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for the Degree of Doctor of Philosophy

Effect of Energy Levels and Sources on Physiological Responses and Reproductive Performance in Sows

사료 내 에너지 수준과 공급원이 모돈의 생리적 변화와 번식성적에 미치는 영향

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이 논문을 농학박사 학위논문으로 제출함

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Summary

The objectives of the three experiments were 1) to evaluate the effect of different dietary energy levels for gestating gilts on physiological responses, reproductive performance and growth of their progeny, 2) to investigate the effect of dietary energy levels on sow reproductivity and growth of their progeny over three consecutive parities and 3) to investigate the effects of *Tenebrio molitor* larva as a dietary energy source on reproductivity of sows and growth of their progeny.

Experiment 1. Effect of Dietary Energy Levels on Physiological Parameters and Reproductive Performance in Gestating Gilts

The experiment was to investigate the effects of dietary energy levels on the physiological parameters and reproductive performance of gestating first parity sows. A total of 52 F1 gilts (Yorkshire×Landrace) were allocated to 4 dietary treatments using a completely randomized design (CRD). Each treatment contained diets with 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg. Subsequently, the daily energy intake of gestating gilts in each treatment were 6,200, 6,400, 6,600 or 6,800 kcal of ME/kg, respectively. During gestation, the body weight ($p=0.04$) and weight gain ($p=0.01$) of gilts increased linearly with increasing dietary energy levels. Backfat thickness at d 110 of gestation was not affected by dietary treatments. There were no significant differences in litter size or litter birth weight. During lactation, the voluntary feed intake of sows tended ($p=0.08$) to decrease when the dietary energy levels were high during gestation. No difference was observed in the backfat thicknees of sows within treatments but higher energy treatment resulted in decreasing body weight of sows at d 21 of lactation ($p<0.05$) and body weight gain during lactation ($p<0.01$). The 3,400 kcal of ME/kg treatment showed the highest number of weaning piglets among treatments ($p<0.05$). The culling rate was higher

in 3,100 (38%) and 3,400 (15%) kcal of ME/kg treatments. No significant differences were observed in the chemical compositions of colostrum and milk. Consequently, the adequate energy intake for gestating gilts should be 6,400 or 6,600 kcal of ME/d.

Experiment 2. Effect of Dietary Energy Levels on Physiological Parameters and Reproductive Performance in Gestating Sows over Three Consecutive Parities

This experiment was to evaluate the effects of the dietary energy levels on the physiological parameters and reproductive performance during gestation over three parities in sows. A total of 52 F1 gilts (Yorkshire×Landrace) were allotted to one of four dietary treatments using a CRD. The treatments contained 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg diet but feed was provided at 2.0, 2.2 and 2.4kg/day in the first, second and third parity, respectively. Experimental diets and treatment of sows were not changed during the whole experiment period. The body weight and body weight gain during gestation increased as the dietary energy level increased ($p<0.05$, and $p<0.01$) in the first parity. In the second parity, the body weight of sows was the lowest ($p<0.05$) when 3,100 kcal of ME/kg treatment diet was provided. The body weight was higher as the dietary energy level increased ($p<0.05$) during the gestation period in the third parity. During lactation, the voluntary feed intake of lactating sows tended to decrease when gilts were fed higher energy treatment diet ($p=0.08$) and the body weight, body weight gain were increased by dietary energy level during gestation ($p<0.05$). Backfat thickness was not affected by dietary treatment during the gestation period in over three parity, interestingly backfat change from breeding to d 110 of gestation was higher as the dietary energy level increased at the first parity ($p<0.05$). When gilts were fed 3,400 kcal of ME/kg treatment diet, higher number of weaning piglet was observed in the first parity ($p<0.05$). The highest culling rate (69%) was seen when gestating sows were fed

3,100 kcal/kg ME treatment diet during three parities. No significant differences were observed in the chemical compositions of colostrum and milk. In conclusion, the adequate energy intake of gestating sows should be 6,400 or 6,600 kcal of ME/d, 7,040 or 7,260 kcal of ME/d, and 7,680 or 7,920 kcal of ME/d for parity 1, 2 and 3, respectively.

Experiment 3. Effect of *Tenebrio molitor* Larva as an Energy Source on Reproductivity of Sows and Growth of their Progeny

This experiment was conducted to evaluate the effect of *Tenebrio molitor* larva as a dietary energy source on reproductivity and growth performance of their progeny in lactating sows. A total of 25 F1 sows (Yorkshire×Landrace) were allotted to one of five dietary treatments using a CRD. Various levels of *Tenebrio molitor* larva were supplemented and treatments were 1) CON (tallow 2%), 2) F1 (tallow 3%), 3) F2 (tallow 4%), 4) L1 (tallow 2% + *Tenebrio molitor* larva 1%) and 5) L2 (tallow 2% + *Tenebrio molitor* larva 2%). The body weight, backfat thickness and weaning to estrus interval were not affected by dietary treatments. There were no differences in litter weight and litter weight gain in lactation period among dietary treatments. Lower blood urine nitrogen concentrations were observed in L2 treatment in sows ($p<0.01$). In nursing pigs, higher triglyceride ($p<0.01$) and very low density protein ($p<0.01$) were observed in L1 treatment. In alanine aminotransferase concentration, L1 treatment showed higher concentration than other treatments ($p<0.05$). Consequently, *Tenebrio molitor* larva is available energy source instead of tallow in lactating diet and addition of *Tenebrio molitor* larva as an energy source up to 2% in lactating sow diet did not show detrimental influences on sow’s performance and growth performance of their progeny.

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List of Abbreviations

ADFI	Average daily feed intake
AI	Artificial insemination
AST	Aspartate aminotransferase
ADG	Average daily gain
ALT	Alanine aminotransferase
BW	Body weight
BFC	Backfat change
BUN	Blood urine nitrogen
CRD	Completely randomized design
DE	Digestible energy
FI	Feed intake
FFA	Free fatty acid
HDL	High density lipoprotein
IgG	Immunoglobulin G
IgA	Immunoglobulin A
LDL	Low density liprotein
LCT	Lower critical temperature
MUFA	Monounsaturated fatty acid
ME	Metabolizable energy
NE	Net energy
PUFA	Polyunsaturated fatty acid
SFA	Saturated fatty acid
SEM	Standard error of the means
SNF	Solid not fat
VLDL	Very low density protein
WEI	Weaning to estrus interval

Chapter I. General Introduction

In general, feed cost, weaning pigs per sow per year (PSY) and longevity are the most important three factors in sow's productivity. Weaning pigs per sow per year in Korea was approximately 22.54 (Korea pork producers association, 2014), but this in Denmark was 29.6 (Agriculture and Horticulture Development Board, 2014). The reason of low productivity may be caused by application of dietary nutrirents and fram management technique without the verification in Korea environment.

Nutrient requirement is the most important factors because of immediately influenced the sows body condition, reproductive performance and feed cost, which from 70% costs in fram prodution. Sow productivity has developed incredibly during last decades due to the improvement of high genetic potential of modern sows. Gestation diets of the gilts and sows are of central importance to swine industry, because it is related closely to the reproductive productivity and longevity of the entire system. Sows must be carefully kept to provide adequate energy during gestation because of maintaining body maturation, growth of fetus and body reservation (Jang et al., 2014). However, previous results in supplementing more energy in the diet are still controversial. Almeida (2000) reported that high dietary energy level at ovulation period can increase ovulation rate and promote progesterone secretion to increase the fetal survival. There is sufficiency body weight and backfatthickness when fed higher energy during gerstation and increase the conception rate (Kongsted, 2005). Besides, Moehn (2011) suggested the need for parity-segregated phase feeding of pregnant sows. NRC (2012) also suggested that higher energy intake have positive affect on fetus growth and development, corresponding tissues (placenta, uterus and mammary tissue) and deposition of maternal lipid and protein. The energy requirement of the gestation gilt and sow should be between 6,678 and 8,182 kcal of ME/d, which is 1,650 kcal higher than its previous version (NRC, 1998). Therefor, adequate energy supply could be one of the nutritional methods for improving sow productivity.

The properties of animal fats are related to their source and quality and their qualities are determined by fatty acid composition, hardness, color, stability and so on (Sharma et al., 2013). Dietary insect called *Tenebrio molitor* larva has been used as feed ingredients as an energy source, because the nutritional values of *Tenebrio molitor* larva contains high fat level in dry matter (Ravzanaadii et al., 2012). Some studies had reported *Tenebrio molitor* larva had high degree of fat up to 32.7%, which used as an energy source with high digestibility (Ramos-Elorduy et al., 2002). Huang (2006) reported *Tenebrio molitor* larva contains high level of oleic and linoleic acid in total un-saturated fatty acid content and the amount of un-saturated fatty acids had high ratio to 72% in total fatty acid composition. Some researchers reported that *Tenebrio molitor* larva is used to alternative protein source in pig and poultry feed (Ramos-Elordoy et al., 2002; Deng et al., 2008; Chen et al., 2012). However, litter information was known to be used *Tenebrio molitor* larva as fat source in sow diet.

Concenquently, for increasing sow productivity and decreasing production cost, three experiments were 1) to evaluated the effect of different energy levels for gestating gilts on physiological response, reproductive performance and growth of their progeny, 2) to investigate the effect of energy levels on sow reproductivity and growth of their progeny of sows over three consecutive parities and 3) to investigate the effects of *Tenebrio molitor* larva as an energy source on reproductivity of sows and growth of their progeny.

Chapter II. Review of Literatures

1. Saving feed cost and improving productivity

1.1. General approaches

1.1.1 Nutrient requirement

Many researches had been conducted to examin the nutrition requirement, maxium reproductive performance and growth rate in animal to save the feed cost. Nutrition was a material that should be provided from outside to keep animals. The purpose of nutrient supply is to maxium genetic potential providing all suitable necessary nutrirent in feed. Also, physiological feature of animal and nutrition demand across stages of growth should be considered. Diets containing excess level of nutrients could increase the feed cost, also have negative effcts on animal production, such as icrease toxicants substance, harmful bacterial formation, environmental pollution (Porter and Kenworthy, 1969; Ball and Aherne,1987; Hobbs et al., 1996). Sow productivity has advanced at an incredible rate in the past decades because of high-producing genetic sows. However, little information had been conducted to evaluate the requirement of some nutrients despite of genetic changes. Therefore, the experiments to evaluate the requirements of some nutrients and ingredients of feed by treatments in order to improve sow productivity and decrease feed cost.

1.1.2 Feed ingredients

Corn and soybean meal is the most widely used ingredients in the swine feed industry in Korea (Feed association of Korea, 2012). So many researches were conducted to find new feed ingredients with cheaper price, steady supply and have similar growth performance for pig industry. Rapseed meal (RSM), palm kernel meal (PKM) and copra meal (CM) have been widely used as feed ingredients in South Korea. But those ingredients include high fiber, low palatability and some anti-nutritional factors such as glucosinolates (Gls) and erucic acid, mannan, galactomannan, xylan and arabinoxylan (Thorne et al., 1990; Dale, 1997). PKM and CM include the mannan which is non-starch polysaccharides (NSP), mainly composed of manose, and lack of several essential amino acids (Thorne et al., 1989). The NSP is mainly composed of pure mannan and galactomannan, but lack of enzyme in mono-gastric animals to deconposition these nutrients (Dale, 1997). So ß-mannanase must be added as an enzyme when PKM and CM used in feed formulate of pigs (Sundu et al., 2006). The erucic acid has reduces growth rate, digestibility (Food Standards Australia New Zealand, 2003) in RSM and Gls hydrolysis products are mainly toxic because of products such as thiocyanates, oxazolidinethiones which have negative affects on swine production (European Food Safety Authority, 2008; Quiniou et al ., 2012). So it is very imporotant to controlling the anti-nutritional and supplementation levels. Recently some other competitive feed ingredients have been used in pig diets such as cassava residue, wheat and rice.

1.1.3 Management techniques

Pig management techniques are very important in pig productivity and directly affect profit of fram. Many management techniques have been carried out on pig productivity. There was various feeding method in gestation period used in Korea for improving the sow productivity. Rduced feed intake in early gestation will increase embryo survival (Dyck et al., 1980) and the mammary gland was develop between 75 to 90 d, therefore, cell numbers of mammary gland decreased when increase feed intake in this period and decreased milk production in subsequent lactation period (Weldon et al., 1991). During late gestation (90-110 d), increased feed intake could be increased fetus growth and piglet birth weight (NRC, 1998). However, our previous studies suggested that flat feeding in getation period did not affect litter size, litter weight and litter growth, aslo increased longevity due to decreased culling rate (Piao et al., 2010).

In Korea the utilization rate of artificial insemination was more than 98% and the most important in sow's productivity (Kim et al., 2005). The duration of estrus interval was 48~72 h and ovalution at 30~40 h after set to the estrus (Bartol et al., 2008). Ovalution time have a relation with WEI and duration of estrus will decrease as WEI increase (Knox and Rodriguez-Zas, 2001). Kemp and Soede (1996) reported that there was the highest conception rate in sows when insemination at 24h before ovalution. So if could be exactly catch the beginning of estrus and ovalution time in fram, a lot of expense could be saved by incermination less times.

1.1.4 Effect of enviroment

Feeding environments will immediately influce the swine productivity such as tempreture, floor space and lighting.

At a higher temperature than the optimal range, ADG decreases primarily as a result of the severe decline in feed intake (Massabie et al., 1997). The exposure to high ambient temperatures has negative effects on pig performance, especially in lactating sows, could decrease the voluntary feed intake and increase the body weight and back fat loss (Prunier et al., 1997). In the finishing pigs and lactating sows, it is important to decrease heat stress in high ambient temperatures by increased evaporative heat loss or manipulation of diet to unhold performance.

In recent decades, pigs generally have been breeding from weaning to market weight in groups of 10 to 50 animals. Now, however, group sizes of 50 to 100 or even more are being advocated as a management strategy to minimize housing cost, maximize housing use, and improve overall profitability. But, confinement floor space can reduce piglet growth (Hyun et al., 1998; 2005), increase plasma cortisol (Arnone and Dantzer, 1980) and decrease immunity (McGlone and Curtis, 1985). Space allocation for maximizing growth performance and immune response of weaning pigs until 15 kg BW is between 0.30 and 0.43 m^2/pig (Oh et al., 2010) and 0.6, 0.9 m^2/pig in growing, finishing pigs respectly in South Korea (Livestock Research Institute of Korea, 2002).

Photoperiods could affect the reproductive performance of sow, because it can affect the LH secretion, promote ovarian and uterine growth in gilts (Surmubin et al., 1970; Ntunde, 1979b). Ntunde (1979b) reported that gilts photoperiods of 9 h in daily or greater daily will have positive effct to attain the puberty. There had heavier uterine and ovarian weights when gilts exposed to photoperiods of 12-14 h of light from 3.5 to 9.0 mo of age than exposed to 8 h of light (Surmuhin et al. 1970). Terefore, the aforementioned results indicted the intensity of light cycle could stimulate the hormonal secretion, and subsequently affect the reproductivity.

1.2 Nutritional approaches for sows

1.2.1 Energy

Sow productivity has developed extensively in recent decades due to the improvement of the high genetic potential in modern sows. Efforts to meet the nutrient requirements of high-producing sows have been undertaken by supplementing nutrients to support both the normal reproductivity and body maturement (Boyd et al., 2000). High energy level could increase the body weight and backfat thickness in gestation period but decrease the feed intake during lactation (Long et al., 2010). Low feed intake during lactation could result in higher BW loss and subsequently lead to several common reproductive problems, such as an increased WEI (Reese et al., 1982; Kirkwood and Thaeker, 1988; Baidoo et al., 1992), increased anestrus incidence after weaning, and decreased conception rate (Kirkwood and Thacker, 1988). However, high dietary energy levels during the ovulation period can increase the ovulation rate and promote progesterone secretion to increase fetal survival (Almeida et al., 2000). Kongsted (2005) demonstrated that higher energy intake during gestation may increase the conception rate and reduce the culling rate due to sufficient body weight gain and backfat deposition. Recently, NRC (2012) suggested that higher energy intake have positive affect on the fetus development and growth, corresponding tissues (placenta, uterus and mammary tissue) and deposition of maternal lipids and proteins. The energy requirement of gestating gilts and sows should be between 6,678 and 8,182 kcal of ME/d, which is 1,650 kcal higher than previous recommendations (NRC, 1998).

More research is needed to understand the precise energy requirements of gestating gilts and sows in domestic environment for determine the optimal dietary energy level for reproductive performance and decreased feed cost.

1.2.2 Protein

Modern prolific sow have leaner but less fat and large litter size (NRC, 2012). Reproductive performance immediately influenced by protein and amino acids in sows (Kim et al., 2009). High protein supply could be increased BW, milk production at farrowing and improved the reproductive performance in lactation period (Belstra et al., 1998; Mahan, 1998; Kusina et al., 1999b). Previous research reported that decresed birth weight, litter weight gain, milk production and increased the body weight loss when protein intake was insufficient in sows (Schoknecht et al., 1993; Manhan, 1977; Manhan and Grifo, 1975). Sow body reserves increased as dietary protein level increased during gestation period and improved litter growth but not have difference in litter size and birth weight (Jang et al., 2014). Sows fed higher levels of protein in gestation (16 vs. 13%) could be decreased the backfat thickness with parity, but litter performance is similar (Mahan, 1998). Jang (2014) reported that more than 13% protein could be maximize the piglet growth in geatating gilts. Kusina et al., (1995) reported that enhanced CP (lysine 16 g/day) improved milk production and litter weight gain in primiparous sow.

1.2.3 Lipid

Dietary fat is considered as the lipid component of the diet. Most fat used in swine diets will be made with either vegetable oils or fats from animal species such as poultry fat and tallow.

