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Backfat Thickness at First Insemination Affects Litter Size at Birth of the First Parity Sows

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ABSTRACT

The present study was undertaken to investigate the influence of backfat thickness (BF) at the first insemination on the litter size at birth of the first parity sows. In total, 249 Landrace × Yorkshire crossbred gilts were measured for BF at the last rib, about 6-8 cm away from the dorsal midline (P2) by A-mode ultrasonography. The BF measurement was performed three times on the gilts: the first day of insemination; the 70th day of the gestation period; and 1 w prior to the expected farrowing day. The gilts were categorized into three groups based on BF measured on the first insemination day: high (BF ≥ 17.0 mm, n=75), moderate (BF = 14.0-16.5 mm, n=121) and low (BF ≤ 13.5 mm, n=53). The results revealed that the average BF of the gilts was 15.4 ± 2.3, 17.7 ± 2.7, and 20.1 ± 2.9 mm on the first insemination day, the 70th day of gestation, and 1 w before farrowing, respectively. The gilts in the high group had a higher total number of piglets born per litter (TB; 13.1 ± 0.4) than those in the moderate group (12.0 ± 0.4, P = 0.04), and tended to have higher TB than those in the low group (12.1 ± 0.6, P = 0.1).
Keywords: backfat thickness, gilts, litter size at birth, A-mode ultrasonography

INTRODUCTION

Currently, swine production is considered one of the economically important livestock industries in Thailand (Kunavongkrit and Heard, 2000; Tummaruk *et al.*, 2010). In the breeding herds of the swine production industry, the replacement gilts are regarded as the major production unit, since the substitution of removed sows by the gilts amounts to approximately 40 - 55% per annum (Lucia *et al.*, 2000; Stalder *et al.*, 2005; Engblom *et al.*, 2007). In the preceding decade, the supplantation of the replacement gilts increased continually because the pig rearers decided to cull sows from the herd earlier than in the past (Engblom *et al.*, 2007; Roongsitthichai *et al.*, 2010). Moreover, a high mortality rate and many reproductive problems with sows in the first and second parities were observed (Roongsitthichai *et al.*, 2010). These resulted in the removal of a high proportion of sows in low and middle parities (Friendship *et al.*, 1986; Dial and Koketsu, 1996; Lucia *et al.*, 2000; Engblom *et al.*, 2007). An increase in the culling and replacement rates in the modern swine industry has led to a requirement to increase the size of the gilt pool and to optimize the administration of replacement stock. Therefore, the management of

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the gilts under field conditions is a crucial research area to be investigated. Information pertinent to the biological background of the gilts, such as backfat thickness (BF) is emphasized in order to develop appropriate breeding management practices on pig farms.

The body condition score (BCS) has been used traditionally for the selection of replacement gilts into the gilt pool. Moreover, in various commercial swine herds, gilts and sows are fed based on their BCS. However, BCS and BF are poorly correlated (r^2=0.19; Young *et al.*, 1991). A previous study undertaken in Canada and the United States of America demonstrates that sows with a BCS of 3 ranged in BF from 9 to 28 mm (Young *et al.,* 1991). This illustrates the need to determine more objective methods for measuring body condition, so that the feeding level can be adjusted more appropriately and the nutritional management is optimized to attain the highest yield from the pigs (Young *et al.*, 1991).

BF in pigs is normally used to predict fat quantity and lean content. The most common area to measure BF is the P2 position, which is about 6-8 cm from the dorsal midline at the same level as the last rib curve (Tummaruk *et al.*, 2009). Normally, BF measurement in pigs can be conducted by A-mode ultrasonography. In general, this procedure uses either an optical or an ultrasonic probe. Recent studies indicate that an ultrasonic probe is preferable to measure BF in live animals (Magowan and McCann, 2006). The present study used a Renco lean meter ultrasonic probe, which has been proven to be as accurate as other ultrasonic probes (Kanis *et al.*, 1986).

