ความสัมพันธ์ทางพันธุกรรมของอายุการใช้งานแม่สุกรกับอัตราการเจริญเติบโตต่อวัน
และความหนาไขมันสันหลัง

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GENETIC ASSOCIATIONS OF SOW LONGEVITY WITH AVERAGE DAILY GAIN AND BACKFAT THICKNESS

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for the Degree of Master of Science Program in Animal Breeding
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ณัฏฐา วงศาขจรกิจ : ความสัมพันธ์ทางพันธุกรรมของอายุการใช้งานแม่สุกรกับอัตราการเจริญเติบโตต่อวันและความหนาไขมันสันหลัง (GENETIC ASSOCIATIONS OF SOW LONGEVITY WITH AVERAGE DAILY GAIN AND BACKFAT THICKNESS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: อ. ดร.นลินี อิ่มบุญตา, 76 หน้า.

ข้อมูลแม่สุกรคัดทิ้งทั้งหมดจำนวน 2,865 ตัว มาจากแม่สุกรพันธุ์แท้แลนด์เรซ 1,706 ตัว และแม่สุกรพันธุ์แท้ยอร์คเชียร์ 1,159 ตัว ที่ถูกคัดทิ้งในฟาร์มสุกรพ่อแม่พันธุ์แห่งหนึ่งของประเทศไทย ในช่วงระหว่างปี พ.ศ. 2551-2556 ถูกนำมาใช้ในการประเมินค่าอัตราพันธุกรรม และค่าสหสัมพันธ์ทางพันธุกรรมระหว่างลักษณะอายุการใช้งานแม่สุกร อัตราการเจริญเติบโต และความหนาไขมันสันหลัง อายุการใช้งานแม่สุกรวัดได้จาก จำนวนวันที่นับตั้งแต่วันที่แม่สุกรคลอดลูกครั้งแรกจนถึงวันที่แม่สุกรถูกคัดทิ้ง ค่าองค์ประกอบความแปรปรวนและความแปรปรวนร่วมถูกประเมินโดยใช้แบบหุ่นของตัวสัตว์และทำการวิเคราะห์หลายลักษณะพร้อมกัน ด้วยวิธี restricted maximum likelihood (REML) ค่าองค์ประกอบความแปรปรวนและความแปรปรวนร่วมถูกใช้ในการคำนวณค่าพารามิเตอร์ทางพันธุกรรมของลักษณะที่ทำการศึกษาทุกลักษณะ ผลการศึกษาพบว่า ค่าเฉลี่ยของอายุการใช้งานแม่สุกร อัตราการเจริญเติบโต และความหนาไขมันสันหลัง สำหรับแม่สุกรพันธุ์แลนด์เรซ มีค่าเท่ากับ 633 วัน 863 กรัม/วัน และ 11.8 มิลลิเมตร ตามลำดับ สำหรับแม่สุกรพันธุ์ยอร์คเชียร์ มีค่าเท่ากับ 579 วัน 805 กรัม/วัน และ 10.7 มิลลิเมตร ตามลำดับ ค่าอัตราพันธุกรรมของอายุการใช้งานแม่สุกร อัตราการเจริญเติบโต และความหนาไขมันสันหลัง มีค่าเท่ากับ 0.15 ± 0.03, 0.31 ± 0.05 และ 0.57 ± 0.07 ในแม่สุกรพันธุ์แลนด์เรซ และ 0.11 ± 0.03, 0.23 ± 0.05 และ 0.46 ± 0.07 ในแม่สุกรพันธุ์ยอร์คเชียร์ ตามลำดับ อายุการใช้งานแม่สุกรมีสหสัมพันธ์ทางพันธุกรรมแบบไม่พึงประสงค์กับอัตราการเจริญเติบโต (-0.27 ± 0.12 ในแม่สุกรพันธุ์แลนด์เรซ และ -0.36 ± 0.15 ในแม่สุกรพันธุ์ยอร์คเชียร์) และกับความหนาไขมันสันหลัง (0.24 ± 0.10 ในแม่สุกรพันธุ์แลนด์เรซ และ 0.30 ± 0.13 ในแม่สุกรพันธุ์ยอร์คเชียร์) อัตราการเจริญเติบโตมีสหสัมพันธ์ทางพันธุกรรมแบบพึงประสงค์กับความหนาไขมันสันหลังในแม่สุกรพันธุ์แลนด์เรซเท่านั้น (-0.21 ± 0.10) ส่วนในแม่สุกรพันธุ์ยอร์คเชียร์มีแนวโน้มว่าจะมีความสัมพันธ์แบบพึงประสงค์อย่างไรก็ตามค่าสหสัมพันธ์มีค่าไม่ต่างจากศูนย์ (-0.18 ± 0.12) ผลจากการศึกษาค่าอัตราพันธุกรรม บ่งชี้ว่าการคัดเลือกเพื่อเพิ่มอายุการใช้งานแม่สุกรสามารถเป็นไปได้ อย่างไรก็ตามผลจากการศึกษาครั้งนี้ยังชี้ให้เห็นว่า การคัดเลือกเพื่อเพิ่มอัตราการเจริญเติบโตและลดความหนาไขมันสันหลัง จะส่งผลให้อายุการใช้งานแม่สุกรลดลง นอกจากนี้การคัดเลือกเพื่อเพิ่มอัตราการเจริญเติบโต ยังส่งผลให้ความหนาไขมันสันหลังลดลง ในทำนองเดียวกันการคัดเลือกเพื่อลดความหนาไขมันสันหลังยังช่วยทำให้อัตราการเจริญเติบโตเพิ่มขึ้น ถึงแม้ว่า อายุการใช้งานแม่สุกรจะเป็นลักษณะที่มีค่าอัตราพันธุกรรมต่ำ แต่ก็มีความสำคัญทางเศรษฐกิจสูง ดังนั้น จึงควรพิจารณาลักษณะอายุการใช้งานแม่สุกรเป็นเกณฑ์การคัดเลือกในการวางแผนผสมพันธุ์