Emphasis on sow nutrition is the greatest interest in the use of fat in swine diets. Fat feeding in late gestation and lactation could affect the fat level in colostrum and milk (Seerley et al., 1974; Pettigrew, 1981). Moreover, the study reported that by supplying fat to sows before farrowing could be increase piglets survival (Drochner, 1989), as well as increase in piglet weight gain (Tilton et al., 1999). Energy intake during gestation which can either increase energy density (added fat) or simply intake is generally related with reduced intake during lactation (Weldon et al., 1994). Increased sow weight loss and days to estrus happens while reduced energy intake is given during lactation. Contrarily, fat feeding during laction is related with three things such as reduced sow body weight, backfat losses and decreased the WEI (Pettigrew and Moser, 1991). High nutrient density could not be improved the (Coffey et al., 1994; Dove and Haydon, 1994) survival rates when considering the effect of increased lactation diet nutrient density. Recent work shows that an increase in carcass fat of the pigs can be explained by weaning pigs weight from sows which fed fat during gestation (Tilton et al., 1999).

1.2.4 Feed intake

There are various feeding method usually used in gestating sows, because of maximum litter size and body condition (Boyd et al., 2000; Trottier and Johnston, 2001). Rduced feed intake in early gestation will increase embryo survival (Dyck et al., 1980) and the mammary gland was developed between 75 to 90 d, so increasing feed intake in this period could decreased cell numbers of mammary gland and decreased milk production in lactation period (Weldon et al., 1991). During late gestation (90-110 d), increased feed intake could increase fetus growth and piglet birth weight (NRC, 1998). However, there was not have positive effects by increasing feed intake at last 25 days of gestation on born litter weight and piglet weight (Ju et al., 2010). Also, flat feeding in getation period did not affect litter size, litter weight and litter growth (Piao et al., 2010). Previous researches also reported that feed intake decreased during lactation when increased body weight at farrowing (Dourmad, 1991; Xue et al; 1997; Revell et al., 1998; Young et al., 2004) and concequently several common reproductive problems, such as increased WEI (Reese et al., 1982; Kirkwood and Thaeker, 1988; Baidoo et al., 1992), an increased anoestrus after weaning, and decreased conception rate (Kirkwood and Thacker, 1988). Therefore, it is very important to supply the nutrirent sufficient for the best body condition and reproductive of sows, but nutrient provide during gestation could be influenced the pergormance of lactation and subsequent flowing parity.

1.2.5 Feed additives

There are many feed additives used in diets such as probiotics, oligosaccharides and enzymes and theses additives were increased because of the ban of antoboitics in South Korea. The probiotic is refered to a microorganism which have positive affects on the host animal by improving the microbial balance of intestinal, body condition and reproductive performance in sows (Stamati et al., 2006; Kim et al., 2008; Maxwell et al., 2003). Many previous studies reported the effects of yeast in sows such as improve body condition, increase liiter weight, and piglet survival rate (Kim et al., 2008). However, Zhang et al. (2011) reported that the yeast supplementation not have effect on sows body condition, litter size, and litter weight, but could be decreased the WEI and increased the IgG concentration of colostrum.

Mannan-oligosaccharide (MOS) is the one type of oligosaccharides and play a role in gastrointestinal tract (GI) tract and supplying MOS can alter the microbial flora and modulate immufunction in swine (Davis et al., 2004). Supply the MOS in sow diets could increase the IgG, IgA, and IgM concentrations in colostrum (O'Quinn et al., 2001) and Newman and Newman (2001) demonstraded that IgM concentration was increased but not IgG and IgA. Funderburg (2002) reported that adding MOS could be decrased the WEI and improved the piglet weight gain (Pettigrew et al., 2005).

Soybean meal were mainly used in swine diets, but price of these are highly increase in recently and containing a lot of anti-nutritional which pigs do not fully utilize due to lack of secretion of enzymes (Ji and Kim, 2004). So increase nutrients utilization is an indirectly method to decrease feed cost. In lactation period supply carbohydrase can decrease the BW loss and WEI (Ji and Kim, 2004). Supply the multi-enzyme which derived from *Aspergills nige* to feed restriction sows could reduced the feed cost and have higher litter performance than ad libitum sows without muti-enzyme during lactation (Lee et al., 2010). Concenquently, feed additives positively affect the in nutrients utilization and improved sows productivity.

2. Energy levels in gestating sows

2.1 Dietray energy levels in gestation period

Energy is required for the maintenance, growth and development of the conceptus (fetus and maternal tissue). The conceptus development takes firstly, then develop the expense of maternal tissue when deficiency of nutrirents (Walach-Janiak et al., 1986). During gestation period, the maternal bodyweight of sows should be gained 25 kg per parity over three or four parities (Aherne and Kirkwood., 1985). Beyer et al. (1986) also suggested that total weight gain of the uterus, uterine fluids, products of conception, and mammary tissue was 22.8 kg and was not affected by energy level or parity.Body weight was increased when sows were consumed high dietary energy in gestation period (Averette Gatlin et al., 2002) and attributed to the high dietary energy in gestation period could be increased backfat thickness (BFT) (Long et al., 2010), but fed high energy in gestation period decresed feed intake in lactation (Young et al., 1989). Negative effect was often observed duing following parity after lactation when loss the accumulated nutrition in the boday severely (Clowes et al., 1998; 2003) , such as increased WEI (Baidoo et al., 1992) and decreased reproductive performance (Kirwood and Thacker, 1998). The number of fetuses 60 days after mating tend to be increased in the sows fed the high energy intake (Cox et al., 1987), but litter size in primiparous sows was not affected by feed intake of lactation (25 MJ/d ME or ad libitum), also weaning to breeding (19.3 or 50.1 MJ/d ME) (King and Williams, 1984). The embryos number and litter size was not affected by fed high energy level at mating after 3 days or instantly after mating (Toplis et al., 1983; Sbrensen, 1994; Sbrensen and Thorup, 2003). Increased energy intake during late gestation can positively affect fetal growth (NRC, 2012). However, Long et al. (2010) demonstrated that the average piglet body weight at farrowing was not affected by different energy levels in gestation diet. The total lipis and lactose content were increased when sows with fat supply in late gestation (Heo et al., 2008). However, there was no difference in clostrum composition when energy level increased from 13.7 to 14.2 MJ of ME/kg in gestation diet (Yang et al., 2008), Which is also the same in terms of chemical composition of colostrum and milk during gestation because sow could mobilize their body reserves to compensate the deficient nutrients (Willams et al., 1985).

2.2 Energy requirements of gestating sows

Eenergy system was well developed from TDN (NRC, 1971) to ME, NE for determining the energy requirements of swine. ME system have been used frequently last several decades in research. Net energy (NE) is the subtract heat increment (HI) form ME and HI is not utilizing for productive, however in cold environments can be utilized for maintain body temperature (NRC, 1998). Animals use net energy for maintenance (NEm) and production (NEp) (NRC, 1998).

Rencently, progressing recerch of NE system in laboratory, also the portion of feed companies already used in swine diets due to decreased saved energy value, protein content and decreased pollution souce. NE usually inference form DE and ME. NRC (2012) reported that energy requirements of gestating sows was 2,518 kcal/kg NE and 3,300 kcal/kg ME, which is 35 kcal/kg ME higher than previous recommendations (NRC, 1998). There were few recerch to determine the NE requirement. Despite insufficient recent information, it is still available on the nutrient content, total tract nutrient digestibility coefficients or empirical energy values for many ingredients in the current feed database (NRC, 2012). Therefore, priorities should be decided to assemble the chemical composition of feedstuffs determining availability of nutrients. This will be used to measure their NE content and subsequent validation with growth performance and body composition indexes which will be estimated from ideal and total tract energy and nutrient digestibility, and development of standardized or reference procedures (NRC, 2012). Birkett and Lange (2001) reported that measured heat production can be varied due to limited experiment environment and challenges quantifying fasting heat production.

Further study is needed to demonstrate the inference the prediction equations of NE system.

2.3 Effect of dietary energy levels on BW and BFT

During gestation period, the maternal body weight of sows should be gained 25 kg per parity over three or four parities (Aherne and Kirkwood., 1985). In gestation period for a total 45 kg of weight gain by the sow, 20 kg is the weight of the placenta and other products of conception out of the total weight (Verstegen et al., 1987). The reproductive frequency was decreased when backfat thickness of sows below 14 mm and have negatively affect on ovulation rate and reproductive performance in following parity (Young et al., 1990; Tantasuparuk et al., 2001). Protein and fat accumulation in the body during gestation for mik production and body condition in sows have a relation with body weight and backfat thickness. Boday protein affects a lot in reproductive performance (Sinclair et al., 1998) and N retention was increased by high energy level (Walach-Janiack et al., 1986; King and Brown, 1993).

Sow productivity has been developed extensively in recent decades due to the improvement of the high genetic potential and less fat but more lean tissues in modern sows. The body weight was increased when sows consumed high dietary energy in gestation period (Averette Gatlin et al., 2002). This result may be attributed to the high dietary energy in gestation period could be increased backfat thickness (BFT) (Long et al., 2010), but feeding too much feed (energy) in gestation period reduced the voluntary feed intake, increased body weight and backfat loss in lactation (Young et al., 1990). Also providing high energy feed during gestation showed increased body weight and backfat thickness (BFT) loss in lactation period (Long et al., 2010). There was negative effect following parity after lactation when loss the accumulated nutrition in the body severely (Clowes et al., 1998; 2003). Yang et al. (1989) reported that loss the body fat severely would has negative affect in following parity. Thus, energy level in gestating sows should be controlled for adequate body reserves and subsequent lactation period.

2.4 Effect of dietary energy levels on reproductive performance

The litter size and piglet birth weight are very important to improved sow productivity. The numbers of fetuses 60 days after mating tend to be increased in sows fed the high energy intake (Cox et al., 1987). There was no treatment effect on number of embryos or embryo survival when increasing the energy intake from moderate (28 MJ ME/d) to high (37 MJ ME/d) during early gestation (Prunier et al., 1999). The embryos number and litter size was not affected by fed high energy level at mating after 3 days or instantly after mating (Toplis et al., 1983; Sbrensen, 1994; Sbrensen and Thorup, 2003). King and Williams (1984) reported litter size in primiparous sows was not affected by feed intake of lactation (25 MJ/d ME or *ad libitum*).

There are many of scientific results assessing the effects of increased feed intake or energy intake in gestation sows on piglet birth weight (NRC, 1998). Increased energy intake during late gestation can positively affect fetal growth (NRC, 2012). However, Long et al. (2010) demonstrated that the average piglet body weight at farrowing was not affected by different energy levels in gestation diet. Also, increased feed intake in gestation period did not increase litter weight or individual piglet weight (Piao et al., 2010). Concenquently, more precisive recerch need to determine the relation between the litter size, piglet birth weight and energy level.

2.5 Effects of dietary energy levels on sow colostrum and progeny

Sows colostrum composition and milk yield were manily factors affecting the litter performance. The main affect of colostrum is to provide the piglet with energy and passive immunity (Le Dividich et al., 2005). Colostrum is a rich source of high nutrients digestibility and relation to the survival of the new born piglets (Pigsite, 2008). The chemical composition of colostrums and milk of sows is variable due to the dietary regimens (Jackson et al., 1995) and body condition of sows (Klaver et al., 1981). Yang et al. (2008) reported that there was no change in colostrum composition when energy level increased from 13.7 to 14.2 MJ of ME/kg in the gestation diet. Willams et al. (1985) confirmed that the chemical composition of colostrum and milk was not affected by dietary energy levels in gestation period because sows mobilized their body reserves to compensate the deficient nutrients. The fatty acid composition of colostrum is affected by the dietary fat level (Christon et al., 1999) and type of fat provided in dietary (King' ori, 2012). Passive immunity of colostrum immunoglobulins by piglets plays an important role in their life (Corino et al., 2009) and greater colostrum intake of immunoglobulins may increase the immune function. There was no difference in colostrum yield with diffrernces litter size, litter birth weight (Quensel, 2011). Addition of fat in sow diets during late gestation or lactation could be increased the milk production, but addition fat to sows before farrowing not affect the survival of piglets, piglet weight gain and body loss of the sows duting lactation (Drochner, 1989; Tilton et al., 1999; Kornblum et al., 1991). Thus, it's very important of the sow's clostrum and milk on survival, immunity and growth performance of piglets.

2.6 Effects of dietary energy levels on sow longevity

Sow longevity is one of the most important indicators in sow productivity and immediately influence the profitability of the farm. Many fators can influence the sow longevity, such as nutrient and management technique. The culling rate of sows completing three parity tend to be lower in both the lowest (3.0 Mcal ME/d) and the highest (7.5 Mcal ME/d) energy levels during gestation (Frobish et al., 1973). Low energy intake during gestation period may increased culling rate (Kongsted, 2004) and the rate of return to estrus after weaning tended to be lower in sows , which restricted during gestation although voluntary feed intake was increased in lactation (Dourmad, 1991). Young et al. (1990) observed that fewer sows completed three parities when intake the lowest energy (22 MJ ME.d) level in gestation period. Thus, too high or low energy level could be decreased the sows longevity and much importance to supply the suitable energy level during gestation for longevity.

3. Effect of *Tenebrio molitor* larva in lactation sows

3.1 General characteristics of *Tenebrio molitor*

Tenebrio molitor is a species of insect, darking beetle. In world, many countries used *Tenebrio molitor* to replace other protein sources for human and animal food. In physiology, *Tenebrio molitor* has four life stages including egg, larva, pupa and adult. Generally, *Tenebrio molitor* as a protein source is used in animal feed because of its high protein. *Tenebrio molitor* has many advantages including high nutritional value, survival rate, growing fast and anti disease ability (Veldkainp et al., 2012). These can bring more profits to human and animal feed as a sustainable low cost protein source.

3.2 Nutritional values of *Tenebrio molitor*

Tenebrio molitor as an alternative animal protein source has high level of protein and the range of protein may be from 18% to 65% in dry matter basis (Table 1). *Tenebrio molitor* larva has a lower level of protein compared with adult, but contained the lowest crude fiber than other types of *Tenebrio molitor* larva. Also, it has a highest fat content than adult and excreta (Table 1). So, larva can be used as protein source as same using as energy source.

Table 1. Percentage nutritional composition of *Tenebrio molitor* larva, Adult, Exuvium and Excreta

Items	Larva	Adult	Exuvium	Excreta
Proximal analysis				
Crude protein	46.44	63.34	32.87	18.51
Crude fat	32.70	7.59	3.59	1.30
Crude fiber	4.58	19.96	25.96	13.66
Crude ash	2.86	3.56	3.22	7.29
Moisture	5.33	3.54	13.02	12.20

Sources: Nergui Ravzanaadii, 2012

3.2.1 Protein and amino acid

Protein quality depends on balance of amino acid, especially the contents of essential animal acid like lysine and methionine and total amino acid compositions. *Tenebrio molitor* as alternative protein source has high level of protein and it is also a good source to supply lysine and other amino acid (Ravzanaadii et al., 2012). *Tenebrio molitor* larva and adult have higher lysine in amino acid composition than other types (Table 2). In diet formulation, this advantage in high lysine can reduce the supplementation of artificial-lysine. In corn-soybean meal basis diet, lysine was the first limited essential amino acid (Kerr et al., 1993). *Tenebrio molitor* larva has many types of amino acids and excellent amino acid composition (Table 2). FAO (2001) reported that there are two conditions to estimate high-quality protein source, one was essential amino acid was accounted for 40% of total amino acid and another one was essential amino acid was occupied 60% of non-essential amino acid (Pellett and Yong, 1980). Defoliart (1992) gave the report, who said using insects as protein source had low content of methionine in diet formulation. So using *Tenebrio molitor* larva in swine feed should pay more attention to its limiting amino acids. In summary, *Tenebrio molitor* has been used as an alternative protein source and could be supplemented in swine diet.

Table 2. Amino acid content of *Tenebrio molitor* larva, Adult, Exuvium and Excreta

Amino acid	Larva[1]	Adult[1]	Exuvium[1]	Excreta[1]	Larva[2]
Isoleucine	3.556	3.918	1.90	0.330	2.6
Leucine	3.405	5.165	1.981	0.368	4.6
Lysine	2.906	2.227	1.009	0.193	1.6
Cysteine+Methionine	1.189	1.134	0.426	0.251	1.6
Phenylalanine +Tyrosine	5.219	3.173	3.016	0.366	7.5
Threonine	1.807	2.153	1.124	0.276	2.7
Valine	2.439	3.368	2.423	0.253	3.8
Histidine	1.527	1.71	1.236	0.438	2.1

Sources: [1]NerguiRavzanaadii,2012;[2]E.D.Aguilar-Miranda,2002.

3.2.2 Fat

Tenebrio molitor could be used as an energy source has high content of fat in dry matter basis. Ramos-Eloruy et al. (2002) reported energy value was higher than the house fly (554 kcal) more to 252kcal in *Tenebrio molitor* (806 kcal). Fatty acid composition was relative to fat digestibility (Freeman et al., 1968; Stahly, 1984). Braude and Newport (1973) reported the availability of fatty acid had an interaction with main carbon length and shorter chain fatty acid has more digestibility than long chain fatty acid. The optimal U: S ratio was 5.71, value of which maximized fat digestibility in weaning pigs (Powles, et al., 1994). According to these factors are relative to fat digestion, *Tenebrio molitor* has higher composition in the degree of un-saturated fatty acid and optimal unsaturated: saturated fatty acid (Table 3). *Tenebrio molitor* contains high content of palmitic acid in total saturated fatty acid composition (Table 3). Also, *Tenebrio molitor* also has high level in oleic acid and linoleic acid (Table 3). Linoleic acid was an essential limited fatty acid which can not be synthesized by itself, so it should be supplied from the diet (Cunnane, 1984). In animal body, linoleic acid can decrease cholesterol concentration and increase high density lipoprotein content (Huang et al., 1984).

In some insects, linolenic and linoleic acids which are essential fatty acids were even higher than their contents of fish and poultry (Defoliart, 19922).