Earlier studies demonstrated a close relationship between BF and the reproductive performance in female pigs. For example, the gilts with high BF were younger at first mating and had a shorter wean-to-first-service interval, a larger litter size and a higher farrowing rate (FR) as the second parity sows compared with those with low BF (Tummaruk *et al.*, 2001a,b). Generally, the litter size at birth of the gilts can be measured by various indicators, including the total number of piglets born per litter (TB), the number of piglets born alive per litter (BA), the proportion of stillborn piglets per litter (SB), and the proportion of mummified fetuses per litter (MM). TB is dependent on the number of ovulations, the fertilization rate and the number of embryonic/fetal survivals. The embryonic/fetal number is highly correlated with the size of the sow's uterus (Pâ rez-Enciso *et al.*, 1996). It has been shown that a smaller uterine size contributes to an increase in the number of mummified fetuses (Wu *et al.*, 1988). The heritability of litter size has been reported as relatively low (h^2=0.1; Imboonta *et al.*, 2007). Environmental factors therefore, are an important influence on variation in the litter size. In most cases, parity number is the first priority when considering the factors that influence the litter size in sows (Tummaruk *et al.*, 2000, 2004, 2010). Litter size is generally smallest in the first parity and is largest from parity numbers 3 to 6, after which it slowly declines as the parity number increases (Tummaruk *et al.*, 2000). Thus, an increase in the litter size of first parity sows may substantially improve the overall herd productivity. No evidence was found in the literature of a comprehensive study on the relationship between BF at first insemination and during gestation with the litter size at birth of first parity sows. The objective of the present study was to investigate the influence of BF at insemination on the litter size at birth of first parity sows.

MATERIALS AND METHODS

Animals and management

The present study was carried out in a 900-sow-scaled commercial swine herd in Eastern Thailand between November 2008 and February 2010. In total, 249 Landrace × Yorkshire crossbred gilts were included. All gilts were introduced to the gilt pool at about age 20-24 w with a body weight range 80-100 kg. In the gilt pool, water was available ad libitum from water nipples, feed was supplied twice a day (about 3 kg/d/head). The feed was a rice bran-corn-soybean-fish base containing 16-18% crude protein, 2,800-3,400 kcal/kg metabolizable energy, and 0.85-1.00% lysine. The breeding herd produced replacement gilts internally using its own grandparent stock. All the gilts were accommodated in conventional-open houses facilitated with water foggers and electric fans. In general, the gilts were vaccinated against foot and mouth disease, classical swine fever, Aujeszky's disease, porcine Parvovirus, porcine reproductive and respiratory syndrome, porcine Circovirus type 2, swine influenza virus, atrophic rhinitis, Mycoplasmosis, and Actinobacillosis pleuropneumonia between age 20 and 32 w. In each pen, approximately 6-10 gilts were raised with a density of 1.5-2.0 m^2/gilt. Boar contact and estrous detection of all gilts were performed between age 24 and 32 w. A mature boar was presented to the gilts with fence line contact once or twice a day. The estrous detection was performed on a daily basis by a back pressure test, along with an observation of vulvar characteristics. The gilts with clear vulvar mucus and/or expressing a standing estrus were recorded. Generally, the gilts were inseminated from age 32 w onwards, when they weighed at least 130 kg at the second or later observed estrus. Intra-uterine artificial insemination (Sumransap *et al.*, 2007) was used for all gilts, with diluted fresh semen having at least $3{,}000 \times 10^6$ spermatozoa/100 mL. Such semen was used either to inseminate the gilts immediately or within 24 h after preparation.

