this reaction may progress into independent behaviors from the stimulation which originally has induced the performance (Levy, 1944; Hinde, 1970). Stereotypic behaviors sometimes develop in the animal who has insoluble problems (Stolba et al., 1983; Wiepkema, 1983), and are partly produced by external or internal factors such as brain damage, metal disorder and even taking drugs (Robbins, 1976; Ridley and Baker, 1982). These behavior patterns depend on the species and the environment, also have a difference between individuals.

Stereotypes are common among sows when their feed is restricted. Typically, sows with stereotypes show chewing and biting the bar of their stall, or performs chewing without food in her mouth (Fraser, 1975; Cronin, 1985; Rushen, 1985), also exhibiting the behaviors such as manipulating drinkers and drinking water needlessly. These temporal drinking patterns and excessive water intake of sow cannot be controlled by autoregulation mechanisms (Terlouw et al., 1991). Stereotypic behaviors of sow tend to increase sharply just after the meal (Rushen, 1984). Sow are apt to perform rooting and nosing the feeding bowl and drinking water during the post-meal period, while sow presents other behavior patterns such as drinking water and manipulating other things during the later period. The time which gilt shows stereotypic behaviors also has negative relations with their feed allowance (Appleby and Lawrence, 1987). Gilt with restricted feeding condition shows the increase in developing mouth-based behaviors regardless of housing condition although the gilt fed with large amounts of meal has less of a tendency to develop stereotypic behaviors (Terlouw et al., 1991).

5. Effects of feeding frequency in gestation sow

5.1. Physiology and behaviors

In the study of Robert et al. (2002), duration of eating was not affected by feeding frequency. But, sow behaviors including stereotypes reduced by the decrease in feeding frequency (i.e. once daily feeding). Before meals, the frequency of stereotypes and vocalizations were decreased by feeding once daily, compared to feeding twice daily. Prior to morning meal, gits fed high fiber diet with single meal per day showed more active behaviors, but the frequency of both treatments were not different. In the other hand, the gilt with control diet and two meal per day lay down less, compared to one meal per day. After meals (or non-meal period of the gilt fed once daily), the frequency of drinking, licking the empty feeder and performing stereotypes was lower when gilt were fed once a day, compared to feeding twice a day. The authors concluded that feeding gilt once a day reduced feeding motivation more effectively than feeding twice daily, regardless of diet.

According to Holt et al. (2006), feeding frequency (feeding once daily versus twice daily) had no effect on postures and non-eating behaviors. However, sow with twice daily feeding spent more time feeding at day 40 and 80 of gestation. the authors presumed that sow with twice daily feeding spent some time licking and nosing the feeder trough at the end of mealtime before stepping back from the feeder. Therefore, combined the results, sow behavior were not improved by twice daily feeding.

5.2. Reproductivity and sow performance

Holt et al. (2006) reported that sow with once daily feeding gained less body weight and backfat, compared to fed twice daily. In addition, the litter and piglet weight between treatment was not different. The initial sow body weights of feeding once and twice daily were 190.6 kg and 194.0 kg, respectively. But sow body weights at day 40 and 80 of gestation and 24 h post-farrowing were higher in the treatment of twice daily feeding, compared to once daily feeding. Sow BF is thick in the treatment of twice daily feeding by day 80 of gestation and at 24 h post-farrowing. The ADFI in lactation and WEI were not affected by feeding frequency. The ADFI of Feeding once and twice daily was 7.6 and 7.3 kg, respectively. The WEI of each treatment was 4.5 and 4.7, respectively. However, sow digestibility in gestation was not affected by feeding frequency, according to the results of Holt et al. (2006) wich was similar to Sharma et al. (1973).

5.3. Endocrine status

Farmer et al. (2002) have studied the effects of feeding frequency on endocrine status (i.e. the concentrations of cortisol, insulin, glucose and free fatty acids in the blood samples) of gilts. In their study, feeding gilt twice daily increased baseline cortisol and decreased morning cortisol area under the curve (AUC) and baseline free fatty acids (FFA), when it compared to feeding once daily. And, twice feeding a day also increased afternoon insulin maxium values and AUC as well as morning and afternoon maximal glucose and decreased morning maxiumal FFA. The researchers concluded that feeding gilts once a day, compared to twice, increased the FFA concentrations before the meal, indicating that the gilt with one meal per day were drawing on their body reserves. Besides, they said that the increased morning concentrations of cortsol by one large meal per day indicated the increase in postprandial excitation of the gilt.