Table 3. Fatty acid composition of *Tenebrio molitor* larva pupa and adult

Component	*Tenebrio molitor*[1]			Larva[2]
	Larva[1]	Pupa[1]	Adult[1]	
Myristic acid	4.87	5.15	2.22	4.60
Palmitic acid	17.13	18.28	18.83	16.40
Palmitoleic acid	2.54	2.21	1.55	2.98
Stearic acid	1.92	2.43	4.67	2.46

Oleic acid	43.85	43.74	40.03	42.19
Linoleic acid	25.31	24.10	27.63	28.92
Linolenic acid	0.68	0.56	0.56	1.13
Saturated fatty acids	23.92	25.86	25.72	23.46
Un-saturated fatty acids	72.38	70.61	69.77	75.22
U/S	3.03	2.73	2.71	3.21

Sources: [1]Huang,2010,[2]Dai,2009.

3.2.3 Other nutritional values

The studies about vitamins was to show and the mineral composition of *Tenebrio molitor* was published (Huang et al., 2006). The exuvium and excreta had higher levels in Ca and K compared with larva and adult (Table 4). Ca is the most normal mineral in the body relative very important to the growth of bone. Exuvium and excreta as the wastes also are used in animal food. *Tenebrio molitor* larva contained low level of Ca, but high level of P and contents of many minerals in mealworm were increased as increasing age (Table 2).

Table 4. Mineral composition of *Tenebrio molitor* larva, adult and exuvium, and excreta (mg of mineral/kg of sample)

Criteria	Larva	Adult	Exuvium	Excreta
Mineral				
Calcium (Ca)	432.59	484.39	801.14	1,537.97
Phosphorus (P)	7,060.7	8,087.07	5,252.29	14,552.01
Potassium (K)	9,479.73	10,459.8	14,725.66	21,171.75
Iron (Fe)	66.87	78.71	55.86	127.75
Natrium (Na)	3,644.84	4,302.73	6,343.16	3,954.33
Magnesium (Mg)	2,026.88	1,932	1,388.09	7,135.14
Zinc (Zn)	104.28	108.98	265.18	101.31

Copper (Cu)	13.27	18.01	10.04	10.73

Sources: Nergui Ravzanaadii, 2012

3.3 *Tenebrio molitor* larva as feed ingredients in swine diets

Generally, addition of insects as protein source pays more attention to poultry diet and little informations about *Tenebrio molitor* larve were found in swine diets. For poultry nutrition, maggots always were used in poultry. Teguia and Mpoame (2002) reported fish meal can be replaced by maggot and decrease the cost of feed. This meaned the nutrition value of insect was available as same as fish meal. Replacing fish meal up to 25% maggot meal used, performance was improved and increased protein digestibility (Awonyi et al., 2003). Hwangbo et al. (2009) reported that improve the performance in broiler chickers fed diet containing 10 to 15% maggots. The result also indicated increased body weight, feed intake, and feed efficiency when addition *Tenebrio molitor* meal in broiler (Shen et al., 2006). Ramos-Elorduy et al. (2002) demonstraded that using *Tenebrio molitor* to replace fish meal in pig diet was available. Newton et al. (1977) reported that larva meal had similar digestibility of crude protein and higher fat digestibility for the larva meal compared to soybean meal in growing pigs, because black soldier fly had ideal composition of fatty acid which easy to digest and utilize. In summary, *Tenebrio molitor* larva could be considered available as protein and energy source for replacing other expensive protein and fat sources.

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Chapter III. Effect of Dietary Energy Levels on the Physiological Parameters and Reproductive Performance of Gestating Gilts

ABSTRACT: The experiment was to investigate the effects of dietary energy levels on the physiological parameters and reproductive performance of gestating first parity sows. A total of 52 F1 gilts (Yorkshire×Landrace) were allocated to 4 dietary treatments using a completely randomized design (CRD). Each treatment contained diets with 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg. Subsequently, the daily energy intake of gestating gilts in each treatment were 6,200, 6,400, 6,600 or 6,800 kcal of ME/kg, respectively. During gestation, the body weight (p=0.04) and weight gain (p=0.01) of gilts increased linearly with increasing dietary energy levels. Backfat thickness at d 110 of gestation was not affected by dietary treatments. There were no significant differences in litter size or litter birth weight. During lactation, the voluntary feed intake of sows tended (p=0.08) to decrease when the dietary energy levels were high during gestation. No difference was observed in the backfat thicknees of sows within treatments but higher energy treatment resulted in decreasing body weight of sows at d 21 of lactation (p<0.05) and body weight gain during lactation (p<0.01). The 3,400 kcal of ME/kg treatment showed the highest number of weaning piglets among treatments (p<0.05). The culling rate was higher in 3,100 (38%) and 3,400 (15%) kcal of ME/kg treatments. No significant differences were observed in the chemical compositions of colostrum and milk. Consequently, the adequate energy intake for gestating gilts should be 6,400 or 6,600 kcal of ME/d.

Key words: Energy Level, Gilts, Body Weight, Backfat Thickness, Reproductive performance.

Intoduction

Sow productivity has developed extensively in recent decades due to the improvement of the high genetic potential in modern sows. According to the Canadian Centre for Swine Improvement (2015), the average litter size is 14.00 in modern sows, mainly due to the increased sow productivity. Efforts to meet the nutrient requirements of high-producing sows have been undertaken by supplementing nutrients to support both the normal reproductivity and body maturement (Boyd et al., 2000). Primiparous sows are particularly sensitive to energy intake during gestation, as they are still growing and utilizing ingested nutrients to support body maturation, growth of the fetus and body maintenance (Jang et al., 2014). However, previous research in energy supplementation in the diet is still controversial. Almeida et al. (2000) reported that high dietary energy level in the ovulation period can increase the ovulation rate and promote progesterone secretion to increase fetal survival. In addition, Kongsted (2005) demonstrated that higher energy intake in gestation period may reduce the culling rate because of the enough body weight gain and backfat deposition. Recently, NRC (2012) suggested that higher energy intake have positive affects on the fetus development and growth, corresponding tissues (placenta, uterus and mammary tissue) and deposition of maternal lipids and proteins. The energy requirement of gestating gilts and sows should be between 6,678 and 8,182 kcal of ME/d, which is 1,650 kcal higher than previous recommendations (NRC, 1998). However, more research is needed to understand the precise energy requirements of gestating gilts.

Thus, the purpose of present study is to determine the optimal dietary energy level for reproductive performance in high-producing modern sows.

Materials and method

Animal preparation

A total of 52 gilts (Large White x Landrace) that were, on average, 150 d old and weighed approximately 85 kg were selected and housed in an 11×14 m barn. Sows were provided feed and water *ad libitum* until reaching 120 kg of body weight and then moved to individual gestation stall cages with concrete slatted floors (0.64×2.40 m). Diets were fed individually, twice daily with 800 g each time for an ADG of 750 g/d. Gilts were mated at an average body weight of of 135.82 ± 0.85 kg after three or four estrus cycles. Semen (Darby AI center, ChungJu, Korea) collected from 88 boars (Duroc) in the same batch was provided for the artificial insemination (AI) of gilts.

Experimental design and animal management

A total of 52 crossbred gilts (large White x Landrace) averaging 240 days of age with a body weight of 135.82 ± 0.85 kg were allotted to 4 dietary treatments by body weight and backfat thickness in a completely random design (CRD) with 13 replicates. Experimental diets for gestating gilts were formulated to contain 13.08% crude protein, 0.86% lysine, 0.90% calcium and 0.70% phosphorus, with energy contents of 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg, respectively. Feed was provided at 2.0 kg/d for all treatments. Lactating diets contained 3,265 kcal ME/kg, 17.07% crude protein, 1.26% lysine, 0.90% calcium and 0.70% phosphorus, respectively (Table 1). All other nutrients were formulated to meet or exceed the NRC requirements (2012). Gilts were housed in temperature-controlled rooms and placed in an individual crate (2.4×0.65 m) with a concrete floor until d 110 of gestation. After d 110 of gestation, gilts were washed and moved into farrowing crates (2.4×1.8 m). During the lactation period, all sows were fed the same commercial lactation diet. After farrowing, the lactation diet was increased gradually from 1.0 kg/d until 5 d postpartum and then provided *ad libitum* during the lactation period. Weaning was performed at approximately 21 d.

Measurements and analysis

The body weight and backfat thickness at the P2 position of sows were measured. Body length was measured from the center of both ears to the tail with a measuring tape. Blood samples were collected at breeding, 110 days of gestation, 24 h post-farrowing and 21 days of lactation from sows. The number of total born, piglets born alive, still born, and mummified fetuses as well as the piglet body weight were recorded. The fat and protein mass of primiparous sows were calculated using the equations of Dourmad et al. (1997).

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

Fat (kg)= $-26.4+0.221\times$(EBW, kg)$+1.331\times$(Backfat, mm)

Protein (kg)= $2.28+0.178\times$(EBW, kg)$+0.333\times$(Backfat, mm)

Blood samples were collected from the jugular vein of sows with tubes (serum and EDTA tube) and centrifuged immediately at 3,000 rpm at 4℃, and then, samples were stored at -20℃ until later analysis. Colostrum and milk were collected from the first and second teats at 24 h and 21 d postpartum after an intravascular injection of 5 IU oxytocin (Komi oxytocin inj. Komipharm International Co., Ltd., Siheung, Korea) in the ear. All samples were stored at -20℃ until analysis. Proximate analysis of colostrum and milk samples was conducted using a Milkoscan FT 120 (FOSS Electric, Sungnam, Korea). The glucose and BUN concentrations were analyzed using a kinetic UV assay (Glucose Hexokinase Kit; UREA/BUN Kit, Roche, Mannheim, Germany). Plasma free fatty acid (FFA) concentrations were determined according to the colorimetric Acyl-CoA synthetase Acyl-CoA oxidase (ACS-ACOD) method (Shimizu et al., 1979) using a commercial kit (Wako FFA c

Kit; Wako chemical, Osaka Japan). The fatty acid content in colostrum was analyzed on a Agilent 7890 Gas Liquid Chromatograph (Agilent Technologies, Palo Alto, CA, USA) equipped with a flame ionization detector and a SP-2560 (i.d. 100 m x 0.25 mm x 0.20㎛) film column. Nitrogen was used as carrier gas, injector core temperature was 250℃, detector temperature was 260℃and column temperature was programmed to begin at 170℃ and then increase to 250℃ remained at 240℃ for 40 min. Chromatography was calibrated with a mixture of 37 different fatty acids (FAME 37; Supelco Inc., Bellefonte, PA, USA) and this standard containing fatty acids ranging from C4:0 to C24:1n9 and samples were added 250µl of internal standard spike solution (Pentadecanoic acid; Sigma) by the method of AOAC (1990). Colostrum samples were centrifuged at 105,000 x g at 4℃ for 1 hour and the supernatant was separated and kept frozen until colostrum IgG and IgA analysis. Colostrum IgG and IgA concentrations were determined using ELISA according to the manufacture's protocols (Elisa Starter Accessory Package, pig IgG ELISA Quantification Kit, pig IgA ELISA Quantification kit; Bethyl, Texas, USA).

Statistical analysis

Data were analyzed by ANOVA with a completely randomized design using the GLM procedure implemented in SAS (SAS Institute, 2004). The least squares means were calculated for each independent variable. Orthogonal polynomial contrasts were used to determine the linear and quadratic effects by increasing the dietary energy levels in gestation for all measurements of sows and piglets. Individual sows and their litters were used as the experimental unit. The alpha level used for the determination of significance for all analyses was 0.05 and for the determination of trends was $p>0.05$ and $p<0.10$.

Results

The effects of the energy level on body weight and backfat thickness are presented in (Table 2). Body weight and body weight gain in gestation increased as the dietary energy level increased (linear, $p<0.05$). Back fat thickness was not affected by dietary treatments during the gestation period, but back fat gain from breeding to 110 d of gestation increased linearly ($p<0.05$) as the dietary energy level increased. Body length was not affected by dietary treatments. During the lactation period, the body weight and body weight gain of sows decreased as energy levels increased (linear, $p<0.05$), but backfat thickness was not affected by treatments. Consequently, the body weight change of gilts from mating to 3 weeks of lactation tended to decrease as energy levels increased (linear, $p=0.06$). During the lactation period, the voluntary feed intake of sows tended to decrease (linear, $p=0.08$) when dietary energy levels increased (Table 2). The weaning to estrus interval (WEI) was not significantly affected by treatments, but the culling rates of sows were highest in the 3,100 kcal/kg ME treatment (Table 2). The estimated protein and fat masses of gilts were calculated based on the body weight and backfat thickness (Dourmad et al., 1997). The protein mass and fat mass increased as energy levels increased (linear, $p<0.01$, and $p<0.05$, respectively) during the gestation period (Table 3). During the lactation period, the protein mass and fat mass decreased (linear and quadratic, $p<0.01$, and $p<0.05$, respectively), while the dietary energy level increased (Table 3). There were no significant differences in the total number of pigs born per litter or litter birth weight (Table 4). There were also no significant differences in the fat, protein, lactose, or solid-not-fat (SNF) content of colostrum and milk (Table 5).There was no significant difference in the fatty acid content of colostrum due to dietary energy levels (Table 6). The BUN concentration in the serum of gilts tended to be increase with dietary energy level at d 110 of gestation and 24 h postpartum (linear, $p=0.06$, and $p=0.07$, respectively) (Table 7). The glucose concentrations tended to increase with dietary energy level (linear, $p=0.07$) at 24 h postpartum, but the free fatty acid concentration was not affected (Table 7). There were no significant differences in the concentration of IgG or IgA in colostrum (Table 8).

Discussion

In the current study, increasing energy intake led to a higher body weight (BW) and body weight gain from 42.5 to 50.46 kg, which agreed with the results of Noblet et al. (1990), who observed an increased body weight of gilts during gestation with higher energy intake. This observation may be attributed to the higher backfat thickness (BFT) due to the high dietary energy during gestation (Long et al., 2010). In the present study, although gilts consumed an equal amount of amino acids, fat tissue and protein tissue was increased during gestation, but decreased during lactation, which implies that the energy supply should be considered as important factor to maintain adequate body weight and back fat thickness for subsequent reproductive cycles. These results are in agreement with previous studies, which demonstrated that increased feed intake during gestation increased sow body weight loss during subsequent lactation (Piao et al., 2010). Moreover, Long et al. (2010) demonstrated that providing high-energy feed during gestation increased BW and BFT loss in the lactation period. The BFT loss during lactation was observed in the highest energy level treatment, which may be attributed to reduced feed intake during lactation due to higher dietary energy levels in gestation.

In this study, WEI was not affected by treatments and the culling rate was highest in the 3,100 kcal/kg ME treatments. Previous studies reported that decrease feed intake in lactation period when increased body weight at farrowing (Xue et al., 1997). Low feed intake during lactation could result in higher BW loss and subsequently lead to several common reproductive problems, such as an increased WEI interval (Baidoo et al., 1992), increased anestrus incidence after weaning, and decreased conception rate (Kirkwood and Thacker, 1988). Although feed intake decreased and body weight loss increased during lactation with increasing energy levels during gestation, high dietary energy levels did not increase the culling rate in the first parity. However, treatment with 3,100 kcal of ME/kg showed the highest culling rate (38%) due to pregnancy failure and post-weaning anestrus, which suggests that low energy intake during gestation may increase the culling rate (Kongsted, 2005). The pregnancy rate and post-weaning anestrus may be correlated with some hormones and the dietary energy levels differentially affect the release of some reproductive hormones (Kemp et al., 1995). Whitley et al. (2002) reported that insulin targets during reproduction had little connection to nutrition, the body condition and other management factors. These results indicated that dietary energy levels during pregnancy for optimal longevity are not easy to establish. Further study is needed to clearly demonstrate a possible correlation between dietary energy levels during gestation and reproductive hormones. WEI is delayed by low plasma insulin concentrations during lactation, and the concentration is increased by glucose but lowered by FFA concentrations in the plasma of weaning sows (Armstrong et al., 1986). In this study, the plasma glucose and FFA concentrations of sows at weaning were not affected by treatments, indicating that dietary energy levels did not affect WEI.

NRC (2012) suggested dietary energy levels for 140 kg BW gilts during gestation between 6,678 kcal of ME/kg to 7,932 kcal of ME/kg daily. However, our results suggested that litter size was not affected by increasing dietary energy, which may be considered to be a balance between gestation preparation and early gestation. High energy levels had positive effects on the ovulatory rate, but high energy levels might decrease embryonic survival after breeding (Jindal et al., 1996), while low energy supplies from day 3 after mating until day 15 do not affect embryo survival.

There are many of scientific studies assessing the effects of increased feed or energy intake in gestating sows on piglet birth weight (NRC, 1998). Daily energy requirements during gestation include maintenance for the sow maternal gain as well as uterine growth. Increased energy intake during late gestation can positively affect fetal growth (NRC, 2012). In this experiment, there was no treatment effect on litter birth weight and individual piglet birth weight, which is consistent with the results from Long et al. (2010), who demonstrated that the average piglet body weight at farrowing was not affected by energy levels in gestation diets. Increased feed intake during gestation also did not increase the litter weight or individual piglet weight (Piao et al., 2010). This result demonstrates that increased feed intake during gestation could increase body weight gain and backfat thickness in gestating gilts. However, increased body weight and backfat did not increase litter weight or individual piglet weight.

Yang et al. (2008) reported that there was no change in colostrum composition when the energy levels increased from 13.7 to 14.2 MJ of ME/kg during gestation. Our study suggests that there were no significant differences in the chemical composition (fat, protein, lactose and SNF) of sow colostrum and milk, which is consistent with the results from Willams et al. (1985), who confirmed that the chemical composition of colostrum and milk was not affected by dietary energy levels during gestation because sows mobilized their internal reserves to compensate for deficient nutrients. In the present study, the composition of fatty acids in colostrum did not show any changes due to the dietary energy level of the gestation diets. The fatty acid composition of colostrum is affected by dietary fat levels (Christon et al., 1999). Several studies have investigated how the composition of fatty acids in colostrum is affected by energy levels in gestation diets, and the mechanism is not yet clearly understood. In this experiment, the composition of fatty acids did not show any changes due to the different treatments, but the differences in energy levels among treatments simply may not have been high enough to affect the composition of fatty acids in colostrum.