Measurement of body weight and average daily gain

The body weight of all the replacement gilts entering the herd was measured individually at age 150 d, using a conventional balance. In addition, average daily gain (ADG, g/d) was calculated from the date of birth to age 150 d using Equation1:

$$ADG = [(\text{body weight}_{(kg)} - 1.5) \times 1000]/ 150. \quad (1)$$

Measurement of backfat thickness

The measurement of BF in the gilts was performed using A-mode ultrasonography (Renco lean meter®, Minneapolis, MN, USA) at the P2 position, about 6-8 cm from the dorsal midline, on both sides above the last rib of the gilts. The average value of the two sides was calculated and recorded as the BF of the gilt (Tummaruk *et al.*, 2009). The BF was measured three times; first, on the day of insemination (BF1), secondly, on the 70^{th} day of gestation (BF2), and finally, 1 w before the expected farrowing day (BF3). Moreover, the BF gain (BFG) was also calculated for each interval, as BFG1 (the insemination day to the 70^{th} day of gestation) and BFG2 (the 70^{th} day of gestation to 1 w before farrowing). The gilts were categorized according to the value of BF1 into high (BF ≥ 17.0 mm), moderate (BF = 14.0-16.5 mm), and low (BF ≤ 13.5 mm). The BFG of the gilts was also classified into three classes: high (BFG ≥ 7.0 mm), moderate (BFG 2.5-6.5 mm), and low (BFG ≤ 2.0 mm).

Data collection

The data collected from the gilts included individual identity, date of birth, body weight at age 150 d, ADG at age 150 d, date of insemination, BF1, BF2, BF3, date of farrowing, TB, BA, MM, SB and age at first farrowing. Additionally, TB, BA, MM, and SB were recorded within 12 h of farrowing. Age at first farrowing was calculated from the difference between the date of farrowing and the date of birth.

Statistical analysis

The data in the present study were analyzed statistically using the Statistical Analysis System (SAS) software version 9.0 (SAS Inst. Inc., Cary, NC, USA). Descriptive statistics were calculated, including the mean, standard deviation, and range of all variables, which were body weight, BF1, BF2, BF3, BFG, ADG, TB, BA, MM and SB. The correlation among body weight, BF1, BF2, BF3, BFG, and age at first farrowing was analyzed using Pearson's correlation. The gilts were also classified according to age (w) at first mating. The effect of BF1, BFG and age at first mating on TB, BA, SB, MM, and age at first farrowing was analyzed using a general linear model procedure. The statistical models included BF1 class (high, moderate, low) as the independent variable and TB, BA, MM, SB; and age at first farrowing as dependent variables. The BFG class (high, moderate, low) and age at first mating were included in the statistical model as independent variables. Least-squares means and the standard error of the means were obtained from each class of the factors and were compared using a least significant difference test. The effect of BF1 class on farrowing proportion was analyzed by a chi-squared test. Values with $P < 0.05$ were regarded as statistically significant.

RESULTS

The measurement of BF at the P2 position from 249 gilts in the present study revealed mean values (± standard deviation, SD) for BF1, BF2 and BF3 of 15.4 ± 2.3, 17.7 ± 2.7 and 20.0 ± 2.9 mm, respectively (Table1). On average, the gilts gained 4.7 ± 3.1 mm of BF during the gestation period. However, among individuals, the BFG varied substantially from -4.0 to 14.0 mm. Mean values for BFG1 and BFG2 were 2.3 ± 2.8 and 2.5 ± 2.4, respectively. Table 1 shows descriptive statistics for body weight at age 150 d, ADG, BF1, BF2, BF3 and FR. Mean values for TB, BA, SB and MM of the gilts in the present study were 12.4 ± 3.6 piglets per litter, 10.8 ± 3.7 piglets per litter, 9.7% and 3.8%, respectively.