ภาควิชา	สัตวบาล	ลายมือชื่อนิสิต	....
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NUTTHA WONGSAKAJORNKIT: GENETIC ASSOCIATIONS OF SOW LONGEVITY WITH AVERAGE DAILY GAIN AND BACKFAT THICKNESS. ADVISOR: NALINEE IMBOONTA, Ph.D., 76 pp.

Data collected from 2,865 removed sows (1,706 Landrace and 1,159 Yorkshire) in a Thai swine breeding herd from 2008 to 2013 were used to estimate the heritability and genetic correlations among sow longevity, average daily gain, and backfat thickness. Sow longevity was determined as the number of days from first farrowing to removal dates. Estimation of variance and covariance components were carried out with multiple – trait animal models using restricted maximum likelihood (REML) method. The variance and covariance components were used to calculate genetic parameters of all traits. The average sow longevity, average daily gain, and backfat thickness were 633 days, 863 g/day and 11.8 mm for Landrace; 579 days, 805 g/day and 10.7 mm for Yorkshire, respectively. Heritability estimates of sow longevity, average daily gain, and backfat thickness were 0.15 ± 0.03, 0.31 ± 0.05 and 0.57 ± 0.07 for Landrace and 0.11 ± 0.03, 0.23 ± 0.05 and 0.46 ± 0.07 for Yorkshire, respectively. Sow longevity unfavorably genetically correlated with average daily gain (-0.27 ± 0.12 in Landrace and -0.36 ± 0.15 in Yorkshire) and with backfat thickness (0.24 ± 0.10 in Landrace and 0.30 ± 0.13 in Yorkshire). Average daily gain genetically correlated favorably with backfat thickness only in Landrace (-0.21 ± 0.10). Although genetic correlation between average daily gain and backfat thickness in Yorkshire tended to be favorable, it was not significantly different from zero (-0.18 ± 0.12). The results revealed that the heritability estimates would be possible to be selected for sow longevity. However, the selection for high average daily gain or low backfat thickness may result in decreased sow longevity. Besides, it was possible to select for average daily gain without adversely affecting backfat thickness and vice versa. Although sow longevity was lowly heritable, it contributed to high economic importance. Thus, sow longevity should be considered to use as a selection criterion in breeding program.

Department:	Animal Husbandry	Student's Signature	....
Field of Study:	Animal Breeding	Advisor's Signature	....
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CHAPTER I

INTRODUCTION

Sow longevity plays an important role in efficient piglet production because it is an ability of sows to survive and produce more piglets in the herd (Serenius and Stalder, 2004). It is, therefore, directly associated with the lifetime number of piglets produced (Serenius and Stalder, 2006b). Sows having high longevity may have a greater opportunity for piglet production. Hence, improving sow longevity can increase herd productivity (Sasaki and Koketsu, 2011).

Besides, sow longevity is one of the functional traits being improved in order to reduce herd production costs (Yazdi et al., 2000). Herds having high sow longevity lead to a decrease in culling and replacement rates (Koketsu, 2007). When replacement rate is low, the preparatory costs of replacement gilts usually decrease as the proportion of sows reaching their maximum productivity increase (Hoge and Bates, 2011). Moreover, low replacement rate results in low risk of many transmissible diseases to the sow facility (Serenius and Stalder, 2006b).

According to earlier studies, sow longevity is commonly used as female life day (Koketsu et al., 1999), sow herd life days (Takanashi et al., 2011), and length of productive life (Serenius and Stalder, 2004). It can be the number of days from birth date (Koketsu et al., 1999), first service date (Takanashi et al., 2011), or first farrowing date (Serenius and Stalder, 2004) to removal date.

In the herds, sows are mainly removed with planned and unplanned phenomena. Those with low longevity are always removed with unplanned reasons, such as reproductive disorders and legs problems (Engblom et al., 2008). Moreover, this event mainly occurs with younger sows (Engblom et al., 2007; Segura-Correa et al., 2011a). Approximately 15 to 20% of the removed sows can produce only one litter. In addition, more than 50% of them are removed before reaching their fifth parity (Lucia et al., 2000a; Engblom et al., 2007; Koketsu, 2007). Nonetheless, those having high longevity are mainly removed due to old age and low production (Engblom et al., 2008; Hughes et al., 2010) which are called planned removal; it usually occurs in the sows with a parity number 5-8 (Lucia et al., 2000b; Engblom et al., 2007). Thus, planned removal causes an increase in high longevity sows and herd productivity. (Engblom et al., 2007).