Holt et al. (2006) showed the similarity to the result of Farmer et al. (2002). In their study, feeding once daily did not reduce the salivary cortisol concentration of the sows, resulting in decreased trend throughout gestation regardless of treatment.

Ⅲ. Effects of Feeding Frequency on Reproductive Performance and Stress Response in Gestating Sows

Abstract: A total of 20 F1 multiparous sows (Yorkshire×Landrace) were used to investigate the effects of feeding frequency on their reproductive performance and stress responses. The sows were alloted to one of two treatments, i.e. 1) once daily feeding (OF) and 2) Twice daily feeding (TF), in a completely randomized design (CRD) based on their parity, body weight (BW), backfat thickness (BF) and weaning to estrus interval (WEI). Gestating diet with 3,265kcal of ME/kg, 12.90% of CP, and 0.75% of lysine was provided at 2.4 kg for the 3rd parity and 2.2 kg for the 2nd parity during pregnancy, while a same lactating diet with 3,265kcal of ME/kg, 16.80% of CP and 1.08% of lysine was provided *ad libitum* regardless of treatment. In gestation, sow BW, BF and BF gain were not affected by feeding frequency, but significantly higher BW gain from day 35 to 90 and from day 35 to 110 of gestation were observed in OF treatment ($P<0.05$ and $P<0.10$, respectively). In lactation, sow BW, BW gain, BF, BF gain, ADFI and WEI did not differ significantly between treatments. Although litter and piglet performance were not affected by gestation feeding frequency, litter weight at birth was significantly higher in OF ($P<0.05$). When it compared to TF, OF had no influence on colostrum and milk compositions of lactating sow as well as IgG in sow colostrum and piglet serum. Sows with OF showed significantly or numerically lower average daily water consumption from day 35 to 70 of gestation

($P<0.05$), day 70 to 105 of gestation ($P<0.10$) and overall period of gestation ($P<0.05$). While there were no significant differences in stereotypic behaviors and salivary cortisol levels during gestation between treatments, OF treatment showed numerically or significantly lower sow activities at day 70 and day 105 of gestation ($P<0.10$ and $P<0.05$, respectively), and numerically increased inactivities at day 70 and day 105 ($P<0.10$). In conclusion, OF did not have negative influence on sow reproduction and reduced the stress-related responses of sow in gestation compared to TF. However, considering the higher BW gain of OF in gestation, more research for nutrient digestion and utilization of OF sow is recommended.

Key words: Gestating sow, Reproductive performance, Salivary cortisol, Stereotypic behavior, Water consumption

Introduction

Gestation is one of the most important period which determines farm productivity. Preparing farrowing and lactation, gestating sow experiences several changes such as placental and fetal development, maternal body tissue reserve and mammary gland development (Kensinger et al., 1982; Dourmad et al., 1994; Kusina et al., 1999; Rehfeldt et al., 2004; Young et al., 2004). So, two restrict conditions are generally imposed on gestating sow for successful reproductive performance, but each of these conditions has some controversial issues.

The first condition is stall housing which is able to manage individual sow and prevent aggression (McGlone et al., 2004). However, the stall disturbs freedom of movement and social interaction of the sows, indicating poor welfare. The second is feed restriction, which is easy to control body condition and stimulate lactation feed intake (Friend, 1971; Weldon et al., 1994). However, this strategy sustains sow hunger (Lawrence et al., 1988) and could increase stereotypes related to feeding motivation (Appleby and Lawrence, 1987; Damm et al., 2003). Therefore, it needs to reduce those stressors from the restricted conditions for better productivity and welfare of gestating sow.

Several studies have showed that the less feeding frequency in gestation can reduce the sow behavioral responses which indicates stress levels. Brouns and Edwards (1994) documented that omission of feeding can decrease the level of post-feeding stereotypes. Robert et al. (2002) reported that once daily feeding reduced feeding motivation and active behaviors including stereotypes than twice daily feeding in primiparous sow. Holt et al. (2006) also reported that sow active behavior in gestation could be reduced by reducing feeding frequency. However, in contrast to the behavioral response, the previous studies of Farmer et al. (2002) and Holt et al. (2006) presented that reduced daily feeding frequency did not lower the level of stress hormone. Moreover, very few studies have been done to determine the effects of gestation feeding frequency on sow productivity.