Based on the BF classification, the gilts in the high group produced 13.1 ± 0.4 TB, while those in the moderate and low groups had 12.0 ± 0.4 and 12.1 ± 0.6 TB, respectively (Table 2). During the gestation period, the gilts gained BF from -4.0 to 14.0 mm. Based on the BF1 classification, the gilts in the high group had a mean BFG of approximately 3.3 ± 0.4 mm, whereas those in the moderate and low groups had mean BFG of 4.8 ± 0.3 and 6.3 ± 0.5 mm, respectively. The BFG and TB of gilts in the present study were not significantly correlated ($r= -0.09$, $P=0.22$). The influence of BFG on TB, BA,

Table 1 Descriptive statistics of body weight at age 150 d, average daily gain (ADG), backfat thickness (BF) at first insemination, at 70 d gestation, at 1 w before farrowing, farrowing rate and litter size at birth in Landrace x Yorkshire (LY) crossbred gilts.

Parameter	N	Mean± standard deviation	Range
Body weight at age 150 d (kg)	247	78.8±8.1	63.0-111.0
ADG (g/day)	247	525.3±53.7	420.0-740.0
BF at first insemination (mm)	249	15.4±2.3	10.0-24.5
BF at 70 d gestation (mm)	227	17.7±2.7	11.0-26.0
BF at 1 w before farrowing (mm)	192	20.0±2.9	9.0-26.0
Farrowing rate (%)	249	84.0	0.0-100.0
Total number of piglets born/ litter	197	12.4±3.6	3-28
Number of piglets born alive/ litter	197	10.8±3.7	0-19
Mummified fetuses/litter (%)	197	3.8	0.0-58.0
Stillborn piglets/litter (%)	197	9.7	0.0-100.0

SB, and MM demonstrated in Table 3 shows that the gilts with a high BFG tended to have a lower TB than those with low and moderate BFG (*P*=0.1).

The distribution of the gilts according to age (w) at first mating was: less than 34 (n = 18), 35 (n = 22), 36 (n = 24), 37 (n = 20), 38 (n = 26), 39 (n = 36), 40 (n = 36), 41 (n = 40), and more than 42 (n = 27), respectively. On average, the gilts were inseminated for the first time at age 272.9 ± 19.3 d or age 38.9 ± 2.8 w (age range 31-45 w) and farrowed at age 388.6±19.3 d. The gilts inseminated at age 35 w tended to deliver more TB than those inseminated at less than age 34 w (11.0 ± 0.9 versus 13.2 ± 0.8 TB; *P*=0.06). However, the gilts first inseminated at age 35 w onwards showed no statistical difference in terms of TB (Table 4). The age at first farrowing of the gilts with varying BF1 was not significantly different (*P*>0.05).

DISCUSSION

In the present study, the gilts with high BF at the first insemination farrowed with the largest TB, with respect to all other groups. This corresponded with the findings of Tummaruk *et al*. (2009) that the BF of gilts might predominate over their reproductive performance. Furthermore, not only was there a shorter wean-to-first-service interval for the gilts with high BF, but also an extra 0.1 piglet per litter would be farrowed in the next

Table 2 Effect of backfat thickness (BF) at insemination on litter size at birth, age at first farrowing of the first parity sows, farrowing rate and backfat gain (BFG) of the gilts. (Least-squares mean± standard error of the mean).

Variable	Backfat thickness		
	Low (≤13.5 mm)	Moderate (14.0-16.5 mm)	High (≥17.0 mm)
Total number of piglets born/ litter	12.1±0.6[ab]	12.0±0.4[a]	13.1±0.4[b]
Number of piglets born alive/ litter	10.6±0.6[a]	10.8±0.4[a]	10.8±0.4[a]
Mummified fetuses/litter (%)	4.3±1.3[a]	3.5±0.9[a]	3.9±1.0[a]
Stillborn piglets/litter (%)	8.0±2.8[a]	7.2±1.8[a]	14.5±2.2[b]
Age at first farrowing (d)	387.4±3.0[a]	388.0±2.0[a]	390.2±2.5[a]
Farrowing rate (%)	82.0[a]	82.6[a]	86.7[a]
Backfat gain (mm)	6.3±0.5[a]	4.8±0.3[b]	3.3±0.4[c]

[a,b,c] Different superscripts within a row are significantly different (*P* < 0.05).