It is well known that BUN is related to nitrogen retention in the body (Whang and Easter, 2000). In the present study, the BUN concentration in serum tended to decrease with the increasing energy level at 110 days of gestation and 24 hours post-farrowing. Ruiz et al. (1971) reported that the BUN concentration was higher in swine fed low-energy diets compared to pigs fed high-energy diets, which may suggest that energy intake in sows is affected by protein metabolism during gestation. The glucose concentration influences insulin secretion (Quesnel and Prunier, 1998) and the oxidation of FFA for the energy production is decreased by insulin (Gamble and Cook, 1985). The glucose concentration increased with higher energy levels 24 hours post-farrowing in the current study, whereas free fatty acids were not affected by treatments. Xue et al. (1997) demonstrated that increased energy levels during gestation could decrease glucose utilization and subsequently decrease feed intake during lactation. Piao et al. (2010) also suggested that increased feed intake in gestating gilts may cause sows to become insensitive to insulin, thereby exhibiting a smaller response in glucose clearance and decreased feed intake during lactation. Therefore, insulin influenced metabolites of glucose, feed intake and body condition of sows during lactation, which may explain our result that BW and BFT decreased with energy levels during lactation.

A greater intake of immunoglobulins in colostrum may increase immune function in nursing pigs. Some previous research reported that polyunsaturated fatty acids (PUFAs) can influence production of immunoglobulins in mammals. Mitre et al. (2005) reported that supply of shark-liver oil to sows form d 80 of gestation to farrowing could be increased IgG concentrations in the colostrum, but not IgA. Mateo et al. (2009) reported that sows supply fish product could be increased the IgG content in the colostrum and milk. Thus, dietary omega-3 and omega-6 fatty acids are positively affect the immmunity.

In the present study, the concentrations IgG and IgA in colostrum was not affected by the tallow in gilt diets, which has lower PUFA than other energy source.

Implications

NRC (2012) suggested that the energy requirement of the gestation gilt should be between 6,678 and 7,932 kcal of ME/d. Similarly, our results suggested that 3,100 kcal of ME/kg is not enough to maintain the reproductive performance for gilts during gestation with 2 kg feed daily. The treatment 3,400 kcal of ME/kg have higher weaning piglets, but bodyweight and backfat loss were higher than other treatments during lactation. Consequently, the adequate daily energy intake of gestating gilts should be 6,400 or 6,600 kcal of ME.

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Table 1. Formula and chemical composition of gestating and lactating diets (%)

Criteria	Gestating diets				Lactating diets
	ME 3,100 kcal/kg	ME 3,200 kcal/kg	ME 3,300 kcal/kg	ME 3,400 kcal/kg	
Ingredients (%)					
Corn	56.59	54.56	52.53	50.50	67.51
Soybean meal (46% CP)	10.09	10.44	10.78	11.12	25.57
Tallow	0.45	2.13	3.82	5.50	-
Soy oil	-	-	-	-	1.30
Barley	25.00	25.00	25.00	25.00	-
Rapeseed meal	3.60	3.60	3.60	3.60	-
L-Lysine-HCl	0.41	0.40	0.40	0.40	0.60
DL-Methionine	0.04	0.04	0.04	0.04	-
Dicalcium phosphate	2.36	2.39	2.41	2.43	2.30
Limestone	0.86	0.84	0.82	0.81	0.85
Vit. Mix[1]	0.10	0.10	0.10	0.10	0.20
Min. Mix[2]	0.10	0.10	0.10	0.10	0.10
Salt	0.25	0.25	0.25	0.25	0.42
Choline chloride-50	0.15	0.15	0.15	0.15	0.15
Chemical compositions [3] (%)					
ME (kcal/kg)	3,100	3,200	3,300	3,400	3,265
CP	13.08	13.08	13.08	13.08	17.07
Lys	0.86	0.86	0.86	0.86	1.26
Met	0.23	0.23	0.23	0.23	0.25
Ca	0.90	0.90	0.90	0.90	0.90
Total P	0.70	0.70	0.70	0.70	0.70

[1] Provided per kg of diet: Vit. A, 10,000 IU; Vit. D3, 1,500 IU; Vit. E, 35 IU; Vit. K3., 3 mg; $VitB_2$, 4 mg; $VitB_6$, 3 mg; $VitB_{12}$, 15 µg; Pantothenic acid, 10 mg; Biotin, 50 µg; Niacin, 20 mg; Folic acid 500 µg.

[2] Provided per kg of diet: Fe, 75 mg; Mn, 20 mg; Zn, 30 mg; Cu, 55 mg; Se 100 µg; I, 250 µg; Co, 250 µg.

[3] Calculated value.

Table 2. Effects of the dietary energy levels on the body weight, back-fat, body length, feed

intake and WEI of primiparous gestating and lactating sows

Criteria	**Treatment**				**SEM[2]**	**P-value**	
	3,100[1]	**3,200**	**3,300**	**3,400**		**Linear**	**Quadratic**
Gestation							
No. of Sows	13	13	13	13			
Body weight, kg							
Breeding[3]	136.00	135.95	135.68	135.35	0.85	0.64	0.96
d 110	178.50	182.18	182.59	185.81	1.42	0.04	0.74
Breeding-110day (change)	42.50[b]	46.22[ab]	46.91[ab]	50.46[a]	1.08	0.01	0.69
Backfat thickness, mm							
Breeding	19.32	19.18	18.55	19.08	0.56	0.90	0.55
d 110	20.72	21.27	20.45	23.08	0.70	0.22	0.26
Breeding-110day (change)	1.40	2.09	1.91	4.00	0.43	0.05	0.32
Body length, cm							
Breeding	113.90	115.00	114.17	113.62	0.56	0.31	0.40
d 110	121.55	122.18	120.96	121.96	0.58	0.83	0.80
Breeding-110day (change)	7.65	7.18	6.79	8.35	0.53	0.51	0.33
Lactation							
Body weight, kg							
24 hr postfarrowing	164.72	165.68	162.08	169.00	1.28	0.53	0.26
Weaning	174.11[a]	173.45[a]	168.88[b]	167.27[b]	1.55	0.03	0.70
Postfarrowing-21 d (gain)	9.39[a]	7.77[a]	6.79[a]	-1.73[b]	1.24	0.01	0.10
Breeding-21d postpartum (gain)	39.72	37.50	33.79	31.92	1.31	0.06	0.90
Backfat thickness, mm							
24 hr postfarrowing	21.06	20.32	20.83	21.77	0.64	0.57	0.49
Weaning	18.94	18.73	19.37	18.27	0.57	0.87	0.77
0-21d (gain)	-2.12	-1.59	-1.46	-3.5	0.35	0.19	0.08
Breeding -21d (gain)	0.56	-0.45	0.66	-0.81	0.47	0.91	0.72
Average feed intake(kg/d)	5.99	5.77	5.79	5.32	0.11	0.08	0.16
Weaning to estrus interval	5.29	5.27	5.17	5.67	0.18	0.99	0.20
Culling rate (%)	38	7	7	15	–	–	–

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[3] Breeding day.
[a, b] Means with different superscripts indicate significant differences ($p<0.05$).

Table 3. Effects of the dietary energy level on the estimated protein, fat mass and its gain of primiparous gestating and lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Estimated protein mass[4] in gestation(kg)							
Breeding[3]	31.57	31.90	31.59	31.76	0.27	0.93	0.95
d 110	39.80[b]	40.50[ab]	40.54[ab]	41.72[a]	0.39	0.04	0.41
Breeeding-110day(gain)	8.23[b]	8.60[ab]	8.95[ab]	9.95[a]	0.30	0.01	0.31
Estimated protein mass in lactation(kg)							
24 hr postpartum	37.44	37.36	36.91	38.40	0.36	0.47	0.28
d 21	38.34	38.16	37.59	36.95	0.40	0.16	0.70
0-21day(gain)	0.90[b]	0.80[b]	0.67[b]	-1.46[a]	0.28	0.01	0.03
Breeeding-21day(gain)	6.76	6.26	5.99	5.19	0.41	0.23	0.71
Estimated fat mass[5] in gestation(kg)							
Breeding	26.94	27.98	27.16	27.71	0.82	0.88	0.94
d 110	39.45	40.57	40.71	43.74	1.08	0.09	0.39
Breeeding-110day(gain)	12.51	12.59	13.56	16.03	0.80	0.03	0.26
Estimated fat mass in lactation(kg)							
24 hr postpartum	36.58	35.79	35.72	38.43	0.99	0.51	0.38
d 21	35.75	35.32	35.21	33.40	0.97	0.44	0.73
0-21day(gain)	–0.83[b]	–0.47[b]	–0.51[b]	–5.03[a]	0.62	0.02	0.03
Breeding-21d (gain)	8.81	7.35	8.05	5.70	1.12	0.48	0.75

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[3] Breeding day.
[4]Prediction equation from Dourmad et al. (1997): 2.28+0.178 × (EWB, kg) + 0.333 × (Backfat, mm).
[5]Prediction equation from Dourmad et al. (1997):-26.4+0.221 × (EWB, kg) + 1.331 × (Backfat, mm).
[a, b] Means with different superscripts indicate significant differences ($p<0.05$).

Table 4. Effects of the dietary energy level on the reproductive performance and growth of progeny of primiparous sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Reproductive performance (No. of piglet)							
Total born	12.11	13.00	12.33	12.00	0.33	0.36	0.66
Born alive	11.44	12.27	11.75	11.54	0.33	0.42	0.76
Stillbirth	0.67	0.73	0.58	0.46	0.08	0.61	0.56
After cross-fostering	11.33	11.18	11.25	11.62	0.24	0.65	0.31
Weaning pigs	11.00[ab]	10.27[b]	10.58[ab]	11.31[a]	0.24	0.66	0.02
Litter weight on lactation (kg)							
Litter birth weight	14.47	16.03	15.42	15.29	0.44	1.00	0.62
After cross-fostering	14.29	14.30	14.40	14.59	0.43	0.85	0.77
Weaning litter weight	58.16	56.82	57.49	63.55	1.36	0.31	0.19
Piglet weight on lactation (kg)							
Piglet birth weight	1.19	1.25	1.25	1.30	0.03	0.23	0.96
After cross-fostering	1.26	1.28	1.27	1.26	0.03	0.94	0.82
Weaning piglet weight	5.35	5.56	5.47	5.64	0.09	0.10	0.60

[1] Energy intake ME kcal/ kg.
[2] Standard error of mean.
[a,b]Means with different superscripts indicate significant differences ($p<0.05$).

Table 5. Effects of the dietary energy level in gestating sows on the components of colostrum and milk in primiparous lactating sows.

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Chemical composition of colostrum at 24 h postpartum (%)							
Fat	6.44	7.40	7.33	7.67	0.36	0.69	0.24
Protein	8.26	8.15	7.62	7.30	0.34	0.10	0.47
Lactose	4.15	4.04	4.21	4.31	0.07	0.12	0.22
Solids-not-fat	12.79	12.55	12.25	11.96	0.27	0.11	0.56
Chemical composition of sow milk at 21d postpartum (%)							
Fat	5.56	7.01	6.58	6.86	0.21	0.10	0.06
Protein	4.19	4.58	4.66	4.52	0.07	0.20	0.08
Lactose	6.08	5.93	5.85	5.81	0.06	0.12	0.41
Solids-not-fat	10.50	10.64	10.72	10.50	0.05	0.91	0.13

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[a,b]Means with different superscripts indicate significant differences ($p<0.05$).

Table 6. Effects of dietary energy level in gestating sows on fatty acid compositions of colostrum of sow

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Fatty acid composition at colostrum[3](mg/g)							
Saturated	11.11	13.28	13.49	9.14	1.36	0.63	0.23
Monounsaturated	15.07	18.43	20.97	13.77	2.15	0.95	0.25
Polyunsaturated	6.93	7.85	8.91	5.46	0.80	0.65	0.20

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[3] 24 hours postfarrowing.

Table 7. Effects of the dietary energy level on the blood urine nitrogen, glucose and free fatty acid concentrations in the primiparous sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
BUN (mg/dL)							
Breeding[3]	10.60	10.60	10.60	10.60	-	-	-
d 110	9.06	8.72	7.08	7.82	0.37	0.07	0.39
24 hr postpartum	11.68	10.48	9.06	9.50	0.59	0.06	0.36
Weaning	20.76	19.70	17.12	18.68	0.83	0.24	0.44
Glucose (mg/dL)							
Breeding	76.20	76.20	76.20	76.20	-	-	-
d 110	74.00	81.60	69.80	73.00	2.56	0.39	0.57
24 hr postpartum	87.50	88.40	89.25	95.20	1.77	0.07	0.37
Weaning	82.50	82.00	81.40	82.80	3.37	0.99	0.90
Free fatty acid (μEq/L)							
Breeding	140.60	140.60	140.60	140.60	-	-	-
d 110	145.20	146.00	189.40	183.20	12.10	0.22	0.90
24 hr postpartum	257.60	211.00	232.20	292.60	21.03	0.56	0.27
Weaning	182.20	158.00	171.40	170.20	12.81	0.86	0.69

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[3] Breeding day.
[a,b]Means with different superscripts significant difference ($p<0.05$).

Table 8. Effects of the dietary energy level in gestating sows on immune parameters of colostrum[3] in primiparous lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
mg/ml							
IgG	5.44	5.58	5.36	4.95	0.60	0.81	0.86
IgA	5.58	4.03	5.46	5.25	0.67	0.94	0.58

[1] Energy intake ME kcal/kg.
[2] Standard error of mean.
[3]24 hours postpartum.

Chapter IV. Effect of Dietary Energy Level on the Physiological Parameters and Reproductive Performance of Gestating Sows over Three Consecutive Parities

A B S T R A C T: This experiment was to evaluate the effects of the dietary energy levels on the physiological parameters and reproductive performance during gestation over three parities in sows. A total of 52 F1 gilts (Yorkshire×Landrace) were allotted to one of four dietary treatments using a CRD. The treatments contained 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg diet but feed was provided at 2.0, 2.2 and 2.4kg/day in the first, second and third parity, respectively. Experimental diets and treatment of sows were not changed during the whole experiment period. The body weight and body weight gain during gestation increased as the dietary energy level increased ($p<0.05$, and $p<0.01$) in the first parity. In the second parity, the body weight of sows was the lowest ($p<0.05$) when 3,100 kcal of ME/kg treatment diet was provided. The body weight was higher as the dietary energy level increased ($p<0.05$) during the gestation period in the third parity. During lactation, the voluntary feed intake of lactating sows tended to decrease when gilts were fed higher energy treatment diet ($p=0.08$) and the body weight, body weight gain were increased by dietary energy level during gestation ($p<0.05$). Backfat thickness was not affected by dietary treatment during the gestation period in over three parity, interestingly backfat change from breeding to d 110 of gestation was higher as the dietary energy level increased at the first parity ($p<0.05$). When gilts were fed 3,400 kcal of ME/kg treatment diet, higher number of weaning piglet was observed in the first parity ($p<0.05$). The highest culling rate (69%) was seen when gestating sows were fed 3,100 kcal/kg ME treatment diet during three parities. No significant differences were observed in the chemical compositions of colostrum and milk. In conclusion, the adequate energy intake of gestating sows should be 6,400 or 6,600 kcal of ME/d, 7,040 or 7,260 kcal of ME/d, and 7,680 or 7,920 kcal of ME/d for parity 1, 2 and 3, respectively.

Key words: Energy Level, Sow, Body Weight, Bakfat Thickness, Reproductive Performance, Culling Rate.

Introduction

Gestation diets for gilts and sows are of central importance to the swine industry because of their importance to reproductive productivity and longevity of the entire system. Jang et al. (2014) also indicated that the energy intake during gestation should be limited to control body weight gain and maintain an appropriate body condition, especially, in sows from the first to third parity, which requires adequate energy consumption during gestation for the maintenance of body maturation, the growth of the fetus and body preservation. With the development of the genetic potential, many studies were performed to evaluate the nutrient requirement for modern sows. Trottier and Johnson (2001) insisted that restricting feed intake after maturation as well as the establishment of a regular estrus cycle may be necessary to prevent gilts from becoming too fat before breeding. Long et al. (2010) stated that the provision of high energy feed during gestation caused increased body weight and a backfat thickness loss during lactation. Moreover, the model developed by NRC (2012) suggested that the energy requirement of the gestating gilt and sow should be between 6,678 and 8,182 kcal of ME/d. However, data on the development of the energy level during gestation and its effect on successive parities of gestating sows are lacking.

Therefore, the objective of the study was to evaluate the optimum dietary energy level that produced the best physiological parameters and reproductive performance in high-producing modern sows over three consecutive parities.

Materials and methods

Animal preparation

A total of 52 gilts (Large White×Landrace) of weighing approximately 85 kg were selected and housed in an 11×14 m barn. The sows were provided feed and water *ad libitum* until 120 kg of body weight was reached and were then moved to an individual gestation stall cage with a concrete slatted floors (0.64×2.40 m). The sows were fed 800g of an individual diet, twice daily for an ADG of 750 g/d. Gilts were mated at an average body weight of 135.82 ± 0.85 kg after three or four estrus cycles. Estrus was diagnosed twice daily in the presence of a mature boar, using the backfat pressure test. Gilts and weaning sows were artificially inseminated (AI) with fresh diluted semen (Darby A.I. center, Chungju-si, Chungcheongbuk-do, Korea Republic) twice at a 12 h interval. Pregnancy of gilts and sows were diagnosed by an ultrasound analyzer (Easyscan, Dong-jin BLS Co., Ltd., Gwangju-si, Gyeonggi-do, Korea Republic) on days 30 and 60 after mating.