Sow longevity can be affected by several factors. Not only the sow's biology, but also breed, season, age at first conception, age at first farrowing, litter size, and weaning-to-first-service interval (Koketsu et al., 1999; Koketsu, 2000; Yazdi et al., 2000; Tantasuparuk et al., 2001a; Johnson and Nugent, 2003; Hoge and Bates, 2011). Additionally, it depends on the herdsman's decision in each herd (Engblom et al., 2008). Improving genetics, managements, and environments can increase sow longevity (Knauer et al., 2010). Heritability estimates for sow longevity vary from 0.05 to 0.27 (Serenius and Stalder, 2004; Engblom et al., 2009; Sobczyńska et al., 2013). Although those are relatively low, genetic variation is sufficient to increase sow longevity by selection (Yazdi et al., 2000).

Nowadays, swine production plays an important role in livestock industry of Thailand. In commercial swine production, great emphasis is placed on improving production traits, such as average daily gain and backfat thickness (Tarres et al., 2006). Generally, moderate-to-high heritability estimates are obtained for production traits (Lo et al., 1992). The heritability estimates range from 0.29 to 0.40 for average daily gain, and from 0.30 to 0.61 for backfat thickness (López-Serrano et al., 2000; Serenius and Stalder, 2004; Imboonta et al., 2007b). In addition, the selection for improved average daily again and reduced backfat thickness influences the sow longevity (Hoge and Bates, 2011). The genetic correlations among sow longevity, average daily gain, and backfat thickness are found to be unfavorable for German Landrace and German Large White sows by López-Serrano et al. (2000). This indicates that the selection for improved average daily gain and reduced backfat thickness is associated with low longevity of sows. On the other hand, Serenius and Stalder (2004) found no significant genetic correlations among average daily gain, backfat thickness, and sow longevity in Finnish Landrace and Large White sows. Therefore, relationship among average daily gain, backfat thickness, and sow longevity are still not clear.

Genetic parameters may vary depending on populations and environments (Imboonta et al., 2007b). The studied genetic parameters in this research were heritability and genetic correlations. To date, few studies have provided estimates for the heritability and the genetic correlation among sow longevity, average daily gain, and backfat thickness, based on data from swine population in tropical areas. Consequently, it becomes necessary to estimate genetic parameters specifically for tropical areas. This research will be a preliminary study of genetic parameters among sow longevity, average daily gain, and backfat thickness for Landrace and Yorkshire crossbred sows in Thailand.

The objectives of this study are:

1. To determine factors influencing sow longevity, average daily gain, and backfat thickness
2. To estimate heritabilities of sow longevity, average daily gain, and backfat thickness
3. To estimate genetic and phenotypic correlations among sow longevity, average daily gain, and backfat thickness

CHAPTER II

LITTERATURE REVIEW

1. Traits analyzed

1.1. Sow longevity

Sow longevity has been defined and measured in several ways. Different definitions and average sow longevity are summarized in Table 1. Definitions of sow longevity, such as female life day (Koketsu et al., 1999), sow herd life days (Takanashi et al., 2011), and length of productive life or productive life length (Serenius and Stalder, 2004; Engblom et al., 2009; Meszaros et al., 2010) have been used. Additionally, sow longevity could be defined as stayability (López-Serrano et al., 2000) which was an ability of sows to survive until a fixed parity in the herd (Tholen et al., 1996). Based on Table 1, sow longevity varied from 439 to 617 and 521 to 602 days for Landrace and Large White sows, respectively. For crossbred sows, it varied from 536 to 1138 days.

1.2 Average daily gain and backfat thickness

Normally, in private herds, production data were strictly confidential in order to avoid income tax problems and conflicts with other herds. Although production data were not easily obtained from private herds, average daily gain and backfat thickness reported in Thailand were done in most herds. The average daily gain and backfat thickness from different experiments both in Thailand and other countries are summarized in Table 2. For research in Thailand, mean average daily gain of

Landrace and Yorkshire sows, ranging from 624 to 780 g/day, are higher than that of crossbred sows (Landrace x Yorkshire), ranging from 531 to 583 g/day. However, mean backfat thickness of purebred sows did not differ from that of crossbred sows, ranging from 13.00 to 17.30 mm (Table 2). The studies from other countries demonstrated that mean average daily gain ranged from 529 to 885 g/day, whereas mean backfat thickness ranged from 9.48 to 18.29 mm in Landrace, Large White or Yorkshire, Duroc, and Hamshire sows (Table 2).