Table 3 Influence of backfat gain (BFG) during gestation on total number of piglets born/litter (TB), number of piglets born alive/litter (BA), percentage of mummified fetuses/litter (MM) and percentage of stillborn piglets/litter (SB).

Variable	Low BFG (≤2.0 mm)	Moderate BFG (2.5-6.5 mm)	High BFG (≥7.0 mm)
TB (piglets/litter)	12.5±0.6[a]	12.5±0.4[a]	11.8±0.5[a]
BA (piglets/litter)	11.1±0.6[a]	11.0±0.4[a]	10.0±0.6[a]
MM (%)	3.5±1.3[a]	4.2±0.8[a]	3.0±1.3[a]
SB (%)	11.3±2.8[a]	9.6±1.8[a]	9.2±3.0[a]

[a] Means with common letters do not differ significantly (*P* > 0.05).

Table 4 Total number of piglets born per litter (TB; Least-squares mean ±standard error of the mean) categorized by age at first mating in gilts.

Age at first mating (w)	N*	TB
≤ 34	17	11.0±0.9[a]
35	18	13.2±0.8[a]
36	22	11.8±0.8[a]
37	19	13.2±0.8[a]
38	22	12.0±0.8[a]
39	28	12.8±0.7[a]
40	28	12.5±0.7[a]
41	30	12.9±0.7[a]
≥ 42	22	11.6±0.8[a]

* N = number of pigs which could farrow a litter.

[a] Means with common letters do not differ significantly ($P > 0.05$).

parity (Tummaruk *et al*., 2001a). Moreover, Tarrés *et al*. (2006) performed a growth test on the gilts and found that if the BF at the end of the growth test decreased, culling rate according to low productivity and sow mortality increased. In addition, the gilts with BF < 16 mm at the end of growth test tended to be removed from the herd owing to low productivity, since they had a litter size at weaning of less than 7.5 piglets per litter (Tarrés *et al.,* 2006).

In the present study, the gilts in the high group significantly had the lowest BFG, and vice versa. Based on observations in the present study, when members of the feeding staff observed that a pregnant gilt was very thin, they would feed the gilt more than its programmed feeding regimen, with an expectation that the animal would reach an optimum BCS. This led to overfeeding in the gestating pen, especially in the gilts in the low group. Overfeeding in the gestation period could increase the BF accumulation of the gilts. Aherne and Kirkwood (1985) indicated that the amount of feed in the gestation period affected the serum progesterone (P_4) level and porcine embryo survival. Providing that the pigs were fed a large amount in the gestation period, mean blood P_4 concentration would be 11.8 ng/mL, with 71.9% embryo survival. On the other hand, if a lower quantity of feed was provided during this period, the mean blood P_4 concentration would be 71.9 ng/mL and the survival percentage of pig embryos was 82.8%. This highlighted that the amount of feed provided did affect the pig litter size at birth.

Despite the higher number of TB, the gilts in the high group delivered more SB piglets than those in both moderate and low groups. This might have been caused by an obstruction in the birth canal contributing to difficulty in farrowing and the procrastination of piglet delivery (Ash, 1986; Dial *et al*., 1992; Muirhead and Alexander, 2000). Moreover, an overweight female would have prolonged parturition and, subsequently, increased SB due to the fetal canal being less stretched and weak contraction of the uterus (Bos, 1987). Furthermore, SB could also be associated with secondary uterine inertia. Such condition might occur in a farrowing complicated by the delivery of a large litter size and/or large piglets (Ash, 1986).