Experimental design and animal management

A total of 52 crossbred gilts (large White×Landrace) with 135.82 ± 0.85 kg body weight were allotted to 4 dietary treatments by body weight and backfat thickness in a CRD with 13 replicates. Experimental diets and treatment of sows were not changed in the whole experiment period. Experimental diets for gestating gilts and sows were formulated to contain 13.08% crude protein, 0.86% lysine, 0.90% calcium and 0.70% phosphorus, with an energy content of 3,100, 3,200, 3,300 or 3,400 kcal of ME/kg and diets were provided daily at 2.0 kg/day for the 1st parity, 2.2 kg/day for the 2nd parity, 2.4 kg/day for the 3rd parity and 3 kg from weaning to estrus. Lactation diets contained 3,265 kcal ME/kg, 17.07% CP, 1.26% lysine, 0.90% calcium and 0.70% phosphorus (Table 1). All other nutrients were formulated to meet or exceed the NRC requirements (2012). Gilts and sows were housed in temperature-controlled rooms and placed in an individual crate (2.4×0.65 m) with a concrete floor until 110 d of gestation. After 110 d of gestation, pregnant gilts and sows were washed and moved into farrowing crates (2.4×1.8 m). During lactation, all sows were fed the same commercial lactation diet. After farrowing, the lactation diet was increased gradually from 1.0 kg/d until 5 d postpartum and then provided ad libitum during lactation. Weaning was at approximately 21 d and sows returned to stall cage again for the next reproductive cycle. Gilts and sows were deleted from the experiment for reproductive problems and lameness.

Measurements and analysis

The body weight and backfat thickness at the P2 position of the sows were measured. Blood samples were collected at breeding, 110 days of gestation, 24 h post-farrowing and 21 days of lactation from sows. The number of total piglets born, piglets born alive, still born, and mummified fetuses as well as the piglet body weight were recorded. The fat and protein mass of primiparous and multiparous sows were calculated using the equations of Dourmad et al. (1997).

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

Fat (kg)= $-26.4+0.221\times$(EBW, kg)$+1.331\times$(Backfat, mm)

Protein (kg)= $2.28+0.178\times$(EBW, kg)$+0.333\times$(Backfat, mm)

Blood samples were collected from the jugular vein of sows with tubes (serum and EDTA tube) and centrifuged immediately at 3,000 rpm at 4℃, and then, samples were stored at -20℃ until later analysis. Colostrum and milk were collected from the first and second teats at 24 h and 21 d postpartum after an intravascular injection of 5 IU oxytocin (Komi oxytocin inj. Komipharm International Co., Ltd., Siheung, Korea) in the ear. All samples were stored at -20℃ until analysis. A proximate analysis of colostrum and milk samples was conducted using a Milkoscan FT 120 (FOSS Electric, Sungnam, Korea). The glucose and BUN concentrations were analyzed using a kinetic UV assay (Glucose Hexokinase Kit; UREA/BUN Kit, Roche, Mannheim, Germany). Plasma free fatty acid (FFA) concentrations were determined according to the colorimetric Acyl-CoA synthetase Acyl-CoA oxidase

(ACS-ACOD) method (Shimizu et al., 1979) using a commercial kit (Wako FFA c Kit; Wako chemical, Osaka Japan). The fatty acid content in colostrum was analyzed on an Agilent 7890 Gas Liquid Chromatograph (Agilent Technologies, Palo Alto, CA, USA) equipped with a flame ionization detector and an SP-2560 (i.d. 100 m x 0.25 mm x 0.20㎛) film column. Nitrogen was used as carrier gas, injector core temperature was 250℃, detector temperature was 260℃and column temperature was programmed to begin at 170℃ and then increase to 250℃ remained at 240℃ for 40 min. Chromatography was calibrated with a mixture of 37 different fatty acids (FAME 37; Supelco Inc., Bellefonte, PA, USA) and this standard containing fatty acids ranging from C4:0 to C24:1n9 and samples were added 250μl of internal standard spike solution (Pentadecanoic acid; Sigma) by the method of AOAC (1990). Colostrum samples were centrifuged at 105,000 x g at 4℃ for 1 hour, and the supernatant was separated and kept frozen until colostrum IgG and IgA analyzed. The colostrum IgG and IgA concentrations were determined using an ELISA according to the manufacture's protocols (Elisa Starter Accessory Package, pig IgG ELISA Quantification Kit, pig IgA ELISA Quantification kit; Bethyl, Texas, USA).

Statistical analysis

Data were analyzed by ANOVA with a completely randomized design using the GLM procedure implemented in SAS (SAS Institute, 2004). The least squares means were calculated for each independent variable. Orthogonal polynomial contrasts were used to determine the linear and quadratic effects by increasing the dietary energy level during gestation for all measurements of sows and piglets. The individual sows and their litters were used as the experimental unit. The alpha level used for the determination of significance for all analyses was 0.05 and for the determination of trends was $p>0.05$ and $p<0.10$

Results

The body weight and body weight gain during gestation increased as the dietary energy level increased (linear, $p<0.05$, and $p<0.01$, respectively, Table 2) in the first parity. In the second parity, body weight was the lowest (quadratic, $p<0.05$) in the 3,100 kcal/kg ME treatment with a higher body weight gain (linear, $p=0.07$) (Table 2). Body weight increased with an increasing energy level (linear, $p<0.05$) during gestation in the third parity (Table 2). During lactation, an increasing energy level led to lower body weight, body weight gain and overall body weight gain (linear, $p<0.05$, $p=0.06$, respectively) in the first parity (Table 2).

Back fat thickness was not affected by the diet during gestation in parity 1, 2, or 3. However, back fat difference from breeding to d110 of gestation increased linearly ($p<0.05$) as the dietary energy level increased in parity 1 (Table 3).

The estimated fat and protein masses were calculated based on body weight and backfat thickness (Dourmad et al., 1997). The fat mass and protein mass were higher as the energy level increased (linear, $p<0.01$, and $p<0.05$, respectively) during gestation in parity 1 (Table 4). During lactation, the fat mass and protein mass decreased (linear and quadratic, $p<0.01$, and $p<0.05$, respectively) with an increased dietary energy level in parity 1 (Table 5).

The voluntary feed intake of sows tended to decrease (linear, $p=0.08$) when the dietary energy level increased in parity 1(Table 6). The weaning to estrus interval (WEI) was not significantly affected by treatment over the three parities (Table 6). The culling rate was the highest in the 3,100 kcal/kg ME treatments.

The 3,400 kcal/kg ME treatment showed the highest number of weaning pigs per litter (quadratic, $p<0.05$) in the first parity (Table 7).

The BUN concentration in sows tended to increase by with the dietary energy level at d110 of gestation and 24 h postpartum (linear, $p=0.06$, and $p=0.07$, respectively) in parity 1 (Figure 1). The glucose concentration was higher (linear, p=0.07) and tended to be the lowest in 3,300 kcal/kg ME (quadratic, p=0.06) treatment at 24 h postpartum in parities 1, and 3 (Figure 2). Similarly, the 3,300 kcal/kg ME treatment had a lower glucose concentration at d 110 in the third parity (quadratic, p=0.06, Figure 2). The free fatty acid concentration was not affected by dietary energy level (Figure 3).

No statisticant differences were evident in the fat content of the colostrum and milk (Table 9).

The colostrum fatty acids were not affected by dietary energy level (Table 10).

In the 3,200 kcal/kg ME treatment, the colostrum IG concentration was the highest (quadratic, p<0.05) in parity 3 and IgA tended to be the highest concentration in parity 2 (quadratic, p=0.08, Table 11)

Discussion

During gestation, the maternal body weight of sows should be gained 25 kg per parity over three or four parities (Aherne and Kirkwood, 1985). In gestation period for a total 45 kg of weight gain by the sow, 20 kg is the weight of the placental and other products of conception out of the total weight (Verstegen et al., 1987). In this study, all treatments showed a 45 kg of body weight gain during gestation except the 3,100 kcal/kg ME treatment in the first parity. This result demonstrated that an energy level of 3,100 kcal/kg ME might not be high enough to increase the body weight during gestation.

The reproductive frequency was decreased when backfat thickness was lower than 14 mm and had a negative effect on the ovulation rate and reproductive performance in the following parity (Tantasuparuk et al., 2001). In this experiment, all treatments produced a backfat thickness greater than 20 mm backfat at farrowing and 16 mm at weaning. Averette Gatlin et al. (2002) suggested that the effect of the energy level during gestation on body weight (BW) and body weight gain is highly related to the body weight, which may be attributed to a higher backfat thickness due to a higher energy level (Long et al., 2010). However, Young et al. (1990) indicated that higher energy intake during gestation reduced the voluntary feed intake during lactation. Our results suggested that body weight and backfat loss increased with dietary energy level in the first parity, which was in agreement with previous studies, that demonstrated that the provision of high energy feed during gestation caused increased body weight and a loss of backfat thickness (BFT) during lactation (Long et al., 2010). Clowes et al. (2003) observed a negative effect following parity after lactation if the back fat loss was higher.

Fat tissue and protein tissue were increased during gestation, whereas fat and protein mass decreased with increasing energy level during lactation in the first parity, indicating that the energy supply was important factor to maintain adequate body weight and back fat thickness for subsequent reproductive cycles in sows. These results are in agreement with previous studies, which demonstrated that N retention was increased by a high energy level (King and Brown, 1993) and higher feed intake during gestation (Revell et al., 1994).

Previous studies suggested that an increase body weight at farrowing could be decreased feed intake in lactation period (Young et al., 2004) and several common reproductive problems, such as an increase in the interval from weaning to estrus (WEI) (Baidoo et al., 1992), an increased incidence of anestrus after weaning, and a decreased conception rate (Kirkwood and Thacker, 1988). However, in this study, WEI was not affected by treatment, and the 3,100 kcal/kg ME treatment had the highest culling rate (68%) because of pregnancy failure and anestrus after weaning, which is in agreement with Kongsted (2005), who suggested that a low energy intake during gestation might increase the risk of culling. It is well documented that a late WEI is related to a low concentration of insulin during lactation (Tokach et al., 1992a) or weaned sows (Amstrong et al., 1986) with a high glucose and low FFA concentration in weaned females. Whitley et al. (2002) also suggested that insulin targeted reproduction had little concern with nutrition, body condition, and other management factors. In this study, the plasma glucose and FFA concentration of sows at weaning was not affected by treatment, indicating that the dietary energy level did not affect the WEI. These results indicated that it is difficult to determine the dietary energy level during pregnancy for the best longevity. Further study is needed to clearly demonstrate a possible correlation between dietary energy level during gestation and hormone levels.

Prunier et al. (1999) suggested that there was no treatment effect on number of embryos when the energy intake was increased from moderate (28 MJ d / ME) to high (37 MJ d / ME). The NRC (2012) reported that dietary energy during gestation ranged from 6,678 kcal/kg ME to 8,182 kcal/kg ME daily from parity 1~3. However, previous studies suggested that a high energy supply (50.1, 38.4, and 48.6 MJ/ day ME) 3 days after mating or immediately after mating did not affect the number of embryos or the litter size in sows (Sbrensen, 1994; Toplis et al., 1983; Sbrensen and Thorup, 2003). Similar results were also observed in this study.

It is well documented that increased energy intake during late gestation can positively affect fetal growth (NRC, 2012). However, no effect was observed on litter birth weight and individual piglet birth weight, which is consistent with results of Long et al. (2010), who demonstrated that the average piglet body weight at farrowing was not affected by different energy levels in the gestation diet. Similarly, Piao et al. (2010) also suggested that an increased feed intake during geatation did not increase litter weight or individual piglet weight. In this study, the 3,400 kcal ME/kg treatment showed the highest weaning litter size in the first parity. However, feed in take decreased more than other treatment and increased body weight, backfat thickness loss and culling rate.

It is very well known that BUN is connected straightly to protein intake and contrarily to protein quality (Hahn et al., 1995) and retention of nitrogen in the body

(Whang and Easter, 2000). In this study, the serum BUN concentration tended to decrease with an increasing energy level at 110 days of geataion and 24 hours post-farrowing in the first parity, which is consistent with the results of Ruiz et al. (1971), who reported that the BUN concentration was lower in swine that were fed a high energy diet compared to pigs fed a low energy diets. These results might suggest that the energy intake in sows affects the protein metabolism during gestation. An increased energy level during gestation could decrease glucose utilization and subsequently feed intake during lactation (Xue et al., 1997), because the glucose concentration can affect insulin secretion (Quesnel and Prunier, 1998). Moreover, an increased feed intake in gestating gilts may cause sows to become insensitive to insulin, which presents a smaller response in glucose clearance and decreased feed during lactation (Piao et al., 2010). In this study, the glucose concentration was increased with a higher energy level 24 hours post-farrowing in the first parity, but was lowest in the 3,300 kcal/kg ME treatments at 110 days of gestation and 24 hours post- farrowing in the third parity. Therefore, the effect of insulin on feed intake during lactation might depend on the body condition of the sows and the glucose metabolites, and this can explain our results of higher bodyweight and backfat thickness loss with an increased energy level during lactation in parity 1, but not in parity 3. Chilliard et al. (1993) suggested that the FFA levels is a good indicator that energy demands are satisfied, that the plasma FFA level during gestation peaks when the nergy needs of sows were the greatest, and that it reflected body fat mobilization (Belstra et al., 1998). Gamble and Cook (1985) also suggested that the oxidation of FFA for the energy production was decreased by insulin and that glucose could affect the FFA concentration, whereas free fatty acids were not affected by treatment over the three parities although the glucose concentration behaved differently. Therefore, further study is necessary to clearly demonstrate this interaction.

The chemical composition of the colostrum and milk of sows is variable due to the dietary regimen (Jackson et al., 1995) and the body condition of the sows (Klaver et al., 1981). Feeding a fatty diet in late gestation increased the total lipids in colostrum (Heo et al., 2008). However, Yang et al. (2008) reported that there was no effect on the colostrum composition when the energy level was increased from 13.7 to 14.2 MJ of ME/kg in the gestation diet. In this study, no significant difference in the fat content of sow colostrum and milk was noted, which is in agreement with Willams et al. (1985), who demonstrated that the chemical composition of colostrum and milk was not affected by dietary energy level during gestation because the sow mobilized its body reserves to compensate for the nutrient deficiency.

The fatty acid composition of colostrum is affected by the dietary fat level (Christon et al., 1999) and type of fat provided in the diet (King et al., 2012), which is inconsistent with our results, which showed that the fatty acids composition of colostrum was not influenced by energy level during gestation. However, studies on the effect of energy level during gestation on the fatty acid composition of colostrum is limited, and further studies are still warranted to elucidate a detailed mechanism.

It is well known that passive immunity conferred by colostrum immunoglobulins in piglets plays an important role in their lives (Corino et al., 2009). Field et al. (2000) suggested that adult immune defense development could be affected by the intake of polyunsaturated fatty acids (PUFAs). Dunstan et al. (2004) also reported a higher IgA concentration in milk with supplementation of fish oil and an increased IgG concentrations in the colostrum of sows fed a fish product (Mateo et al. 2009). Thus, dietary PUFAs (omega-3 and omega-6) fatty acids are positively affect the immunity. In this study the IgA and IgG concentration in colostrum tended to be the highest in the 3,200 kcal/kg ME treatment in parities 2 and 3, which indicated that 3200 kcal/kg ME could led to higher immunity in sows and provide better nonspecific immune-stimulators in piglets.

Implications

The NRC (2012) suggested that the energy requirement of the gestating gilt and sow should be between 6,678 and 8,182 kcal of ME/d from parity 1 to 3. Similarly, our results suggested that 3,100 kcal of ME/kg is not sufficient to maintain the reproductive performance of sows during gestation over a three parity with 2 kg, 2.2kg and 2.4kg feed daily, respectively. The treatment 3,400 kcal of ME/kg have greater number of weaning piglets, but culling rate of sow was higher than other treatments in parity 1. Consequently, the adequate energy intake of gestating sows should be 6,400 or 6,600 kcal of ME/d, 7,040 or 7,260 kcal of ME/d and 7,680 or 7,920 kcal of ME/d for parity 1, 2 and 3, respectively.

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Table 1. Formula and chemical composition of gestation and lactation diets (%)

Criteria	Gestation diets				Lactation diets
	ME 3,100 kcal/kg	ME 3,200 kcal/kg	ME 3,300 kcal/kg	ME 3,400 kcal/kg	
Ingredients (%)					
Corn	56.59	54.56	52.53	50.50	67.51
Soybean meal (46% CP)	10.09	10.44	10.78	11.12	25.57
Tallow	0.45	2.13	3.82	5.50	-
Soy oil	-	-	-	-	1.30
Barley	25.00	25.00	25.00	25.00	–
Rapeseed meal	3.60	3.60	3.60	3.60	–
L-Lysine-HCl	0.41	0.40	0.40	0.40	0.60
DL-Methionine	0.04	0.04	0.04	0.04	-
Dicalcium phosphate	2.36	2.39	2.41	2.43	2.30
Limestone	0.86	0.84	0.82	0.81	0.85
Vit. Mix[1]	0.10	0.10	0.10	0.10	0.20
Min. Mix[2]	0.10	0.10	0.10	0.10	0.10
Salt	0.25	0.25	0.25	0.25	0.42
Choline chloride-50	0.15	0.15	0.15	0.15	0.15
Chemical compositions [3] (%)					
ME (kcal/kg)	3,100	3,200	3,300	3,400	3,265
CP	13.08	13.08	13.08	13.08	17.07
Lys	0.86	0.86	0.86	0.86	1.26
Met	0.23	0.23	0.23	0.23	0.25
Ca	0.90	0.90	0.90	0.90	0.90
Total P	0.70	0.70	0.70	0.70	0.70

[1] Provided per kg of diet: Vit. A, 10,000 IU; Vit. D3, 1,500 IU; Vit. E, 35 IU; Vit. K3., 3 mg; $VitB_2$, 4 mg; $VitB_6$, 3 mg; $VitB_{12}$, 15 µg; Pantothenic acid, 10 mg; Biotin, 50 µg; Niacin, 20 mg; Folic acid 500 µg.

[2]Provided per kg of diet: Fe, 75 mg; Mn, 20 mg; Zn, 30 mg; Cu, 55 mg; Se 100 µg; I, 250 µg; Co, 250 µg.

[3] Calculated value.