Table 1 Definitions for sow longevity and the average of sow longevity

Definition	Breed[1]	Longevity[2]	Reference
Female life day	LW×LR	1,138	Koketsu et al. (1999)
Sow life days (Birth date to removal date)	LW×LR	992	Sasaki and Koketsu (2008)
Sow herd life days (1st service date to removal date)	LW×LR	774	Takanashi et al. (2011)
Productive life length (1st farrowing date to removal date)	LR×YS	579	Engblom et al. (2007)
Length of productive life (1st farrowing date to removal date)	LR	617	Yazdi et al. (2000)
	LR	439	Serenius and Stalder (2004)
	LW	438	
	LW	602	Tarres et al. (2006)
	LW×LR	536	Serenius and Stalder (2007)
	LR	615	Meszaros et al. (2010)
	LW	531	

1 LW x LR = crossbred (Large White x Landrace) sow, LR x YS = crossbred (Landrace x Yorkshire) sow, LR = Landrace, LW = Large White, YS = Yorkshire

2 The average sow longevity (days)

Table 2 Summary of the average daily gain (ADG) and backfat thickness (BF)

Country	Breed[1]	n	ADG (g/day)	n	BF (mm)	Reference
Thailand	LR	19,334	780	15,755	13.90	Imboonta et al. (2007a)
Thailand	LR×YS	137	531	202	13.00	Tummaruk et al. (2007)
Thailand	LR×YS	4,569	583	4,167	15.60	Tummaruk et al. (2009)
Thailand	LR	46	654	46	17.30	Roongsitthichai et al. (2013)
	YS	31	624	31	16.60	
Germany	LW	21,870	612	21,870	10.97	López-Serrano et al. (2000)
	LR	14,944	609	14,944	11.00	
Sweden	LR	5,484	529	5,484	11.50	Yazdi et al. (2000)
USA	LR	7,951	853	7,951	17.02	Johnson et al. (2002)
	YS	27,656	866	27,656	16.51	
	DR	5,240	885	5,240	18.29	
	HS	3,615	830	3,615	14.99	
Korea	DR	-	-	1,102	14.72	Kim et al. (2004)
	LR	-	-	1,995	14.11	
	LW	-	-	3,049	13.89	
Finland	LR	26,744	547	26,744	9.58	Serenius and Stalder (2004)
	LW	24,007	534	24,007	9.48	
Poland	LR	19,423	619	19,423	10.90	Sobczyńska et al. (2013)
	LW	16.049	609	16.049	10.80	

[1] LR x YS = crossbred (Landrace x Yorkshire) sow, LR = Landrace, LW = Large White, DR = Duroc, HS = Hampshire, and YS = Yorkshire

2. Removal reasons

Sow removal was determined for many reasons. Two types are mainly categorized: planned and unplanned removals (Englblom et al., 2007). They included reproductive disorders, lameness, low production, and so on. In detail, the removal reasons and percentage of removal sows are summarized in appendix table 10.

Majorly, the sow removals were unplanned type: reproductive disorders and lameness (Engblom et al., 2008). Of these reason, sows were removed for reproductive disorders varied from 16% to 43%, and for lameness and/or leg problems vary from 7% to 26% (Tarres et al., 2006; Dhliwayo, 2007). In addition, removal due to reproductive disorders and lameness mainly occurred with younger sows (Engblom et al., 2007; Segura-Correa et al., 2011a), leading to low longevity and lifetime productivity (Lucia et al., 2000a; Engblom et al., 2007).

According to planned removal, low production and old age were the largest removal reasons which was most evident in older sows (Engblom et al., 2008; Hughes et al., 2010). The previous studies indicated that those culled with low production varied from 10% to 56% (Tarres et al., 2006; Engblom et al., 2007) and 9% to 24% of the removals were culled with old age (Lucia et al., 2000b; Segura-Correa et al., 2011a). Accordingly, the proportion of planned removal increased with greater parity numbers (Engblom et al., 2007).

Due to the study of Sasaki and Koketsu (2008) in Japan, sow removal was divided into three sow groups: 1) sows with high lifetime efficiency (the upper 25 percentile of the lifetime efficiency) and high longevity (parity at culling ≥ 6), 2) sows with ordinary lifetime efficiency (less than the upper 25 percentile of the lifetime efficiency) and high longevity, and 3) sows with low longevity (parity at culling ≤ 5 regardless of lifetime efficiency). They reported that those in group 1 were removed mainly with old age (81.9%), and reproductive failure (6.2%), while those in group 3 were removed mainly with reproductive failure (39.3%), and locomotive problems (14.7%).

3. Survival curve for sow longevity

Another interesting description for sow longevity was the survival curve; it displayed an overall survival of sows in the herd. An illustrative example of survival curve is presented in Figure 1 which the horizontal axis represents sow longevity calculated from differences between date of breeding herd entry and removed date, meanwhile the vertical axis represents the probability of survival of sows (Serenius et al. (2006). The younger sows or those just entered the herd had more chance to survive than the older sows. Moreover, the survival curve differed among lines. As seen that Dekalb-Monsanto GPK347 line had lower risk of being removed from the herd than those from other lines. However, the survival probability of all lines severely decreased, especially after the fourth parity.