Therefore, this study was conducted to investigate whether the gestation feeding frequency, particularly comparing once daily feeding with twice daily feeding, has effects on sow reproduction and stress responses.

Materials and methods

Experimental Design and Diets

A total of 20 F1 gestating sows (Yorkshire×Landrace) with average body weight (BW) of 201.8 ± 12.54 kg and a parity of 2.8 ± 0.41 (parity 2 or 3) were allotted to one of two feeding method treatments by parity, BW, backfat thickness (BF) and weaning to estrus interval (WEI) in completely randomized design (CRD) after confirming pregnancy at day 35.8 ± 1.11 of gestation by ultrasound scanner (Dongjin BLS, South Korea). The treatments consisted of 1) once daily feeding (OF) of 2.4 kg, or 2) twice daily feeding (TF) of 1.2 kg of a gestation diet (Sows of the 2nd parity fed 2.2 and 1.1kg, respectively). All sows received the same lactation diet as an *ad libitum* after parturition till weaning. A gestation diet was formulated based on corn-soybean meal contained 3,265kcal of Metabolizable energy (ME) /kg, 12.90% of CP, and 0.75% of lysine, respectively. A lactation diet was formulated to contain 3,265kcal of ME/kg, 16.80% of CP and 1.08% of lysine, respectively. All the diets met or exceeded National Research Council (NRC) requirement (1998).

Animal Managements

After pregnancy was confirmed, sows were moved to gestation barn from breeding barn at approximately day 35 of gestation. Each treatment was not housed together to reduce the effects by different feeding schedules which were at 08:00 for the treatment fed once daily and at 08:00 and 16:00 for the treatment fed twice daily, respectively. All sows were accommodated in an individual gestation stall (2.40 × 0.64 m) where the indoor temperature was regulated by automatic ventilation system (average 19℃, ranged 17-21℃). At day 110 of gestation, sows were moved from gestation barn to 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 condition of farrowing barn were kept automatically at 25±3℃ by heating lamps and ventilation fans. After weaning, sows were moved to breeding barn again for the next conception.

Stress Measurements

Saliva samples were taken from the sows at day 35, 70, 105 of gestation using a cotton roll (Salivette®) to analyze salivary cortisol concentration. The saturated cottons with saliva were collected from their oral cavity immediately before and 3h after feed delivery (8:00 and 11:00). Samples were frozen at -20℃, then cortisol concentration were determined by an enzyme immunoassay with ER HS Salivary Cortisol kit (Salimetrics, State College, PA, USA).

Water consumption was also measured at day 35, 70 and 105 of gestation by water meter (Sewha Precision co., ltd.). Average water flow rate was adjusted to range from 1.5 to 2 L/min (Carr, 1993; Pederson, 1994). The water spills would be minimized because sow were drunken water directly from the nipple or from the feed bowl beneath the nipple. Therefore, although water consumption represented the total quantity of water intake and spillage by sow, it was also considered to be equal to water intake.

Sow behaviors from 4 sows of each treatment were recorded during daytime (06:00-18:00) using CCTV (Samsung Techwin co., ltd) at the same day with saliva collection. Recorded videos were analyzed by direct view, and then the behaviors classified as stereotypic behavior (bar biting, sham chewing and nosing the floor or feeder), activity (standing and moving without stereotypes, feeding and drinking behaviors) and inactivity (lying and sitting), respectively.

Sow Measurements and Sample Collections

The BW and BF of sows from all treatments were recorded at day 35, 90, 110 of gestation and 12 h, 21 d postpartum. And BF was measured at the P_2 position (last rib, 65 mm from the center line of the back) on both sides of back bone using a lean-meter (RencoCrop., Minneapolis, MN). Values from the two measurements were averaged to record a single BF measurement. During lactation, sow feed intake was recorded at day 7, 14, 21 of lactation.

Blood samples (Approx. 5ml) were collected from the anterior vena cava of piglet at 12 h, 21 d postpartum. All samples were enclosed into SST (Gel tube) and centrifuged at 3,000 rpm and 4℃ for 5 mins after clotting at room temperature for 30 mins.

The upper liquid (serum) of the blood was separated to a microtube (Axygen, Union City, CA, USA) and stored at -20℃ until later analysis.