Table 2. Effects of dietary energy level on the body weight of gestating and lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Gestation, kg							
Breeding							
Parity 1	136.00	135.95	135.68	135.35	0.85	0.64	0.96
Parity 2	155.81	163.17	157.33	156.79	1.47	0.72	0.21
Parity 3	169.90	179.63	178.63	181.69	2.29	0.16	0.53
d 110							
Parity 1	178.50	182.18	182.59	185.81	1.42	0.04	0.74
Parity 2	208.57	220.44	219.13	214.13	1.66	0.28	0.01
Parity 3	220.75	234.25	240.63	236.88	3.01	0.04	0.12
Total body weight gain (Breeding to d 110, kg)							
Parity 1	42.50	46.22	46.91	50.46	1.08	0.01	0.69
Parity 2	51.21	56.39	61.79	57.33	1.52	0.07	0.12
Parity 3	50.85	54.63	62.00	55.19	1.70	0.16	0.10
Lactation, kg							
Farrowing[4]							
Parity 1	164.72	165.68	162.08	169.00	1.28	0.53	0.26
Parity 2	188.29	197.39	193.08	193.45	2.02	0.46	0.18
Parity 3	199.63	219.44	220.00	221.14	3.23	0.03	0.29
Weaning							
Parity 1	174.11	173.45	168.88	167.27	1.55	0.03	0.70
Parity 2	177.00	193.78	182.38	183.15	2.44	0.59	0.06
Parity 3	206.86	221.13	222.14	221.71	3.31	0.24	0.53
Total body weight gain (Farrowing to weaning, kg)							
Parity 1	9.39	7.77	6.79	-1.73	1.24	0.01	0.10
Parity 2	-11.29	-3.61	-10.71	-10.30	1.34	0.82	0.25
Parity 3	7.25	1.69	2.14	0.57	1.67	0.25	0.70
Over all bodyweight gains(Breeding to weaning, kg)							
Parity 1	39.72	37.50	33.79	31.92	1.31	0.06	0.90
Parity 2	19.64	29.72	25.04	24.39	1.56	0.87	0.26
Parity 3	37.13	41.50	43.71	41.07	1.79	0.59	0.54

[1] Energy intake ME kcal/kg.
[2] Standard error of means.

[3] Breeding day.
[4] 24 hours postfarrowing.

Table 3. Effects of dietary energy level on the back-fat of gestating and lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Gestation, mm							
Breeding							
Parity 1	19.32	19.18	18.55	19.08	0.56	0.90	0.55
Parity 2	18.44	18.71	17.58	17.91	0.61	0.81	0.91
Parity 3	17.40	17.00	18.69	19.38	0.69	0.22	0.69
d 110							
Parity 1	20.72	21.27	20.45	23.08	0.70	0.22	0.26
Parity 2	22.50	22.56	21.33	21.92	0.90	0.62	0.82
Parity 3	19.40	19.56	23.13	21.44	0.91	0.32	0.65
Total backfat gain (Breeding to d 110)							
Parity 1	1.40	2.09	1.91	4.00	0.40	0.04	0.32
Parity 2	1.29	3.33	3.75	4.00	0.60	0.38	0.62
Parity 3	2.00	2.56	4.44	2.06	0.54	0.76	0.26
Lactation, mm							
Farrowing[4]							
Parity 1	21.06	20.32	20.83	21.77	0.64	0.57	0.49
Parity 2	20.43	21.50	21.25	21.10	0.82	0.83	0.65
Parity 3	20.00	19.56	21.29	23.14	1.01	0.43	0.48
Weaning							
Parity 1	18.94	18.73	19.37	18.27	0.57	0.87	0.77
Parity 2	16.50	18.61	19.00	17.95	0.71	0.59	0.32
Parity 3	18.63	18.00	20.71	20.21	0.90	0.61	0.91
Total backfat gain (Farrowing to weaning)							
Parity 1	-2.12	-1.59	-1.46	-3.50	0.35	0.19	0.08
Parity 2	-3.93	-2.88	-2.25	-3.15	0.60	0.66	0.45
Parity 3	-1.38	-1.56	-0.57	-2.93	0.48	0.55	0.26
Over all backfat gain (Breeding to weaning, mm)							
Parity 1	0.56	-0.45	0.66	-0.81	0.47	0.91	0.72
Parity 2	-3.07	-0.61	1.41	0.67	0.71	0.13	0.36
Parity 3	0.75	1.00	2.21	1.07	0.52	0.71	0.49

[1] Energy intake ME kcal/kg.

[2] Standard error of means.
[3] Breeding day.
[4] 24 hours postfarrowing.

Table 4 Effects of the dietary energy level on the estimated fat and protein mass of gestating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Estimated fat mass[3] on gestation(kg)							
Breeding							
Parity 1	26.94	27.98	27.16	27.71	0.82	0.88	0.94
Parity 2	33.03	33.99	30.38	30.71	0.99	0.31	0.92
Parity 3	33.41	34.34	36.08	37.40	1.37	0.49	0.70
d 110							
Parity 1	39.45	40.57	40.71	43.74	1.08	0.09	0.39
Parity 2	45.61	50.39	48.48	48.20	1.36	0.84	0.50
Parity 3	48.14	49.34	55.19	52.74	1.75	0.33	0.82
Gain(Breeding to d 110, kg)							
Parity 1	12.51	12.59	13.56	16.03	0.74	0.03	0.26
Parity 2	12.58	16.40	18.10	17.49	0.90	0.18	0.34
Parity 3	14.73	15.00	19.11	15.34	0.92	0.54	0.35
Estimated protein[4] mass on gestation(kg)							
Breeding							
Parity 1	31.57	31.90	31.59	31.76	0.40	0.93	0.95
Parity 2	35.69	36.71	35.02	35.04	0.40	0.31	0.58
Parity 3	37.24	38.64	38.93	39.52	0.61	0.36	0.95
d 110							
Parity 1	39.80	40.50	40.54	41.72	0.41	0.04	0.41
Parity 2	44.87	47.46	46.83	46.17	0.48	0.59	0.16
Parity 3	47.06	49.00	51.39	50.10	0.79	0.15	0.46
Gain(Breeding to d 110, kg)							
Parity 1	8.23	8.60	8.95	9.95	0.30	0.01	0.31
Parity 2	9.18	10.75	11.81	11.13	0.35	0.07	0.16
Parity 3	9.82	10.37	12.46	10.58	0.42	0.29	0.21

[1] Energy intake ME kcal/kg.
[2] Standard error of means.
[3]Prediction equation from Dourmad et al. (1997):-26.4 + 0.221 × (EBW, kg) + 1.331×(Backfat, mm).
[4]Prediction equation from Dourmad et al. (1997): 2.28 + 0.178 × (EBW, kg) + 0.333×(Backfat, mm).

Table 5 Effects of energy level on the estimated fat and protein mass of lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Estimated fat mass[4] on lactation(kg)							
Farrowing[3]							
Parity 1	36.58	35.79	35.72	38.43	0.99	0.51	0.38
Parity 2	40.74	44.09	42.85	42.00	1.36	0.69	0.39
Parity 3	42.57	46.19	48.61	51.32	1.86	0.20	0.82
Weaning							
Parity 1	35.75	35.32	35.21	33.40	0.97	0.44	0.73
Parity 2	32.51	39.48	37.58	34.94	1.24	0.68	0.11
Parity 3	42.28	44.47	48.30	47.54	1.70	0.41	0.87
Gain(Farrowing to weaning, kg)							
Parity 1	-0.83	-0.47	-0.51	-5.03	0.62	0.02	0.03
Parity 2	-8.23	-4.61	-5.27	-7.07	1.10	0.95	0.29
Parity 3	-0.29	-1.72	-0.31	-3.78	0.75	0.28	0.41
Estimated protein[5] mass on lactation(kg)							
Farrowing							
Parity 1	37.44	37.36	36.91	38.40	0.36	0.47	0.28
Parity 2	41.26	43.17	42.35	42.18	0.54	0.52	0.29
Parity 3	43.05	46.29	46.96	47.78	0.81	0.09	0.76
Weaning							
Parity 1	38.34	38.16	37.59	36.95	0.40	0.16	0.70
Parity 2	37.53	41.59	39.77	38.95	0.55	0.60	0.05
Parity 3	43.83	46.06	47.14	46.90	0.78	0.30	0.69
Gain(Farrowing to weaning, kg)							
Parity 1	0.90	0.80	0.67	-1.46	0.28	0.01	0.03
Parity 2	-3.72	-1.57	-2.58	-3.23	0.40	0.97	0.14
Parity 3	0.78	-0.23	0.18	-0.88	0.34	0.19	0.81

[1] Energy intake ME kcal/kg.
[2] Standard error of means.
[3] 24 hours postfarrowing.
[4]Prediction equation from Dourmad et al. (1997):-26.4 + 0.221 × (EBW, kg) + 1.331 × (Backfat, mm).
[5]Prediction equation from Dourmad et al. (1997): 2.28 + 0.178 × (EBW, kg) + 0.333 × (Backfat, mm).

Table 6. Effects of dietary energy level on the lactation feed intake, weaning to estrus interval and culling rate of sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
NO. of sows							
Parity 1	8	12	12	11	-	-	-
Parity 2	6	9	9	8	-	-	-
Parity 3	4	8	8	8	-	-	-
Daily feed intake, kg/d							
Parity 1	5.99	5.77	5.79	5.32	0.11	0.08	0.16
Parity 2	5.34	5.62	5.21	4.47	0.24	0.22	0.47
Parity 3	6.08	6.18	5.97	6.13	0.17	0.89	0.91
WEI, d							
Parity 1	5.29	5.27	5.17	5.67	0.18	0.99	0.20
Parity 2	5.43	5.66	5..17	6.00	0.37	0.56	0.92
Parity 3	7.25	5.25	5.42	5.43	0.31	0.16	0.16
Sow removals, head							
Reproductive problem	9	5	5	4	-	-	-
Lameness	0	0	0	1	-	-	-
Culling rate, %							
Parity 1~3	69.00	38.00	38.00	38.00	-	-	-

[1] Energy intake ME kcal/kg.
[2] Standard error of means.

Table 7. Effects of dietary energy level on the reproductive performance of sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
No.born/litter[3]							
Parity 1	12.11	13.00	12.33	12.00	0.33	0.36	0.66
Parity 2	12.86	14.00	13.50	13.91	0.44	0.52	0.71
Parity 3	15.00	12.50	13.43	14.14	0.53	0.75	0.13
No.born alive/litter							
Parity 1	11.44	12.27	11.75	11.54	0.33	0.42	0.76
Parity 2	11.86	13.11	12.33	12.91	0.42	0.52	0.59
Parity 3	14.00	11.63	12.57	13.29	0.46	0.77	0.06
No.stillbirths/litter							
Parity 1	0.67	0.73	0.58	0.46	0.08	0.61	0.56
Parity 2	1.29	0.89	1.00	1.00	0.21	0.79	0.53
Parity 3	1.00	0.88	0.86	0.86	0.22	0.84	0.99
No.innitial pigs/litter[4]							
Parity 1	11.33	11.18	11.25	11.62	0.24	0.65	0.31
Parity 2	11.43	11.56	11.75	11.40	0.16	0.97	0.58
Parity 3	11.50	11.50	11.57	11.43	0.21	0.77	0.74
No. weaning pigs/litter							
Parity 1	11.00	10.27	10.58	11.31	0.24	0.66	0.02
Parity 2	10.43	11.11	11.08	11.10	0.19	0.42	0.44
Parity 3	11.00	10.38	11.29	10.57	0.31	0.83	0.72

[1] Energy intake ME kcal/ kg.
[2] Standard error of means.
[3] Registered litter size.
[4] After cross-fostering day at d 1 postpartum.

Table 8. Effects of dietary energy level on the progeny growth performance of sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Average litter weight, kg							
Litter birth weight[3]							
Parity 1	14.47	16.03	15.42	15.29	0.44	1.00	0.62
Parity 2	17.92	20.01	20.75	20.13	0.60	0.24	0.33
Parity 3	20.80	18.12	19.72	19.64	0.57	0.70	0.24
Initial litter weight[4]							
Parity 1	14.29	14.30	14.40	14.59	0.43	0.85	0.77
Parity 2	16.80	17.200	17.86	17.39	0.41	0.62	0.64
Parity 3	17.02	17.82	18.16	17.26	0.57	0.83	0.71
21day litter weight							
Parity 1	58.16	56.82	57.49	63.55	1.36	0.31	0.19
Parity 2	51.20	52.67	55.08	52.37	1.52	0.97	0.57
Parity 3	65.38	64.51	68.06	63.41	1.95	0.80	0.44
Average piglet weight, kg							
Piglet birth weight[3]							
Parity 1	1.19	1.25	1.25	1.30	0.03	0.23	0.96
Parity 2	1.55	1.62	1.69	1.58	0.05	0.85	0.58
Parity 3	1.42	1.53	1.51	1.44	0.06	0.87	0.40
Initial piglet weight[4]							
Parity 1	1.26	1.28	1.27	1.26	0.03	0.94	0.82
Parity 2	1.47	1.49	1.52	1.52	0.03	0.51	0.85
Parity 3	1.48	1.55	1.57	1.51	0.05	0.77	0.46
21day piglet weight							
Parity 1	5.35	5.56	5.47	5.64	0.09	0.10	0.60
Parity 2	4.91	4.71	4.97	4.72	0.10	0.49	0.95
Parity 3	5.94	6.26	6.11	5.97	0.15	0.99	0.49

[1] Energy intake ME kcal/ kg.
[2] Standard error of means.

[3] Registered litter size.
[4] After cross-fostering day at d 1 postpartum.

Table 9. Effects of dietary energy level in gestating sows on the fat content in colostrum and milk of lactating sows

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Fat content in colostrum[3] (%)							
Parity 1	6.44	7.40	7.33	7.67	0.36	0.69	0.24
Parity 2	8.99	9.77	11.30	9.09	0.42	0.43	0.20
Parity 3	7.78	7.15	9.43	8.01	0.38	0.36	0.58
Fat content in 21d postpartum (%)							
Parity 1	5.56	7.01	6.58	6.86	0.21	0.10	0.06
Parity 2	6.20	6.28	6.65	7.22	0.23	0.13	0.62
Parity 3	6.67	6.74	7.69	7.14	0.30	0.32	0.56

[1] Energy intake ME kcal/kg.
[2] Standard error of means.
[3] 24 hours post-farrowing.

Table 10. Effects of dietary energy level in gestating sows on the fatty acids compositions of colostrum in primiparous lactating sows (mg/g)

Criteria	Treatment				SEM[2]	P-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Fatty acid composition of colostrum at 24h postpartum (mg/g)							
Saturated							
Parity 1	11.11	13.28	13.49	9.14	1.36	0.63	0.23
Parity 2	12.07	14.57	14.00	12.24	1.340	1.00	0.53
Parity 3	8.78	13.05	13.57	9.55	1.200	0.81	0.14
Monounsaturated							
Parity 1	15.07	18.43	20.97	13.77	2.150	0.95	0.25
Parity 2	17.88	20.62	21.46	18.11	2.000	0.94	0.54
Parity 3	13.28	18.47	19.82	14.62	1.740	0.75	0.19
Polyunsaturated							
Parity 1	6.93	7.85	8.91	5.46	0.800	0.65	0.20
Parity 2	7.29	7.79	7.42	6.27	0.830	0.71	0.70
Parity 3	4.93	7.55	7.30	4.81	0.740	0.93	0.14

[1] Energy intake ME kcal/kg.
[2] Standard error of means.

Table 11. Effects of dietary energy level on the immune parameters of colostrum in lactating sows

Criteria	**Treatment**				**SEM**[2]	**P-value**	
	3,100[1]	**3,200**	**3,300**	**3,400**		**Linear**	**Quadratic**
Colostrum[3]**, mg/ml**							
IgG							
Parity 1	5.44	5.58	5.36	4.95	0.60	0.81	0.86
Parity 2	5.53	5.40	4.74	2.70	0.61	0.24	0.39
Parity 3	4.29	7.93	5.61	3.54	0.72	0.33	0.05
IgA							
Parity 1	5.58	4.03	5.46	5.25	0.67	0.94	0.58
Parity 2	4.48	7.93	5.86	4.04	0.75	0.57	0.08
Parity 3	5.32	4.83	6.80	3.48	0.55	0.51	0.27

[1] Energy intake ME kcal/kg.
[2] Standard error of means.
[3] 24 hours post-farrowing.