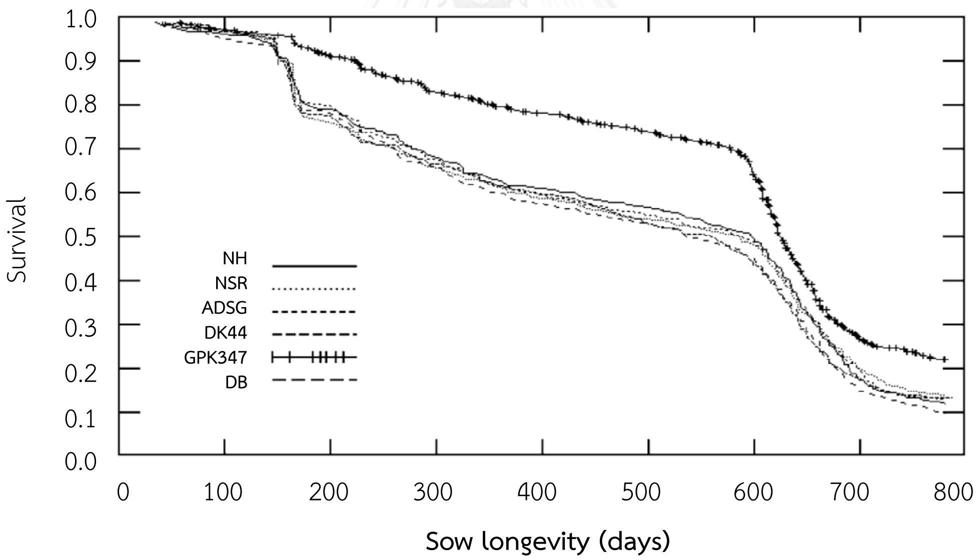

Figure 1 Survival curves for sow longevities of six different genetic lines (NH = Newsham Hybrids, NSR = National Swine Registry, ADSG = American Diamond Swine Genetics, DK44 = Dekalb-Monsanto DK44, GPK347 = Dekalb-Monsanto GPK347 and DB = Danbred North America; Serenius et al., 2006)

The survival curve was created from survival data using the survivor function which was described according to the product limit method of Kaplan and Meier (1958). For survival data, variable of interest was the time until an event occurs. The event referred to the sow removal. The time to event or survival time could be measured from the beginning to the end of the follow-up. In this study, they were first farrowing date and removal date or the latest date of each animal, respectively.

The measurement of sow longevity in survival data, therefore, was created from data of removed and existing sows. Data of sows removed during the study were called complete or uncensored data, where those of sows alive at the end of data collection period were treated as censored data since their survival time was incomplete. Definitions of the censoring code and sow longevity in the survival data are presented in Table 3.

Table 3 Definition of the censoring code and sow longevity in the survival data

Type of circumstance	Censoring status	Sow longevity
Sows removed, known removing date	Uncensored (Complete data)	First farrowing date to removing date
Sows alive at the end of the recording period	Censored (Incomplete data)	First farrowing date to latest date

The survivor function representing fraction of individuals still alive was used for describing the probability of surviving beyond the time. The proportion of sows surviving beyond any follow-up time was estimated by product of conditional probabilities according to the formula given by Kaplan and Meier (1958).

$$\hat{S}(t) = \prod_{t_i<t}\left(1 - \frac{d_i}{n_i}\right) \qquad [1]$$

where

$\hat{S}(t)$ = the survivor function in time t

d_i = the number of sows at removal in i^{th} time

n_i = the total number of sows under risk at time t_i

$\prod$ = the symbol of product operator

4. Factors influencing sow longevity

Sow longevity could be affected by various factors, such as breed, season, age at first conception, age at first farrowing, litter size, and weaning-to-first-service interval (Koketsu et al., 1999; Koketsu, 2000; Yazdi et al., 2000; Tantasuparuk et al., 2001a; Johnson and Nugent, 2003; Hoge and Bates, 2011).

4.1 Breed

The difference of sow longevity might be influenced by different breeds of sow. Johnson and Nugent (2008) studied longevity in four swine breeds of a commercial herd in the USA. They defined sow longevity as the age at birth of the last recorded litter and reported that the age at birth of the last litter was 656, 662, 681, and 746 days in Landrace, Yorkshire, Duroc, and Hampshire sows, respectively. In a study by Meszaros et al. (2010), the length of productive life (number of days between first farrowing and culling) was used to measure sow longevity in an Austrian breeding herds. They reported that the average length of productive life was 615 and 531 days were found in Landrace and Large White sows, respectively. Furthermore, Serenius and Stalder (2007) defined sow longevity as the length of productive life (number of days from first farrowing to culling and/or mortality), and reported that the length of productive life was 536 days on average for Finnish crossbred sows (Landrace x Large White).

4.2 Season

One of the factors effecting on sow longevity was season. Koketsu (2000) estimated sow mortality risk in commercial herds from the USA and found the highest sow mortality risk was in summer (July to September) compared with winter (January to March), spring (April to June), and autumn (October to December). Similarly, Engblom et al. (2008) reported that the farrowing month was one of the important factors for the risk of sow removal on commercial herds in Sweden. They showed that sows farrowing in July and August (summer months) had a greater risk for removal than other months. The cause of sow mortality during summer was the greater ambient temperature (D'Allaire et al., 1996).