The BF measurement in the replacement LY crossbred gilts in the present study was analyzed to determine whether BF was one of the factors dominating litter size at birth in the first parity sows. Body condition assessment of sows in the modern swine production industry has become a major issue, since the main objective of most farms is to achieve economic targets. In previous studies, the body condition of pigs was estimated based on a single visual score (Zaleski and Hacker, 1993; Le Colzer *et al*., 2002; Lucia *et al*., 2002; Borges *et al*., 2005). To evaluate the body condition, visual scoring, ranging from 1 to 5, by pig handlers was an objective way under field conditions (Maes *et al*., 2004). Although grading BCS visually might be applicable and work well in certain farms, various drawbacks could be apparenty observed. First, very thin pigs might have high BF (Muirhead and Alexander, 1997). Second, visual scoring is an individual skill that might be subjective and imprecise. Last, when a pig handler is responsible for the regular scoring of BCS in the herd over time with the same herd, herd blindness might take place due to less attention being by the paid scorers. Furthermore, grading BCS might be far more difficult in a herd containing more than one breed of pigs on account of the inherent variation among breeds (Whittemore and Schofield, 2000). As a result, the measurement of BF has become a more objective and precise way of appraising the body condition in pigs (Charette *et al*., 1996).

To inseminate the gilts, the inseminator should pay attention to estrous expression and the body weight of the gilts. In general, the gilts should be inseminated when they weighed at least 130 kg and had expressed their second or later estrus (Schukken *et al*., 1994; Koketsu, 1999; Tummaruk *et al*., 2001b). In the present study, the gilts were inseminated at age approximately 272.9 d with an average BF of 15.4 mm. A preceding study demonstrated that the conception of gilts should take place before age 220 d (Schukken *et al*., 1994). This indicated that the replacement gilts in the present study may not have reached an optimal BF and body weight before age 220 d. Consequently, the recommended age for first insemination of LY crossbred gilts should take account of BF and body weight. Based on the present findings, it is recommended that the gilts be inseminated whenever they have at least 17 mm BF since, in the current study, the gilts first inseminated that had at least 17 mm BF had one more piglet, but the farrowing time was delayed for 2 d compared with those who were first inseminated with less than 17 mm BF. Moreover, Young *et al*. (1990), who experimented by inseminating the replacement gilts when they expressed the second or third estrus, reported that TB was more farrowed and conception rate was better compared with mating the gilts at the first-observed estrus. In the present study, a tendency of TB difference between the gilts inseminated at age less than 34 w and at age 35 w onwards was abserved. Furthermore, Tummaruk *et al*. (2001a) ascertained that 0.1 piglet per litter would increase if the age at first insemination of the gilts was adjourned by 10 d.

CONCLUSION

The present study demonstrated that the gilts first inseminated with BF of 17 mm or more had a higher TB on farrowing than those first inseminated with BF of 14.0-16.5 mm. In practice, the gilt rearers ought to concentrate on gilt management in terms of nutritional and feed provision, estrous detection, insemination time and objective methods for evaluating body condition, such as BF measurement, in order to prepare high quality sows for subsequent parities.

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LITERATURE CITED

Aherne, F.X. and R.N. Kirkwood. 1985. Nutrition and prolificacy. **J. Reprod. Fert. Suppl.** 33: 169-183.

Ash, M. 1986. Management of the farrowing and lactating sow, pp. 931-934. *In* D.A. Morrow (ed). **Current Therapy in Theriogenology**. 2nd ed. W.B. Saunders Company, Philadelphia.

Borges, V.F., M.L. Bernadi, F.P. Bortolozzo and I. Wentz. 2005. Risk factors for stillbirth and foetal mummification in four Brazillian swine herds. **Prev. Vet. Med.** 70: 165-176.

Bos, F. 1987. Pre and ante care saves piglet's lives. **Pigs-Misset (March-April).** 28-29.

Charette, R., M. Bigras-Poulin and G. Martineau. 1996. Body condition evaluation in sows. **Livest. Prod. Sci.** 46: 107-115.