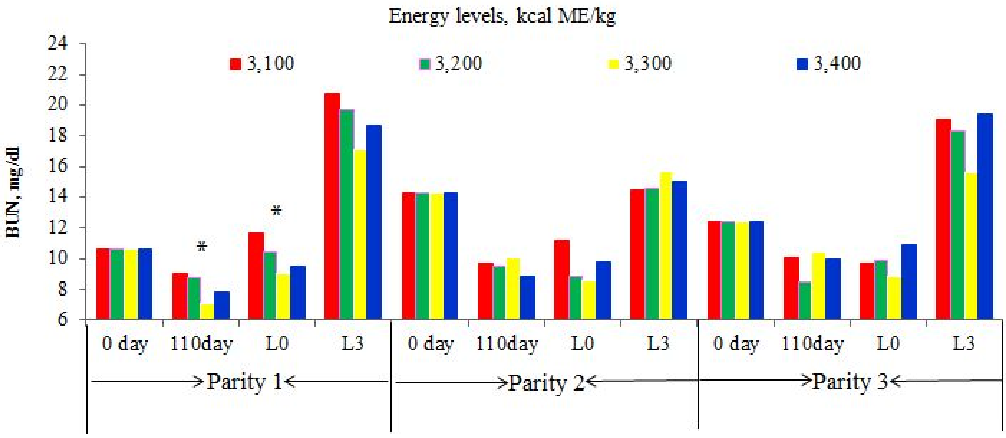

Figure 1. Effects of the dietary energy level on the BUN concentration in the blood of sows (*P<0.1)

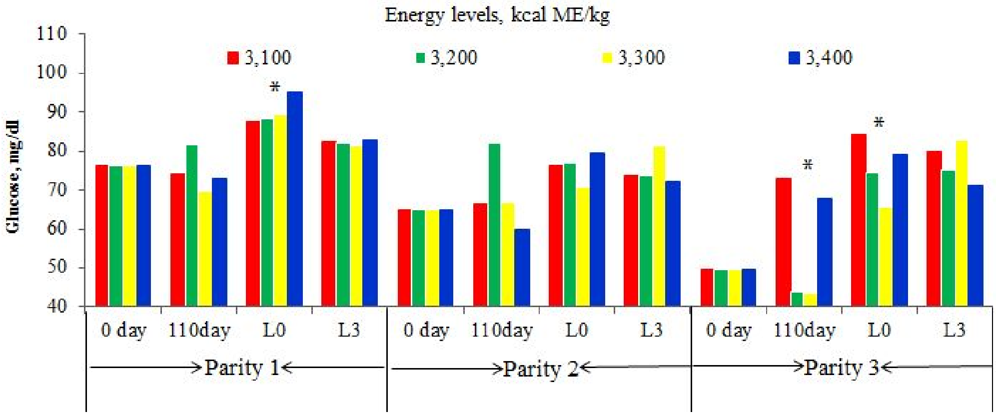

Figure 2. Effects of the dietary energy level on the glucose concentration in the blood of sows (*P<0.1)

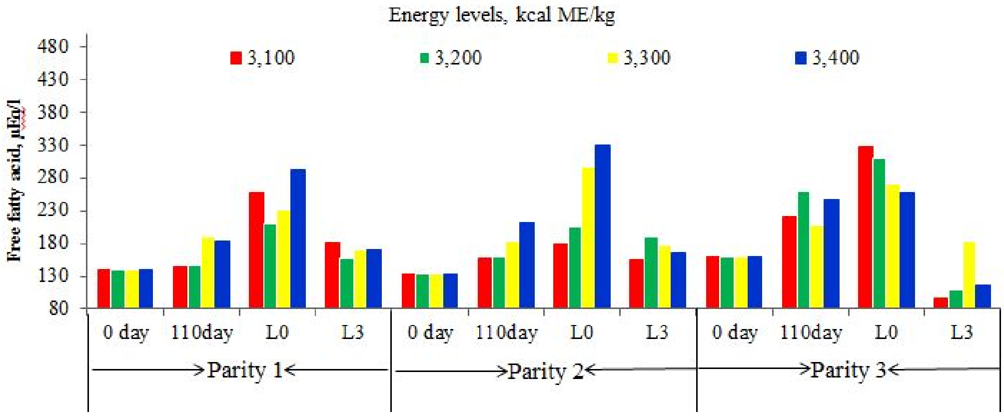

Figure 3. Effects of the dietary energy level on the free fatty acid concentration in the blood of sows

Chapter v. Effect of *Tenebrio molitor* Larva as an Energy Source on Reproductivity of Sows and Growth of their Progeny

Abstract: This experiment was conducted to evaluate the effect of *Tenebrio molitor* larva as a dietary energy source on reproductivity and growth performance of their progeny in lactating sows. A total of 25 F1 sows (Yorkshire×Landrace) were allotted to one of five dietary treatments using a CRD. Various levels of *Tenebrio molitor* larva were supplemented and treatments were 1) CON (tallow 2%), 2) F1 (tallow 3%), 3) F2 (tallow 4%), 4) L1 (tallow 2% + *Tenebrio molitor* larva 1%) and 5) L2 (tallow 2% + *Tenebrio molitor* larva 2%). The body weight, backfat thickness and weaning to estrus interval were not affected by dietary treatments. There were no differences in litter weight and litter weight gain in lactation period among dietary treatments. Lower blood urine nitrogen concentrations were observed in L2 treatment in sows ($p<0.01$). In nursing pigs, higher triglyceride ($p<0.01$) and very low density protein ($p<0.01$) were observed in L1 treatment. In alanine aminotransferase concentration, L1 treatment showed higher concentration than other treatments ($p<0.05$). Consequently, *Tenebrio molitor* larva is available energy source instead of tallow in lactating diet and addition of *Tenebrio molitor* larva as an energy source up to 2% in lactating sow diet did not show detrimental influences on sow's performance and growth performance of their progeny.

Keywords: Energy source, *Tenebrio molitor* larva, Lactation sow, Progeny

Introduction

Dietary energy was an important nutrient for animal production. Addition of dietary fat can provide greater energy in swine diet with low heat increment (Schoenherr et al., 1989; Tilton et al., 1999). With increasingly competitive animal feed industry, insect has been used as a high quality efficient and sustainable alternative ingredient source (Veldkamp et al., 2012). The properties of animal fats are related to their source and quality, and their qualities are determined by fatty acid composition, hardness, color, stability and so on (Sharma et al., 2013). Dietary insect called *Tenebrio molitor* larva has been used as feed ingredients as energy source, because the nutritional values of *Tenebrio molitor* larva contains high fat level in dry matter (Ravzanaadii et al., 2012). Some studies also reported *Tenebrio molitor* larva had up to 32.7% fat, which used as energy source with high digestibility (Ravzanaadii et al., 2012; Ramos-Elorduy et al., 2002). Huang et al. (2006) reported *Tenebrio molitor* larva contains high level of oleic and linoleic acid in total un-saturated fatty acid content and the amount of un-saturated fatty acids accounts for 72% in total fatty acid composition. Generally, some researchers reported that *Tenebrio molitor* larva is used to alternate protein source in pig and poultry feed (Ramos-Elordoy et al., 2002; Deng et al., 2008; Chen et al., 2012). However, litter information was known to be used *Tenebrio molitor* larva as an energy source in sow diet.

Therefore, this experiment was to investigate the effects of mealworm (*Tenebrio molitor* larva) as an energy source on reproductivity and growth performance of their progeny in lactating sows.

Materials and methods

Experimental design and animal management

A total of 25 multiparous sows (average parity 5.5, Large White×Landrace) with a body weight of 244.7 ± 3.0 kg were used for experiments. Sows were allotted to 5 treatments by body weight and backfat thickness with 5 replicates in a completely randomized design. Five treatments were allowed to the addition of different energy sources, 1) CON (tallow 2%), 2) F1 (tallow 3%), 3) F2 (tallow 4%), 4) L1 (tallow 2% + *Tenebrio molitor* larva 1%) and 5) L2 (tallow 2% + *Tenebrio molitor* larva 2%).

Experimental *Tenebrio molitor* larva was harvested until approximate 70 d of age and air-dried prior to utilization in each treatment diet. *Tenebrio molitor* larva were obtained from National Institute of Agricultural Sciences (Wanju, Korea) and *Tenebrio molitor* larva contained metabolizable energy 5,258 kcal/kg, crude protein 46.44%, lysine 2.91% and methionine 0.67%. Dried mealworms were ground wholly by grinder for mealworm powder type before mixing the experimental feed.

Experimental diets for lactating sows formulated to contain 3,265 kcal/kg ME, 16.80% crude protein, 1.09% lysine, 0.90% calcium and 0.70% phosphorus, respectively (Table 1). All other nutrients were formulated to meet or exceed the NRC requirements (1998). At 110 d of gestation, pregnant sows were washed and moved into farrowing crates (2.4×1.8 m) with temperature-controlled rooms. After farrowing, the lactation diet was increased gradually from 1.0 kg/d until 5 d postpartum and then provided *ad libitum* during the lactation period. Weaning was performed at approximately 21 d.

Measurements and analysis

The body weight and backfat thickness at the P2 position of sows were measured. Blood samples were collected from the jugular vein of sows and anterior vena cava of piglets at 24 h post-farrowing and 21 days of lactation. The number of total born, piglets born alive, still born and mummified fetuses as well as the piglet body weight were recorded.

Blood samples were collected in to serum separation tubes and centrifuged immediately at 3,000 rpm at 4°C, and then, serum was separated and stored at –20°C until later analysis. Colostrum and milk were collected from the first and second teats at 24 h and 21 d postpartum after an intravascular injection of 5 IU oxytocin (Komi oxytocin inj. Komipharm International Co., Ltd., Siheung, Korea) in the ear. All samples were stored at -20℃ until analysis. Proximate analysis of colostrum and milk samples was conducted using a Milkoscan FT 120 (FOSS Electric, Sungnam, Korea). The free fatty acid (FFA) concentrations were determined according to the colorimetric Acyl-CoA synthetase Acyl-CoA oxidase (ACS-ACOD) method (Shimizu et al., 1979) using a commercial kit (Wako FFA c Kit; Wako chemical, Osaka Japan). The glucose and BUN concentrations were analyzed using a kinetic UV assay (Glucose Hexokinase Kit; UREA/BUN Kit, Roche, Mannheim, Germany). Insulin was analyzed by using a RIA kit (Coat-A-Count®; Diagnostic Products, Los Angeles, CA). The total cholester, HDL, LDL, VLDL and Triglyceride were analyzed using a enzymatic colorimetric assay (CHOL kit; HDL-C plus 3rd generatin kit; LDL-C plus 2nd generation kit; TG kit, Roche, Germany). The serum AST and ALT were analyzed using a IFCC without p5p (AST –ASAT/GOT kit; ALT-ALAT/GPT kit, Roche, Germany).

Statistical analysis

Data were analyzed by ANOVA with a completely randomized design using the GLM procedure implemented in SAS (SAS Institute, 2004). The least squares means were calculated for each independent variable. Individual sows and their litters were used as the experimental unit. The alpha level used for the determination of significance for all analyses was 0.05 and for the determination of trends was $p>0.05$ and $p<0.10$.

Results

There were not differences in body weight and backfat thickness, feed intake and WEI within treatments (Table 1). There was no difference in litter weight and litter weight gain in lactation period (Table 2). Milk composition and free fatty acid in milk had no difference among treatments (Table 4). There were nosignificant difference on total cholesterol, triglyceride, HDL, LDL within treatments. L2 treatm ent had lower BUN concentration than other treatments in sows ($P<0.01$). AST and ALT concentration were not affected by treatment in sows (Table 5). In nursing pigs higher concentration in triglyceride ($P<0.01$) and VLDL ($P<0.01$) was observe d in L1 treatment. In ALT concentration, the treatment of adding *Tenebrio molitor* to 1% showed higher concentration than other treatments in piglets ($P<0.05$).

Discussion

The body weight and backfat thickness had no significant differences by treatments. Many studies reported that adding fat as an energy source in lactating sow diet could affect performance (Moser and Lewis, 1980; Pettigrew, 1981; Drochner, 1989). In this study, the results of performance of sows indicated that both of energy sources (tallow VS *Tenebrio molitor* larva) and addition of *Tenebrio molitor* larva as energy source had no detectable effect on body weight, backfat thickness. Similarly, Babinszky et al. (1992a) reported using different fat sources did not present any effects on body weight and backafat thickness of sows in lactating diet. May be the same energy supplementation in diet formulation, it could be identified that L2 and L1 treatments with adding *Tenebrio molitor* larva with high fat level and good un-saturated fatty acid ratio had higher fat digestibility to utilize compared with other tallow treatments and not have negative affect on the body weight and backfat thickness in sows.

In terms of the ADFI, some studies presented the dietary fat source had no effect on feed intake of sows (Park et al., 2010; Lauridsen and Danielsen, 2004), which is in agreement with the current study. But some studies presented that *Tenebrio molitor* had an attractive flavor which could increase feed intake in pig and poultry diets (Yang et al., 2010; Shen et al., 2006). In this study addition of *Tenebrio molitor* larva which had high fat digestibility, and thus, could meet enough energy requirement for lactating sows. Previous studies reported that low feed intake during lactation period led to several common reproductive problems, such as increased WEI (Reese et al., 1982; Kirkwood and Thaeker, 1988; Baidoo et al., 1992). In present study, ADFI was not different among treatments and this result can demonstrate the reason why BW and BFT which have no difference during lactation, also WEI.

It had been presented adding fat to sow diet in lactating period could improve litter size and piglet weight (Seerley et al., 1974; Boyd et al., 1978; Barbinszky et al., 1992b). Adding dietary fat to lactating sow diet was relative to improve fat content in milk composition that means increased energy concentration in sow milk (Shurson et al., 1986; Boyd et al., 1982; Shurson and Irvin, 1992; Tilton et al., 1999). Several studies also suggested that higher fat content in sow milk could be utilized with high efficiency by piglets (Cranwell and Moughan, 1989; Friend et al., 1974). However, in current experiment fat content in milk did not have improvement by adding *Tenebrio molitor* larva in lactating diet. This result could be demonstrated that added *Tenebrio molitor* larva was not increased performance of piglets.

Previous studies found that adding dietary fat in lactating sow diet may compensate the energy balance for requirement and could increase fat content in milk composition (Averette et al., 1999; Tilton et al., 1999; Theil et al., 2004). In the current experiment, fat content in milk was unaffected by treatments. This result was in agreements with previous studies, which reported the dietary fat level did not affect milk composition and had a slightly lower content of protein in milk composition (Darragh and Moughan, 1998; Theil et al., 2002). Although *Tenebrio* *molitor* larva had high digestion and absorption with optimal fatty acid composition, less addition of *Tenebrio molitor* larve in lactating diet could not achieve the statistical differences in milk composition. The milk composition was highly related to performance of piglets and could predict that milk composition supported the improvement of piglet growth.

Blood urine nitrogen could be used as indicator to evaluate protein quality or amino acid utilization (Eggum, 1970; Lewis and Speer, 1973). In present study, addition of *Tenebrio molitor* larva up to 2% had significant effect on BUN concentration. Some studies had suggested that application of *Tenebrio molitor* larva was initially to use as protein source, because its amino acid composition with high lysine, methionine and threonine (Dai et al., 2009; Ravzanaadii et al., 2012). Low value of BUN in L2 treatment demonstrated *Tenebrio molitor* larva also can be used as protein source. It is well-known that added *Tenebrio molitor* larva as protein source in poultry and pig diets (Ramos-Elordoy et al., 2002; Deng et al., 2008). In present studies, increasing of *Tenebrio molitor* larva up to 2% can improve protein utilization.

In fat metabolism, VLDL was produced in the liver and released into the bloodstream to supply body tissues with triglycerides (McPherson, 2011), which is in agreement with our results, where triglycerides concentration is related to VLDL concentration. In the piglets, L1 had higher concentrations of VLDL and then led to higher triglycerides than other treatments, which may be due to the high digestibility of fat in milk. The optimal unsaturated fatty acids to saturated fatty acids ratio could be maximize the fat digestibility in the pig (Stahly, 1984; Powles, 1994). In this study L1 treatments may be have optimal unsaturated: saturated fatty acid in milk fat and increased the digestion.

The activities of ALT and AST have been used as indicators of tissue damage, particularly liver and muscle. Both enzymes are released into the blood in increasing amounts when the liver cell membrane is damaged (Pratt et al., 2000). In present study ALT concentration was the highest in L1 treatments, which may be due to the negative effect on liver with high concentration of triglyceride and VLDL. However, the changes of VLDL, triglyceride and ALT did not have negative effects on growth of piglets.

Implications

In summary, *Tenebrio molitor* larva is available as an energy source for replacing other fat sources and addition of *Tenebrio molitor* larva as energy source up to 2% in lactating sow diet did not have detrimental influence on sow's performance and piglet's performance.

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Table 1. Formula and chemical composition of lactating diets (%)

Ingredients, %	**Treatment**				
	Con	**F1**	**F2**	**L1**	**L2**
Corn	66.18	61.67	57.14	64.67	63.12
SBM	25.04	24.26	23.50	23.61	22.16
Wheat bran	2.82	7.16	11.50	4.77	6.79
Tallow	2.00	3.00	4.00	2.00	2.00
L-lysine·HCl	0.28	0.29	0.30	0.28	0.29
DL-methionine	0.00	0.00	0.00	0.00	0.00
MDCP	1.73	1.60	1.47	1.67	1.60
Limestone	1.35	1.42	1.49	1.40	1.44
Vit. Mix[1)]	0.10	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
Tenebrio molitor larva	0.00	0.00	0.00	1.00	2.00
Sum	100.00	100.00	100.00	100.00	100.00
Chemical Composition[3)]					
ME (kcal/kg)	3,265.02	3,265.03	3,265.03	3,265.02	3,265.06
CP (%)	16.80	16.80	16.80	16.80	16.80
Lysine (%)	1.09	1.09	1.09	1.09	1.09
Methionine (%)	0.25	0.25	0.25	0.25	0.25
Ca (%)	0.90	0.90	0.90	0.90	0.90
Total P (%)	0.70	0.70	0.70	0.70	0.70

[1] Provided the following per kilogram of diet: vitamin A, 12,000 IU; vitamin D_3, 2,000IU; vitamin E, 100IU; vitamin K_3, 4.50mg; thiamine, 2mg; riboflavin, 7.2mg; pantothenic acid, 30mg; niacin, 45mg; vitamin B_5, 4.5g; biotin, 0.5mg; folic acid, 3.50mg; vitamin B_{12}, 0.03mg.

[2] Provided the following per kilogram of diet : Se, 0.15mg; I, 0.3mg; Mn, 37mg; Cu, 11mg; Fe, 150mg; Zn, 85mg; Co, 2.0mg; Se, 0.30mg, Cr, 500mg.

[3] Calculated values

Table 2. Effect of *Tenebrio molitor* larva as fat source on the body weight, back-fat, feed intake and WEI of sows[1]

Criteria	**Treatment**					**SEM[2]**	**P-value**
	CON	**F1**	**F2**	**L1**	**L2**		
No. of sows	5	5	5	5	5		
Body weight, kg							
24 hrs postpartum	250.2	239.4	242.4	248.5	242.9	3.04	0.76
Day 21 of lactation	245.2	234.2	236.7	243.7	241.1	2.80	0.61
BW changes(0-21d)	-5.0	-5.2	-5.7	-4.8	-1.8	1.63	0.97
Backfat thickness, mm							
24 hrs postpartum	22.4	22.1	22.4	21.2	22.6	0.96	0.98
Day 21 of lactation	19.60	18.9	19.0	19.6	21.8	0.90	0.66
BF changes (0-21d)	-2.8	-3.2	-3.4	-1.6	-0.8	0.55	0.58
ADFI, kg	5.3	5.7	5.0	5.1	4.8	0.15	0.46
WEI, day	4.9	5.4	5.1	4.8	5.0	0.13	0.73

[1] Initial average body weight of sows: 244.7 ± 3.0kg

[2] Standard error of means.