In fact, swine sweat glands were scant and hardly useful for body temperature adjustment, resulting in the accumulation of heat in the pigs' body. The most effective way to release the heat from their bodies is the respiration. Furthermore, quick change of weather and/or high ambient temperature would lead to an increase in breathing frequency, causing heat stress and heart failure (Chagnon et al., 1991). In addition, the lack of skillful workers on farm during summer influenced sow longevity. Stalder et al. (2004) noted that most workers took vacation during summer. Thus, the rest handled more workload on herds; this might cause a great number of sow mortalities in summer.

4.3 Age at first conception and age at first farrowing

Age at first conception negatively correlated with sow longevity (Koketsu et al., 1999), indicating that sow longevity increased with decreasing age at first conception. The study of Schukken et al. (1994) in Netherlands reported that sows conceiving at 200 days of age were less likely to be culled (18%) from the herd than those conceiving at 300 days of age (24.5%). For crossbred (Landrace x Large White) sows in Japanese commercial herds, Sasaki and Koketsu (2008) showed that the average age at first mating was 240 days. They also found that sows aged between 186 and 227 days at first mating were likely to have higher lifetime efficiency and high longevity than those with higher age at first mating (249 to 269 days). Similarly, Saito et al. (2011) demonstrated that the average age at first mating was 247 days, and reported that sows first bred between 188 and 229 days of age had a higher parity at removal than those first bred between 230 and 365 days of age.

According to a number of studies, age at first farrowing also influenced sow longevity (Yazdi et al., 2000; Meszaros et al., 2010; Hoge and Bates, 2011). Sow longevity increased with decreased age at first farrowing (Yazdi et al., 2000). Engblom et al. (2008) reported that the average age at first farrowing was 365 days for crossbred (Landrace x Yorkshire) sows in Swedish commercial herds. In addition, they found that the hazard for removal was 16% higher in those with age of 14 months at first mating than those with age of 12 months at first mating. In the study of Segura-Correa et al. (2011b) in Mexican commercial herds, age at first farrowing was divided into 3 groups (≤330, 331-347, ≥348 days). They found that sows with younger (≤330 days) age at first farrowing had the longest length of productive life (726 days) when compared to those with medium (331-347 days) age at first farrowing (709 days) and higher (≥348 days) age at first farrowing (670 days).

4.4 Litter size

The effect of litter size on sow longevity was associated with litter size (Sasaki and Koketsu, 2008) and could be considered through the number of piglets born alive, stillborn piglets (Hoge and Bates, 2011), and weaned piglet (Serenitus et al., 2008). Those with a large litter size (more piglets born alive and weaned piglet but fewer stillborn piglets) had a decreased risk of removal and increased sow longevity (Serenius et al., 2008; Hoge and Bates, 2011). The study of Engblom et al. (2008) reported that the hazard for removal was 24 to 60% higher in sows with a litter size of

9 or lower piglets than those with a litter size of 12-13 piglets. Furthermore, Hoge and Bates (2011) showed that the risk of removal could decline between 1.4 and 10% as sows had one more piglet born alive in the first litter, while that risk rose between 4.6 to 6.2% when sows had one more stillborn piglet in the first litter.

In the study of Takanashi et al. (2011), sows were categorized into 3 groups based on annualized lifetime pigs born alive (annualized lifetime PBA) in Japanese commercial herds. They found that those with more than 21.8 annualized lifetime PBA had the longest sow herd life days (1035 days) when compared to those having less than 13 piglets (365 days) and 13 to 21.8 piglets (847 days) annualized lifetime PBA. In addition, the association among the number of piglets born alive, the number of piglets weaned, and sow longevity was estimated by Sasaki and Koketsu (2008) as well as Sobczyńska et al. (2013); they found that the selection for sow longevity had a positive impact on both the number of piglets born alive and the number of weaned piglet. This finding indicated that an increased sow longevity generally resulted in an increased number of piglets born alive and piglet weaned.

4.5 Weaning-to-first-service interval

Weaning-to-first-service interval is considered one of the factors affecting sow longevity (Tantasuparuk et al., 2001b). A previous study on reproductive performance of purebred Landrace, purebred Yorkshire, and crossbred sows from Thai swine herds by Tantasuparuk et al. (2001b) demonstrated that sows with weaning-to-first-service interval longer than 30 days were likely to be removed from the herd by 1.4 times higher than those with 0 to 4 days. Moreover, Sasaki and Koketsu (2008) studied reproductive performance in crossbred (Large White × Landrace) sows from Japanese commercial herds and reported that low longevity sows (parity 1 to 5) had the longest weaning-to-first-service interval as compared to high longevity sows (parity more than 6). Thus, sows with long weaning-to-first-service interval were risky being removed and possessed low longevity.

5 Factors influencing average daily gain and backfat thickness

Average daily gain and backfat thickness could be affected by several factors, such as breed (Sobczyńska et al., 2013), diet (Fischer and Miller, 2005), and environmental temperature (Rinaldo et al., 2000).