Colostrum and milk samples were taken from functional mammary glands of each sow of treatments at 24 h and 21 d postpartum, respectively. After collection, samples were stored in a freezer (-20℃) until further analysis. Proximate analysis of colostrum and milk was conducted using Milkoscan FT 120 (FOSS Electric). The concentration of IgG and IgA of sow milk and piglet serum were also determined by ELISA assay as the manufacture's protocols (ELISA Accessory Package, Pig IgG and IgA ELISA Quantitation Kit; Bethyl, Texas, USA).

Statistical Analysis

The experimental data were analyzed using Student's *t*-test procedure of SAS (SAS Institute, 2004), and a main effect in the statistical model was gestation feeding frequency. For analyzing sow performance, litter performance and other collected data, individual sow and each litter were considered as an experimental unit. Probability values less than 0.05 ($P<0.05$) were considered as significant difference; $P<0.10$ were indicative of a trend; and values equal to or greater than 0.10 were considered as non-significant difference.

Results and Discussion

Sow Performance

The effects of feeding frequency on sow performance in gestation were presented in Table 1. Although sow BW at d 90 and d 110 of gestation were greater in OF treatment, significant differences between treatments were not found in BW, BF and BF changes of the sows. However, the BW gains from day 35 to 90 and from day 35 to 110 of gestation were significantly or numerically higher in OF than those of TF ($P<0.05$ and $P<0.10$, respectively).

These results conflict with previous study which sow BW and BF were significantly higher in TF treatment, regardless of gestation and lactation (Holt et al., 2006). Higher gestation BW gain of OF treatment in the present study can be explained by three possible reasons. One is the change of sow activity by feeding frequency. Cronin (1985) observed that high activity of gestating sow caused the rise in body heat and the consequential increase in energy utilization. According to the review of Noblet et al. (1990), standing posture in gestating sows could rise heat production by 180 kcal per 100 mins in gestation compared to lying posture. Bergeron and Gonyou (1997) reported that sows in the most active group showed the lowest gestation BW gain than other groups throughout their experiment (32.0 kg for the most active group; 45.7, 41.4 and 45.7 kg for the other groups). The second possible reason is the difference of water consumption between treatments. van der Peet-Schwering et al. (1997) demonstrated that sows with the lowest water consumption showed the highest BW gain, the lowest drinking frequency and the lowest drinking time during pregnancy. The authors explained that this was because the sows with the highest water consumption overconsumed water than their physiological needs. The last possibility is the difference in litter weight at farrowing between treatments, yet the impact on sow BW gain in gestation would not be strong. Consequently, it can be assumed that reduced activities and water consumption of the sows in OF caused positive influences on their own nutrient digestion and utilization. But, this hypothesis might be controversial because feeding frequency had little effect on the digestibility of gestating sow and young pig according to the previous studies of Sharma et al. (1973) and Holt et al. (2006).

Reproductive Performance

In lactation, BW, BW gain, BF and BF change of the sows were not affected by gestation feeding frequency ($P>0.10$, Table 2). The mean of sow BW at farrowing was higher in OF treatment. However, during lactation (day 0 to 21), sows in OF treatment showed higher BW loss, resulting in the slight difference in sow BW at day 21 of lactation between treatments (219.5 kg and 217.9 kg, respectively). However, ADFI in lactation and WEI did not differ significantly between treatments (Table 3). These results agreed with previous study of Holt et al. (2006). Furthermore, as shown by Wittman (1986) and Holt et al. (2006), Reproductive performances of lactating sows such as litter size, number of piglet, litter weight and piglet weight at 12 h and 21 d postpartum were not affected by gestation feeding frequency (Table 3). Only in litter weight at birth, the data was significantly higher in the treatment of OF ($P<0.05$).

BW gain and BF deposition of gestating sow can influence on the changes of BW and BF, and the feed intake in lactation (O'Grady et al., 1975; Dourmad, 1991; Revell et al., 1998; Young et al., 2004). Futhermore, if sow BW and BF at weaning are inappropriate, it can be negative effects on WEI and the following sow reproduction (King and Williams, 1984; Whittemore et al., 1988, Young et al., 1991; Hughes, 1993; Tantasuparuk et al., 2001; Clowes et al., 2003). In the present study, although BW at farrowing of OF treatment was higher than that of TF, BW and BF loss of OF sow during lactation were in the proper ranges of previous studies. Therefore, OF during gestation showed better reproductive performance than that of TF treatments, and this is also supported by lactation feed intake and WEI of the results of present study.