Table 3. Effect of *Tenebrio molitor* larva as fat source on growth performance of piglets

Criteria	Treatment					SEM[1]	P-value
	CON	F1	F2	L1	L2		
No. of piglet (initial)	12.20	12.40	12.40	12.20	12.20	0.10	0.90
No. of piglet (weaning)	11.80	11.40	11.00	11.00	10.80	0.17	0.34
Litter weight, kg							
After cross-fostering	18.29	17.09	18.57	17.32	16.68	0.46	0.71
Day 21 of lactation	68.56	65.72	64.94	62.04	56.35	1.91	0.36
Weight gain, kg	50.27	48.63	46.37	44.72	39.75	1.72	0.38
Piglet weight, kg							
After cross-fostering	1.51	1.38	1.50	1.42	1.34	0.04	0.78
Day 21 of lactation	5.80	5.76	5.90	5.62	5.23	0.13	0.62
Weight gain, kg	4.29	4.38	4.40	4.20	3.87	0.12	0.69

[1] Standard error of means.

Table 4. Effect of *Tenebrio molitor* larva as fat source on milk composition of sows

Criteria	Treatment					SEM[1]	P-value
	CON	F1	F2	L1	L2		
Casein, %							
Colostrum	5.20	5.20	5.20	5.20	5.20	-	-
Day 21 of lactation	6.03	4.36	4.47	4.39	4.46	0.34	0.52
Fat, %							
Colostrum	7.89	7.89	7.89	7.89	7.89	-	-
Day 21 of lactation	8.04	7.00	6.83	7.51	7.09	0.27	0.69
Protein, %							
Colostrum	6.51	6.51	6.51	6.51	6.51	-	-
Day 21 of lactation	7.20	4.62	4.86	4.67	4.70	0.50	0.49
Lactose, %							
Colostrum	4.64	4.64	4.64	4.64	4.64	-	-
Day 21 of lactation	5.32	6.00	5.89	5.95	6.06	0.14	0.52
Total solid, %							
Colostrum	21.12	21.12	21.12	21.12	21.12	-	-
Day 21 of lactation	22.59	18.88	18.93	19.41	19.12	0.75	0.55
Solid not fat, %							
Colostrum	11.40	11.40	11.40	11.40	11.40	-	-
Day 21 of lactation	12.76	11.00	11.17	10.96	11.13	0.36	0.55
Free fatty acid, %							
Colostrum	4.44	4.44	4.44	4.44	4.44	-	-
Day 21 of lactation	3.71	3.89	3.60	3.72	4.23	0.09	0.21

[1] Standard error of means.

Table 5. Effect of *Tenebrio molitor* larva as fat source on blood profiles of sows

Criteria	Treatment					SEM[1]	P-value
	CON	F1	F2	L1	L2		
Glucose, mg/dL							
24 hrs postpartum	91.50	91.50	91.50	91.50	91.50	-	-
Day 21 of lactation	79.00	78.33	78.67	77.33	78.67	1.91	0.99
Insulin, μU/mL							
24 hrs postpartum	2.45	2.45	2.45	2.45	2.45	-	-
Day 21 of lactation	1.47	1.03	1.57	2.30	2.77	0.29	0.44
Total cholesterol, mg/dL							
24 hrs postpartum	31.50	31.50	31.50	31.50	31.50	-	-
Day 21 of lactation	64.33	82.67	78.67	60.33	71.67	3.43	0.28
Triglyceride, mg/dL							
24 hrs postpartum	26.50	26.50	26.50	26.50	26.50	-	-
Day 21 of lactation	22.67	22.00	29.67	35.33	29.67	2.04	0.17
HDL cholesterol, mg/dL							
24 hrs postpartum	11.00	11.00	11.00	11.00	11.00	-	-
Day 21 of lactation	25.00	31.00	28.67	23.33	30.00	1.24	0.29
LDL cholesterol, mg/dL							
24 hrs postpartum	18.17	18.17	18.17	18.17	18.17	-	-
Day 21 of lactation	32.67	46.67	44.67	30.33	36.00	2.65	0.27
VLDL cholesterol							
24 hrs postpartum	5.50	5.50	5.50	5.50	5.50	-	-
Day 21 of lactation	4.33^{B}	4.33^{B}	6.00^{AB}	7.00^{A}	6.00^{AB}	0.39	0.09
BUN, mg/dL							
24 hrs postpartum	13.57	13.57	13.57	13.57	13.57	-	-
Day 21 of lactation	17.80^{a}	20.60^{a}	19.90^{a}	18.90^{a}	12.87^{b}	0.95	<0.01
AST, U/L							
24 hrs postpartum	39.60	39.60	39.60	39.60	39.60	-	-
Day 21 of lactation	28.67	39.67	30.67	31.67	27.00	2.63	0.43
ALT, U/L							
24 hrs postpartum	21.33	21.33	21.33	21.33	21.33	-	-
Day 21 of lactation	29.67	41.00	36.33	33.67	31.33	2.12	0.56

[1] Standard error of means.
[ab] Means in a same row with different superscript significantly different (P<0.01).
[AB] Means in a same row with different superscript significantly different (P<0.10).

Table 6. Effect of *Tenebrio molitor* larva as fat source on blood profiles of piglets

Criteria	Treatment					SEM[1]	P-value
	CON	F1	F2	L1	L2		
Total cholesterol, mg/dL							
24 hrs postpartum	29.33	29.33	29.33	29.33	29.33	-	-
Day 21 of lactation	196.3	158.3	153.3	179.3	150.3	12.10	0.82
Triglyceride, mg/dL							
24 hrs postpartum	69.2	69.2	69.2	69.2	69.2	-	-
Day 21 of lactation	95.0^{b}	82.3^{b}	61.7^{b}	190.7^{a}	88.3^{b}	13.67	<0.01
HDL cholesterol, mg/dL							
24 hrs postpartum	16.33	16.33	16.33	16.33	16.33	-	-
Day 21 of lactation	82.33	65.00	58.00	64.33	64.67	3.26	0.24
LDL cholesterol, mg/dL							
24 hrs postpartum	26.33	26.33	26.33	26.33	26.33	-	-
Day 21 of lactation	111.67	89.00	93.33	97.67	75.33	10.97	0.94
VLDL cholesterol							
24 hrs postpartum	18.17	18.17	18.17	18.17	18.17	-	-
Day 21 of lactation	19.00^{b}	16.67^{b}	12.33^{b}	38.00^{a}	17.67^{b}	2.71	<0.01
AST, U/L							
24 hrs postpartum	120.00	120.00	120.00	120.00	120.00	-	-
Day 21 of lactation	38.33	57.00	44.67	68.00	49.00	7.85	0.24
ALT, U/L							
24 hrs postpartum	37.33	37.33	37.33	37.33	37.33	-	-
Day 21 of lactation	27.33^{B}	31.67^{B}	34.33^{B}	55.67^{A}	43.67^{B}	3.30	0.03
Free fatty acid, µEq/L							
24 hrs postpartum	305.4	305.4	305.4	305.4	305.4	-	-
Day 21 of lactation	424.7	398.3	431.3	550.7	455.3	26.56	0.50

[1]Standard error of means.

[ab] Means in a same row with different superscript significantly different (P<0.01).

[AB] Means in a same row with different superscript significantly different (P<0.05).

Chapter VI. Over all Conclusion

Many researchs had been conducted to examin the nutrition requirement, maxxium reproductive performance and save the feed cost. However, sow productivity has advanced at an incredible rate in the past decades because of high-producing genetic sows and limited research had been conducted to evaluate the requirement of some nutrients despite of genetic changes. Therefore, three experiments were 1) to evaluate the effect of different dietary energy levels for gestating gilts on physiological response, reproductive performance and growth of their progeny, 2) to investigate the effect of energy levels on sow reproductivity and growth of their progeny of sows over three consecutive parities and 3) to investigate the effects of *Tenebrio molitor* larva as a energy source on reproductivity of sows and growth of their progeny.

During gestation period, body weight ($p=0.04$) and weight gain ($p=0.01$) of gilts were linearly increased with increasing dietary energy level. Backfat thickness was not affected at d 110 of gestation by dietary treatments but increased linearly ($p=0.05$) from breeding to d 110 of gestation. There was no significant difference on litter size and litter birth weight. During lactation, voluntary feed intake of sows tended to decrease when dietary energy level increased ($p=0.08$). No difference was observed in the backfat thicknees of sows within treatments; increasing energy level linearly decreased body weight of sows ($p<0.05$) at d 21 of lactation and body weight gain during lactation ($p<0.01$). The culling rate was higher in 3,100 (38%) and 3,400 (15%) kcal of ME/kg treatments. No statistical differences were observed on chemical compositions of colostrum and milk.

The body weight and body weight gain in gestation increased as dietary energy level increased ($p<0.05$, and $p<0.01$) in the first parity. In the second parity body weight was the lowest ($p<0.05$) in treatment of 3,100 kcal/kg ME and body weight gain was tend to be increased ($p=0.07$) in gestation. The body weight was increased as dietary energy level increased ($p<0.05$) in during gestation period in third parity.

During lactation, the voluntary feed intake of sows tended to decrease when the dietary energy levels increased ($p=0.08$) and the body weight, body weight gain and overall body weight gain were decreased ($p<0.05$, $p=0.06$) as energy level increased in the first parity. Back fat thickness was not affected by dietary treatments in gestation period in parity over all parities, but backfat change from breeding to d 110 of gestation was increased ($p<0.05$) as dietary energy level increased in parity 1. The treatment 3,400 kcal of ME/kg have greater number of weaning piglets in the first parity ($p<0.05$). The culling rate (69%) was the highest in 3,100 kcal/kg ME treatments over a three parity. No significant differences were observed in the chemical compositions of colostrum and milk. In 3,200 kcal/kg ME treatment concentration of IgG in colostrum showed the highest ($p=0.05$) in parity 3 and IgA tend to showed the highest concentration in parity 2 ($p=0.08$).

The boday weight and backfat thickness had no significant difference within treatments. Also, feed intake and weaning to estrus interval were not affected as well. There was no difference in litter weight and litter weight gain in lactation period. Treatment L1 tend to have higher concentration of VLDL concentration compared with other treatments in sows ($p=0.09$). Lower blood urine nitrogen concentration were observed in L2 treatment ($p<0.01$). In nursing pigs higher concentration of triglyceride ($p<0.01$) and VLDL ($p<0.01$) was observed in L1 treatment. In ALT concentration, L1 treatment showed higher concentrate than other treatments ($p<0.05$).

Consequently, these strategies with dietary energy levels and energy source in sow diets could improve sow productivity including physiological responses and reproductive performance.

Chapter VII. Summary in Korean

본 실험은 임신기 사료 내 에너지 수준이 모돈의 생리적 변화와 번식성적에 미치는 영향, 거지리 유충이 에너지 공급원으로서 포유기 모돈의 생리적 변화와 번식성적에 대한 영향을 평가하기 위해 실행되였다.

Experiment 1. Effect of Dietary Energy Levels on Physiological Parameters and Reproductive Performance in Gestating Gilts

본 실험은 임신기 사료 내 에너지 수준이 1 산차 모돈의 생리적 변화와 번식성적에 미치는 영향을 규명하기 위해 진행되었다. 총 52 두의 F1 (Yorkshire×Landrace) 후본돈을 체중, 등지방을 고려하여 4 처리 13 반복으로 나누어 완전임의 배치법으로 배치 하였다. 시험 처리구는 임신기 사료 내 에너지 수준에 따라 각각 3,100, 3,200, 3,300, 3400 kcal of ME/kg 으로 설정 하였다. 임신기 모돈의 체중은 사료 내 에너지 수준이 증가함에 따라 증가 하였으며 ($p<0.05$). 임신기 등지방은 에너지 수준이 증가함에 따라서 증가하였으나 ($p=0.05$) 등지방 두께 변화량은 유의적인 차이를 보이지 않았다. 총 산자수와 자돈의 생시 체중은 처리구간 유의적인 차이를 보이지 않았다. 포유기 사료섭취량은 에너지 수준이 증가함에 따라서 낮아지는 경향을 보였다 ($p=0.08$). 포유기 등지방은 에너지 수준에 따라서 유의적인 차이를 보이지 않았지만 체중과 증체량은 에너지 수준이 증가함에 따라서 유의적으로 감소 하였다 ($p<0.05$, $p<0.01$). 모돈 도태율은 에너지 함량 3,100 (38%) 와 3,400 (15%)

kcal of ME/kg 처리구가 다른 처리구에 비해 높게 나타났다. 포유기 초유와 상유의 화학적 성분은 처리구에 따라 유의적인 차이를 보이지 않았다. 결론적으로 보았을 때 임신기 초산돈을 위한 일일 에너지 권장량은 6,400 혹은 6,600 kcal ME 가 적절하다고 생각된다.

Experiment 2. Effect of Dietary Energy Levels on Physiological Paramers and Reproductive Performance in Gestating Sows over Three Consecutive Parities

본 실험은 임신기간 중 사료 내 에너지 수준이 1산차부터 3 산차까지 모돈의 생리적 변화와 번식성적에 미치는 영향을 규명하기 위해 진행 되었다. 총 52두의 F1 (Yorkshire×Landrace) 후본돈을 체중, 등지방을 고려하여 4처리 13반복으로 나누어 완전임의 배치법으로 배치 하였다. 실험사료와 처리구는 실험이 완료 될때까지 변하지 않았다. 시험 처리구는 임신기 사료 내 에너지 수준에 따라 각각 3,100, 3,200, 3,300, 3400 kcal of ME/kg으로 설정 하였고 임신기 일일 사료 섭취량은 가각 1산차 2 kg, 2산차 2.2 kg, 3산차 2.4 kg으로 설정 하였다. 1산차에서 임신기 모돈의 체중과 증체량은 에너지 수준이 증가함에 따라서 유의적으로 증가 하는것으로 나타났다 ($p<0.05$, $p<0.01$). 2산차에서 임신기 모돈의 증체량은 에너지 수준 3,100 kcal ME/kg 처리구에서 제일 낮은 수치를 나타내었고 체중은 에너지 수준이 증가함에 따라서 증가하는 경향을 보였다 ($p=0.07$). 3산차에서 임신기 모돈의 체증은 에너지 수준이 증가함에 따라서 유의적으로 증가 하였다 ($p<0.05$). 포유기 사료섭취량은 1산차에서 에너지 수준이 높아짐에 따라 감소하는 경향을 보였고 ($p=0.08$) 포유기 체중과 증체량도 감소하는것으로 나타났다 ($p<0.05$, $p<0.05$). 등지방 두께는 1, 2, 3 산차 에서 모두 유의적인 차이를 나타내지

않았지만 등지방 두께 변화량은 1산차 임신기에서 에너지 수준이 증가함에 따라 유의적으로 증가 하였다 ($p<0.05$). 1산차부터 3산차까지 모돈 도태율은 69%로서 에너지 수준 3,100 kcal ME 처리구에서 제일 높은 수치를 나타내었다. 돈유의 화학적 성분은 모든 산차에서 유의적인 차이를 나타내지 않았다. 에너지 수준 3,200 kcal ME/kg 처리구가 2 산차에서 IgA 농도가 높은 경향을 나타 내었으며 ($p=0.08$) 3산차에서 IgG 농도가 높은 경향을 나타 내었다 ($p=0.05$). 결론적으로 보았을 때 임신기 모돈을 위한 일일 에너지 권장량은 1산차 6,400 혹은 6,600 kcal ME, 2산차 7,040 혹은 7,60 kcal ME, 3산차 7,680 혹은 7,920 kcal ME 가 적절하다고 생각된다.

Experiment 3. Effect of *Tenebrio molitor* Larva as an Energy Source on Reproductivity of Sows and Growth of their Progeny

본 실험은 거저리 유충을 포유기 사료 내 에너지 공급원으로 첨가 하였을 때 포유모돈의 번식성적과 자돈의 성장성적에 미치는 영향을 규명하고자 진행 되었다. 총 25두의 F1 (Yorkshire×Landrace) 모돈을 체중, 등지방, 산차를 고려하여 5 처리 5 반복으로 나뉘어 완전임의배치법으로 배치 하였다. 실험 처리구는 각각 1) CON (tallow 2%), 2) F1 (tallow 3%), 3) F2 (tallow 4%), 4) L1 (tallow 2%+*Tenebrio molitor* larva 1%) 와 5) L2 (tallow 2%+*Tenebrio molitor* larva 2%)으로 나뉘었다. 포유기 모돈의 체중과 등지방은 처리구간 유의적인 차이를 보이지 않았고 사료섭취량과 WEI도 처리구간 유의적인 차이를 보이지 않았다. 자돈의 복당체중과 복당증체량은 처리구간 유의적인 차이를 보이지 않았다. L1 처리구에서 모돈 혈액중 VLDL함량이 다른 처리구에 비해 높은 경향을 보였다 ($p=0.09$). BUN 농도는 L2 처리구에서 다은 처리구에 비해 낮은 수치를

보였다 (P<0.01). 이유 시 자돈 혈액 내 중성지방, VLDL, ALT 농도가 L1 처리구에서 다른 처리구에 비해 높게 나타났다 ($p<0.01$, $p<0.01$, $p<0.05$). 결론적으로 보았을 때 포유기 사료 내 거저리 유충 2%를 첨가 하였을 때 모돈의 번식성적과 자돈의 성장 성적에 부정적인 영향을 미치지 않은것으로 나타났으며 거저리 유충은 포유기 사료 내 다른 지방 소스를 대체하여 에너지 공급원으로 사용할 가능성이 있는것으로 사료된다.