Dial, G., W.E. Marsh, D.D. Poison and J.P. Vaillancourt. 1992. Reproductive failure: differential diagnosis, pp. 88-137. *In* A.D., Leman, B.E., Straw, W.L., Mengeling, S., D'allaire and D.J. Taylor (eds.). **Disease of Swine**. Iowa State University Press, Ames, Iowa.

Dial, G. and Y. Koketsu. 1996. Reproductive failure understanding the reasons that sows are culled for infertility, pp. 15-16. *In* J. Deen (ed.). **International Piletter. Pig World**, Inc., Owalonna, MN.

Engblom, L., N. Lundeheim, A-M. Dalin and K. Andersson, 2007. Sow removal in Swedish commercial herds. **Livest Sci.** 106: 76-86.

Friendship, R.M., M.R. Wilson, G.W. Almond, I. McMillan, R.R. Hacker, R. Pieper and S.S. Swaminathan. 1986. Sow wastage: Reasons for and effect on productivity. **Can. J. Vet. Res.** 50: 205-208.

Imboonta, N., L. Rydhmer and S. Tumwasorn. 2007. Genetic parameters and trends for production and reproduction traits in Thai Landrace sows. **Livest Sci.** 111: 70-79.

Kanis, E., H.A.M. van der Steen, K. de Roo and P.N. de Groot. 1986. Prediction of lean parts and carcass price from ultrasonic backfat measurements in live pigs. **Livest. Prod. Sci.** 14: 55-64.

Koketsu, Y., H. Takahashi and K. Akachi. 1999. Longevity, lifetime pig production and productivity, and age at first conception in a cohort of gilts observed over six years on commercial farms. **J. Vet. Med. Sci.** 61: 1001-1005.

Kunavongkrit, A. and T. Heard. 2000. Pig reproductive in South East Asia. **Anim. Reprod. Sci.** 60-61: 527-533.

Le Cozler, Y., Guyomarc'h, X. Pichodo, P. Quinio and H. Pellios, 2002. Factors associated with stillborn and mummified piglets in high-prolific sows. **Anim. Res.** 51: 261-268.

Lucia Jr., T., G.D. Dial and W.E. Marsh. 2000. Lifetime reproductive performance in female pigs having distinct reasons for removal. **Livest. Prod. Sci.** 63: 213-222.

Lucia, T., M.M. Corrêa, J.C. Deschamps, I. Bianchi, M. Donin, A. Machado, W. Meincke and J.E.M. Matheus. 2002. Risk factors for stillbirths in two swine farms in the south of Brazil. **Prev. Vet. Med.** 53: 285-292.

Maes, D.G.D., G.P.J. Janssens, P. Delputte, A. Lammertyn and A. de Kruif. 2004. Back fat measurements in sows from three commercial pig herds: Relationship with visual body condition scores. **Livest. Prod. Sci.** 91: 57-67.

Magowan, E. and M.E.E. McCann. 2006. A comparison of pig backfat measurements using ultrasonic and optical instruments. **Livest Sci.** 103: 116-123.

Muirhead, M. and T. Alexander. 1997. **Nutrition and Disease**. Managing Pig Health and the Treatment of Disease. A Reference for the Farm. 5M Enterprises, Sheffield, UK, pp. 441-470.

Muirhead, M.R. and T.J.L. Alexander. 2000. The management of infertility. A pocket guide to recognizing and treating pig infertility, pp. 43-102. *In* M.R. Muirhead and T.J.L. Alexander (eds.). **The Management of Infertility**. 5M Enterprises, Sheffield.

Pârez-Enciso, M., J.P. Bidanel, I. Baquedano and J. L. Noguera. 1996. A comparison of alternative genetic models for litter size in pigs. **Animal Science** 63: 255-264.

Roongsitthichai, A., E. Olanratmanee, S. Koonjaenak, M. Techakumphu and P. Tummaruk. 2010. The Removal of Gilts and Primiparous Sows from Swine Breeding Herds in Thailand. pp. 1011. *In* **Proc. 21st International Pig Veterinary Society (IPVS) Congress,** Vancouver, British Columbia, Canada, July 18-21, 2010.