The significant difference in litter weight at birth between treatments considered to be caused by the difference in litter size which is determined in the early stage of gestation. Therefore, this result was not regarded as the effect of gestation feeding frequency like number of mummy and stillborn at farrowing.

Milk Composition and Immune Parameter

Feeding frequency in gestation had no influenced on colostrum and milk compositions of lactating sow including milk fat, protein, lactose, solid-not-fat and total solid ($P>0.10$, Table 4). The immune parameters were presented in Table 5. However, there were also no treatment effect on the concentrations of IgG in sow colostrum and piglet serum.

Although there is a lack of the study on the relationship between the feeding frequency of gestating sow and the immune status of their progeny, previous studies demonstrated that the prenatal stress during pregnancy, in severe cases, could affect the immune status of piglet in lactation. Haussmann et al. (2000) reported that when sows suffered from stress during the middle of gestation, their suckling piglets showed poor healing of the wound in lactation. Otten et al. (2001) also represented that the frequent restraints on sow in the later period of gestation resulted in increasing mortality and morbidity of her progeny in lactation. Tuchscherer et al. (2002) found that the sow stress during gestation caused a reduction in serum IgG concentration of neonatal piglet. These previous results demonstrated OF did not have negative influence on piglet immune system related to sow stress response in comparison to TF.

Sow Behaviors

The effect of gestating feeding frequency on behaviors of gestating sows during daytime (06:00-18:00) were shown in Figure

1. Although stereotypic behaviors showed a increasing trend regardless of treatment, significant difference between treatments were not observed during pregnancy. In contrast, when sows were fed once daily, numerically or significantly lower activities were detected at day 70 (P<0.10) and day 105 (P<0.05) of gestation. Furthermore, inactivities at day 70 and day 105 of gestation were also numerically higher in OF (P<0.10).

When gut fill and nutrient requirement of gestating sow are not satisfied with restrict feeding condition, stereotypic behaviors can be occurred (Lawrence and Terlouw, 1993; Whittaker et al., 1998). Robert et al. (1993) and Terlouw et al. (1993) reported that stereotypes in gestation were stimulated by feed intake and their peak were reached after meal. Robert et al. (2002) represented that gilts fed twice daily performed more activities including stereotypic behaviors before and after meal because the gilts were not induced complete satiation and feeding once daily made them have less expectation for the afternoon meal. Holt et al. (2006) also found that sows fed once daily meal showed lower activities (i.e., feeding, standing and stereotypes) throughout the day except around mealtime spent more time for activity. Also in the case of growing-finishing pig with restricted feeding condition, the pigs with greater feeding frequency showed more aggressive actions, less lying posture, longer belly-nosing time and even greater skin lesion score than those with lower feeding frequency (3 times daily versus 9 times daily; Hessel et al., 2006). In the present study, although stereotypes of sows did not differ significantly between treatments, OF treatment sows showed lower activities and higher inactivities during pregnancy, partially supporting previous research. Thus, it is thought that a once of larger meal per day would have positive effects on reducing activities and expectation of feeding in gestating sow.

Water Consumption

Water consumption was measured during the whole gestation period from initial day (d 35 of gestation) and was converted to average daily consumption. As a result, there were significant or numerical differences in average daily water consumption from day 35 to 70 of gestation ($P<0.05$), day 70 to 105 of gestation ($P=0.08$) and overall period of gestation ($P<0.05$) in the sows with once daily feeding (Table 6).

Rushen et al. (1984) demonstrated that sows with smaller size of meal tended to consume a lot of water to fulfill their stomach. Douglas et al. (1998) reported that water usage of sows was reduced by lengthening the interval between meals with higher feed level (one meal per day versus one meal per every third day). Robert et al. (2002) demonstrated that a reduction of water consumption was derived from less sow drinking behavior during non-meal period (afternoon) in OF treatment. These results supported that a larger meal with reduced meal frequency (i.e., one meal per day) could resulted in lower hunger and water consumption of pregnant sow.

Salivary Cortisol

Regardless of feeding frequency, the level of sow salivary cortisol immediately before morning meal were higher than two hours after meal, and the cortisol level tended to decrease as pregnancy progressed. However, there were no significant differences between treatments during gestation (Figure 2).