5.1 Breed

As for breed of sows, Sobczyńska et al. (2013) measured backfat thickness, adjusted to a weight of 110 kg, at P_2 and P_4 positions, whereas average daily gain was adjusted to 180 days of age. In Polish Landrace and Large White sows, average daily gain was 619 and 609 g/day and backfat thickness was 10.90 and 10.80 mm, respectively.

Moreover, Johnson et al. (2002) collected records of performance test from a commercial swine herd in the USA. They reported that mean average daily gains were 853, 866, 885, and 830 g/day and the mean backfat thicknesses measured at the 12^{th} rib using B-mode ultrasounonography were 17.02, 16.51, 18.29 and 14.99 mm for Landrace, Yorkshire, Duroc, and Hampshire sows, respectively. Besides, Kim et al. (2004), measuring backfat thickness at three different sites (shoulder, mid-back, and loin) using an A-mode ultrasounography from the National Agricultural Cooperatives Federation of Korea, demonstrated that average backfat thicknesses were 14.72, 14.11, and 13.89 mm for Duroc, Landrace, and Large White sows, respectively. Based on these three studies, under the same experiment, different swine breeds cause different average daily gains and backfat thicknesses.

5.2 Diet

Diet was an important factor for average daily gain and backfat thickness. An increased dietary protein concentration led to an increase in average daily gain (Fischer and Miller, 2005). Similarly, Teye et al. (2006) evaluated the effect of high (21%) and low protein diet (18%) on daily weight gain for crossbred (50% Duroc 25% Large White 25% Landrace) gilts in Ghana and reported that those fed with high protein diet had higher daily weight gain than those fed with the low protein diet (955 vs. 849 g/day). In addition, high dietary energy concentration contributed to high backfat thickness (Long et al., 2010). This was confirmed by the study in crossbred (American Landrace × Yorkshire) gilts fed with different dietary energy levels: 5,360, 7,260, 9,060, and 10,570 Kcal/day (Klindt et al., 2001). The result showed that backfat thickness was affected by dietary energy levels: an increased dietary energy levels led to an increased backfat thickness (12.1, 15.6, 19.6 and 23.1 mm, respectively).

5.3 Environmental temperature

Heat stress in gilts usually occurred while they exposed with high environmental temperatures. This stress caused major reductions in gilts performance, especially average daily gain. As a result, stressed gilts would have had a decreased feed intake in order to reduce the body heat production which related to digestion and metabolism of nutrients. This was confirmed by the previous study of Renaudeau et al. (2006) who evaluated the seasonal effect on feed intake and average daily gain between 45 and 90 kg live weight for Creole and Large White pigs in France. They found that feed intake and average daily gain were lower during hot season than during warm season (2.18 vs. 2.38 kg/day and 726 vs. 777 g/day, respectively).

In addition, higher temperature would be associated with a reduced backfat thickness (Rinaldo and Mourot, 2001; Trezona et al., 2004). The effect of stress under high environmental temperature of gilts contributed to a decrease in feed intake, fat deposition, bringing reduced backfat thickness. Similarly, Rinaldo et al. (2000) determined the effect of seasonality on feed intake and fat percentage for Large White in France. The average ambient temperature was 27.3 °C during warm season and 24.6 °C during cool season. They found that feed intake and fat percentage were lower during warm season than it was during cool season (1.97 vs. 2.15 kg/day and 10.0 vs. 11.5 %, respectively).

6 Genetic parameters

6.1 Heritability of sow longevity

The heritability estimates for sow longevity are summarized in Table 4. The range of heritability estimates of sow longevity was from 0.05 to 0.27 (Serenius and Stalder, 2004; Engblom et al., 2009; Sobczyńska et al., 2013). The values of heritability for sow longevity seemed to be different from one another depending on genetic makeup of breeds, populations, and methods of analysis in each study (Yazdi et al., 2000; Serenius and Stalder, 2004). Although heritability estimates of sow longevity were relatively low to moderate, sufficient genetic variation could be utilized to increase longevity by selection (Yazdi et al., 2000). Even though sow longevity is a lowly heritable trait, it is possible to select for improved sow longevity (Stalder et al., 2004).

6.2 Heritability of average daily gain and backfat thickness

Average daily gain and backfat thickness were often considered the indicators of productive trait since they were moderate-to-high heritable. A number of studies have estimated the heritability for average daily gain and backfat thickness using REML procedure. For a commercial Landrace swine population in Thailand, the values of heritability were 0.31 and 0.38 for average daily gain and were 0.45 and 0.61 for backfat thickness (Imboonta et al., 2007a; Imboonta et al., 2007b). Johnson et al. (2002) reported heritability estimates for average daily gain based on Duroc, Hamshire, Landrace, and Yorkshire breeds that it ranged from 0.17 to 0.25, and 0.30 to 0.46 for backfat thickness. In addition, Johnson and Nugent (2003) reported that heritability estimates for backfat thickness were from 0.30 to 0.61, using the same breeds with the study of Johnson et al. (2002).