Schukken, Y.H., J. Burman, R.B.M. Huirne, A.H. Willemse, J.C.M. Vernooy, J. van den Broek and J.H.M. Verheijden. 1994. Evaluation of optimal age at first conception in gilts from data collected in commercial swine herds. **J. Anim. Sci.** 72: 1387-1392.

Stalder, K.J., A.M. Saxton, G.E. Conatser and T.V. Serenius, 2005. Effect of growth and compositional traits on first parity and lifetime reproductive performance in U.S. Landrace sows. **Livest. Prod. Sci.** 97: 151-159.

Sumransap, P., P. Tummaruk and A. Kunavongkrit, 2007. Sperm distribution in the reproductive tract of sows after intrauterine insemination. **Reprod. Domest. Anim.** 42: 113-117.

Tarrés, J., J. Tibau, J. Piedrafita, E. F·brega and J. Reixach. 2006. Factors affecting longevity in maternal Duroc swine lines. **Livest. Sci.** 100: 121-131.

Tummaruk, P., N. Lundeheim, S. Einarsson and A.-M. Dalin. 2000. Factors influencing age at first maing in purebred Swedish Landrace and Swedish Yokshire gilts. **Anim. Reprod. Sci.** 63: 241-253.

Tummaruk, P., N. Lundeheim, S. Einarsson and A.-M. Dalin. 2001a. Effect of birth litter size, birth parity number, growth rate, backfat thickness and age at first mating of gilts on their reproductive performance as sows. **Anim. Reprod. Sci.** 66: 225-237.

Tummaruk, P., N. Lundeheim, S. Einarsson and A.-M. Dalin. 2001b. Repeat breeding and subsequent reproductive performance in Swedish Landrace and Swedish Yorkshire sows. **Anim. Reprod. Sci.** 67: 267-280.

Tummaruk, P., W. Tantasuparuk, M. Techakumphu and A. Kunawongkrit. 2004. Effect of season and outdoor climate on litter size at birth in purebred Landrace and Yorkshire sows in Thailand. 2004. **J. Vet. Med. Sci.** 66: 477-482.

Tummaruk, P., W. Tantasuparuk, M. Techakumphu and A. Kunavongkrit, 2009. The association between growth rate, body weight, backfat thickness and age at first observed oestrus in crossbred Landrace x Yorkshire gilts. **Anim. Reprod. Sci.** 110: 108-122.

Tummaruk, P., W. Tantasuparuk, M. Techakumphu and A. Kunavongkrit, 2010. Seasonal influences on the litter size at birth of pig are more pronounced in the gilt than sow litter. **J. Agric. Sci.** 148: 421-432.

Whittemore, C. and C. Schofield. 2000. A case for size and shape scaling for understanding nutrient use in breeding sows and growing pigs. **Livest. Prod. Sci.** 65: 203-208.

Wu, M.C., M.D. Hentzel and P.J. Dziuk. 1988. Effect of stage of gestation, litter size and uterine space on the incidence of mummified fetuses in pigs. **J. Anim. Sci.** 66:3202-3207.

Young, L.G., G.J. King, J.S. Walton, I. McMillan and M. levorick. 1990. Age, weight, backfat and time of mating effects on performance of gilts. **Can. J. Aim. Sci.** 70: 469-481.

Young, L.G., G.J. King, J. Shaw, M. Quinton, J.S. Walton and I. McMillan. 1991. Interrelationship among age, bodyweight, backfat and lactation feed-intake with reproductive performance and longevity of sows. **Can. J. Anim. Sci.** 71: 567-575.

Zaleski, H.M. and R.R. Hacker. 1993. Variables related to the progress of parturition and probability of stillbirth in swine. **Can. Vt. J.** 34: 109-113.