Farmer et al. (2002) demonstrated that OF did not reduce the cortisol level of sow after morning meal which indicated a excitation for feed, compared to that of TF. Similarly, Holt et al. (2006) reported that the salivary cortisol concentrations of sows were mostly not affected by feeding frequency and a declining trend of the hormone was shown as pregnancy progressed which is analogous to the result of present study.

Conclusion

This study demonstrated that OF under stall housing condition did not have negative influence on sow reproduction including litter and piglet performances. Besides, OF was more efficient to reduce sow activity and water consumption although stereotypic behaviors, salivary cortisol level and immune status were not improved, compared to TF. Therefore, it considered that these results would be related with higher body weight gain in gestation of the sow with OF, but more research into the effect of OF on nutrient digestion and utilization of sow is recommended. To summarize, it would be said that OF is more practical alternative for the swine farm, considering both saving of labour and sow welfare in gestation.

Table 1. The effect of feeding frequency on body weight and backfat thickness in gestating sows

Criteria	Treatment[1] OF	Treatment[1] TF	SEM[2]
No. Sows	10	10	-
Body weight, kg			
d 35	202.0	201.7	2.96
d 90	228.4	222.2	2.93
d 110	243.1	237.3	3.19
Body weight gains, kg			
d 35-90	26.4[a]	20.6[b]	1.23
d 90-110	14.6	15.1	0.74
d 35-110	41.1[c]	35.7[d]	1.45
Back-fat thickness, mm			
d 35	19.0	19.0	0.99
d 90	20.2	20.7	0.92
d 110	21.1	22.0	0.91
Back-fat changes, mm			
d 35-90	1.2	1.7	0.48
d 90-110	0.9	1.3	0.43
d 35-110	2.1	3.0	0.60

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

[a,b] Means with different superscripts in the same row significantly differ ($P<0.05$).

[c,d] Means with different superscripts in the same row numerically differ ($P<0.10$).

Table 2. The effect of feeding frequency during gestation on body weight, backfat thickness, ADFI and weaning to estrus interval in lactating sows

Criteria	Treatment[1]		SEM[2]
	OF	TF	
No. Sows	10	10	-
Body weight, kg			
12 h postpartum	220.2	215.3	2.66
d 21 of lactation	219.5	217.9	3.00
Body weight gain, kg			
d 0-21	-0.7	2.6	1.24
Back-fat thickness, mm			
12h postpartum	20.2	22.3	1.07
d 21	17.5	18.8	0.92
Back-fat changes, mm			
d 0-21	-2.7	-3.6	0.65
Average daily feed intake, kg/d			
d 0-7	5.98	5.81	0.120
d 8-14	6.76	6.88	0.157
d 15-21	7.01	6.75	0.175
Overall	6.58	6.48	0.098
Weaning to estrus interval, day			
	4.5	4.5	0.28

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

Table 3. The effect of gestation feeding frequency on litter size, litter weight and piglet weight in lactating sows

Criteria	Treatment[1] OF	TF	SEM[2]
No. Sows	10	10	-
Litter size, no. of piglets			
Total born	12.7	11.9	0.76
Stillborn	1.3	1.2	0.40
Mummy	0.0	0.0	0.00
Born alive	11.4	10.6	0.53
After-cross-fostering	10.8	10.8	0.14
death	0.3	0.4	0.13
weaning pigs	10.5	10.4	0.17
Litter weight, kg			
At birth	19.82[a]	17.34[b]	1.054
After-cross-fostering	17.34	17.29	0.653
d 21	71.08	70.08	1.653
Litter weight gain (d 0-21)	2.56	2.51	1.442
Piglet weight, kg			
At birth	1.58	1.53	0.071
After-cross-fostering	1.60	1.61	0.063
d 21	6.77	6.75	0.130
Piglet weight gain (d 0-21)	0.25	0.25	0.100

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

[a,b] Means with different superscripts in the same row significantly differ ($P<0.05$).

Table 4. The effect of gestation feeding frequency on milk composition of lactating sows

Criteria	Treatment[1]		SEM[2]
	OF	TF	
Fat, %			
Colostrum	6.78	6.77	0.567
Milk (d 21)	7.17	6.76	0.289
Lactose, %			
Colostrum	4.02	4.42	0.168
Milk (d 21)	5.82	5.95	0.074
Protein, %			
Colostrum	8.96	6.94	0.936
Milk (d 21)	4.80	4.59	0.107
Solid-not-fat, %			
Colostrum	13.43	11.84	0.785
Milk (d 21)	10.83	10.76	0.084
Total solid, %			
Colostrum	21.71	20.22	0.915
Milk (d 21)	19.26	18.65	0.362

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

Table 5. The effect of feeding frequency on immune parameters during lactation

Criteria	Treatment[1]		SEM[2]
	OF	TF	
IgG of colostrum, mg/ml			
12 h postpartum	0.35	0.26	0.032
Serum IgG of piglet, mg/ml			
12 h postpartum	0.93	1.00	0.151
21 d postpartum	0.63	0.57	0.030

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

Table 6. The effect of feeding frequency on water consumption in gestating sows

Criteria	Treatment[1]		SEM[2]
	OF	TF	
Average daily water consumption, L/day			
d 35 - 70 postcoitium	9.46[a]	12.44[b]	0.745
d 70 - 105 postcoitium	11.88[c]	14.81[d]	0.790
d 35 - 105 postcoitium	10.67[a]	13.62[b]	0.625

[1] OF: Once daily Feeding, TF: Twice daily Feeding.

[2] Standard error of means.

[a,b] Means with different superscripts in the same row significantly differ (P<0.05).

[c,d] Means with different superscripts in the same row numerically differ (P<0.10).

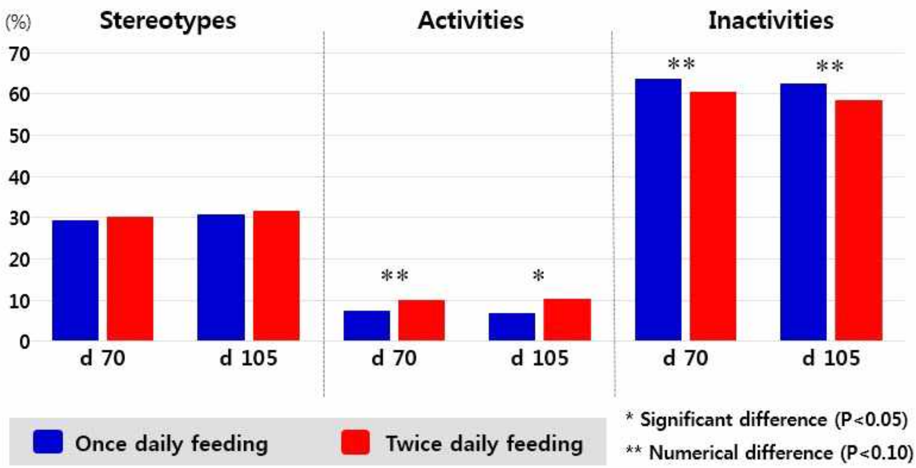

Figure 1. The effect of feeding frequency on sow activities during day time (12-h observation) of gestating sows (%)

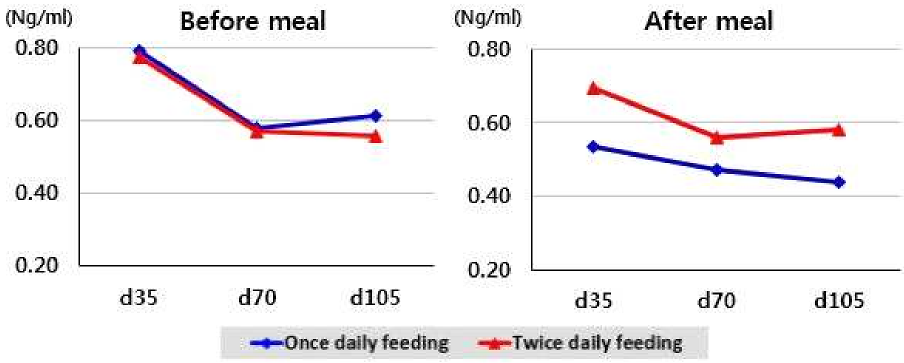

Figure 2. The effect of feeding frequency on salivary cortisol concentrations before and after morning meal of gestating sows (ng/ml)

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Ⅴ. Summary in Korean

최근, 집약화된 생산방식에서 기인한 가축 유행성질병과 환경 문제 등의 증가는 축산물 안전에 대한 소비자들의 우려와 동물복지, 그리고 가축 사양가들의 도덕적 책임을 가중시키고 있다. 따라서 축산농가는 이러한 기존의 사육방식에서 비롯되는 문제들을 개선하는 동시에 수익성까지 추구해야 하는 어려움에 처해 있다. 특히, 양돈산업에 있어서 임신기 모돈에게는 농장의 생산성에 영향을 미치는 다양한 변화가 일어나며, 적절한 번식성적을 위하여 일반적으로 두 가지 제한된 조건, 즉 제한급여와 스톨사양을 모돈에게 적용하고 있다. 하지만, 이러한 제한 조건들은 모돈의 활동성을 제한하고 공복감을 증가시키는 등 부정적인 문제들을 야기하기 때문에 소비자들의 우려를 증가시키고 있다. 따라서 본 실험은 스톨사양 하에서 임신기 모돈의 사료급여 횟수, 특히 일일 일회급여가 모돈의 스트레스 반응에 미치는 효과와 함께, 실제 모돈의 생산성과 어떠한 영향을 미치는지 규명하고자 수행하게 되었다.

실험에는 총 20두의 경산돈 (parity 2 및 3, Yorkshire × Landrace)을 일일 일회급여 처리구와 일일 이회급여 처리구에 각각 산차, 체중, 등지방 그리고 이유 후 재귀발정일 (WEI)을 고려하여 완전임의배치 (CRD) 하였다. 3산차 모돈에게는 2.4kg/일, 2산차 모돈에게는 2.2kg/일를 급여하였고, 포유기에는 무제한 급여를 실시하였다. 실험의 결과, 임신기 모돈의 체중, 등지방, 등지방의 변화는 처리구 간에 유의적인 차이를 보이지 않았지만, 일회급여한 모돈의 체중증가량이 임신 35-90일과 35-110일 구간에서 각각 유의적 ($P<0.05$), 혹은 수치적 ($P<0.10$)으로 높게 나타났다. 하지만, 포유기 모돈의 체중, 등지방, 사료섭취량, 그리고 WEI 모두 처리구 간의 유의적인 차이를 보이지 않았다. 포유기 초유와 상유의 성상, 그리고 초유 및 자돈 Serum

내 IgG 함량 모두 임신기 사료급여횟수에 영향을 받지 않았다. 임신기 모돈의 행동을 분석한 결과에서 사료급여횟수는 모돈의 이상행동 발생빈도에 영향을 주지 않았지만, 일회급여한 처리구에서 임신 105일에 유의적으로 낮은 활동성을 나타내었고 (P<0.05), 임신 70일과 105일에 수치적으로 낮은 비활동성을 나타내었다 (P<0.10). 임신기 물 소비량 역시, 사료급여횟수가 이회에서 일회로 감소함에 따라 임신 35-70일 구간 (P<0.05)과 임신 70-105일 구간 (P<0.10)에서 각각 유의적 혹은 수치적으로 낮은 수치를 나타내었고, 임신기 전체기간 (임신 35-105일) 동안에도 수치적으로 낮은 물소비량을 나타내었다 (P<0.10). 하지만, 임신 35일, 70일, 그리고 105일에 사료공급 전후에 채취한 타액 내 cortisol 수치는 처리구 간에 유의적인 차이를 나타내지 않았다. 실험의 결과, 임신기 일일 이회급여와 비교하여 일회급여는 모돈의 번식성적에 부정적인 영향을 주지 않았으며, 오히려 감소된 활동성과 물소비량을 통하여 일회급여가 모돈의 스트레스 완화에 긍정적으로 작용할 수 있음 확인할 수 있었다. 임신기 일회급여 처리구에서 나타난 더 높은 체중증가는 장기적으로 모돈의 연산성에 부정적으로 작용할 수 있을 것으로 사료되지만, 사료급여횟수에 의한 모돈의 영양소 소화와 이용에 관한 추가적인 연구가 필요할 것으로 사료된다. 실험의 결과를 종합하면, 임신기 일회급여를 실제 현장에 적용하였을 때, 모돈의 스트레스 완화를 통한 모돈 복지의 향상과 함께, 노동력 투입의 감소로 인한 생산비 절감 효과를 기대할 수 있을 것으로 사료된다.