Table 4 Summary of heritability estimates for sow longevity

References	Country	Breed[1]	No.	Analysis/model [2]	h^2
Lopez-serrano et al. (2000)	Germany	LR	14,944	BIV / AM	0.07 - 0.11
		LW	21,870	BIV / AM	0.08 - 0.10
Yazdi et al. (2000)	Sweden	LR	7,967	SUR / PM	0.11 - 0.27
Johnson and Nugent (2003)	USA	LR	578	AM	0.19
		YS	1,803	AM	0.11
		DR	524	AM	0.19
		HS	323	AM	0.15
Serenius and Stalder (2004)	Finland	LR	18,245	SUR / PM	0.16 - 0.17
		LR	18,245	MTA / SM	0.05
		LW	16,285	SUR / PM	0.17 - 0.19

		LW	16,285	MTA / SM	0.10
Engblom et al. (2009)	Sweden	LR x YS	10,373	SUR / SM	0.06 – 0.12
Sobczynska et al. (2013)	Poland	LR	19,423	UNI / AM	0.10 - 0.13
		LW	16,049	UNI / AM	0.09 - 0.11

[1] LR x YS = Crossbred (Landrace x Yorkshire) sow, LR = Landrace, LW = Large White, YS = Yorkshire, DR = Duroc, HS = Hampshire

[2] BIV = Bivariate analyses, MTA = Multi-trait analysis, SUR = Survival analyses, UNI = Univariate analyses, AM = Animal Model, PM = Proportional hazards model, SM = Sire model

6.3 Genetic correlations among average daily gain, backfat thickness, and sow longevity

In general, genetic selection on swine production was based on productive traits, such as average daily gain and backfat thickness (Tarres et al., 2006). During the same period, the selection for average daily again and backfat thickness influenced sow longevity (Hoge and Bates, 2011). Moreover, unfavorable genetic correlations among average daily gain, backfat thickness, and sow longevity were estimated by López-Serrano et al. (2000) and Sobczyńska et al. (2013).

In the study of López-Serrano et al. (2000), they reported that genetic correlation between stayability and daily gain ranged from -0.28 to -0.32 for Large White sows, while that between stayability and backfat thickness ranged from 0.22 to 0.27 for Large White and Landrace sows. Moreover, Sobczyńska et al. (2013) found that genetic correlation between length of productive life and growth rate was -0.11, while that between length of productive life and backfat thickness was 0.16 in Polish

Landrace sows. These indicated that the selection for high average daily gain and thin backfat thickness was associated with short sow longevity.

The genetic correlations among average daily gain, backfat thickness, and sow longevity were not that clear in the study of Tholen et al. (1996). They reported that genetic correlation between stayability and growth rate ranged from -0.31 to 0.02, and that between stayability and backfat thickness ranged from -0.03 to 0.36. In addition, Yazdi et al. (2000) and Serenius and Stalder (2004) found no significant correlation among average daily gain, backfat thickness, and sow longevity.

6.4 Genetic correlations between average daily gain and backfat thickness

Genetic correlations between average daily gain and backfat thickness seemed to be inconsistent. Favorable genetic correlations between average daily gain and backfat thickness were estimated by Kim et al. (2004). Besides, they reported that genetic correlation between the day to 90 kg and backfat measurement at 3 different sites (shoulder, mid-back, and loin), in Duroc, Landrace, and Large White sows ranged from -0.04 to -0.30. Furthermore, Dube et al. (2013) found that the genetic correlation between average daily gain and backfat thickness was -0.26 for Large White sows.

On the other hand, unfavorable genetic correlations between average daily gain and backfat thickness were estimated by Serenius and Stalder (2004). They found that genetic correlation between average daily gain and backfat thickness at approximately 100 kg live weight was 0.32 for Finnish Landrace sows and were 0.39 for Finnish Large White sows.

CHAPTER III

MATERIALS AND METHODS

1. Materials

1.1 Animals

All animals included in the current study were purebred Landrace and purebred Yorkshire sows from a swine breeding farm located on the eastern Thailand. The total number of sows on production was approximately 1,200. Productive records were available for gilts performance test between 2004 and 2013. Reproductive records were also available for sows farrowing first litters during 2005-2013. In total, 2,865 removed sows during 2008-2013 were included in this study.

1.2 Housing and general managements

Gilts and sows were housed in evaporative cooling (EVAP) system buildings. They were composed of automatically controlled ventilation and dry-bulb temperature to maintain thermoneutral zone for females. The temperature inside the EVAP system buildings could be reduced approximately 5-10°C below outside temperature. Thus, the average ambient temperature inside the EVAP system buildings based on temperature outside the building, ranged from 26 to 29°C during the study period. All females were allowed to access *ad libitum* water via nipple drinkers. They received diets of the same composition at all stages of the reproductive cycle. Diets were formulated to meet National Research Council (NRC, 1998) recommendation. The diets for non- and early-gestating females (0-83 days) contained 17% crude protein and 3,000 kcal metabolizable energy/kg (ME/kg) on a dry matter basis. For late gestating (83+ days) and lactating females, the diets contained 17% crude protein and 3,200-3,300 kcal ME/kg on a dry matter basis.

Production cycle of female pigs in breeding herd generally consisted of 6 units (Figure 2). For gilts and sows, they mainly involved with only 5 units, including performance test, replacement, mating and gestation, farrowing, and weaning units.

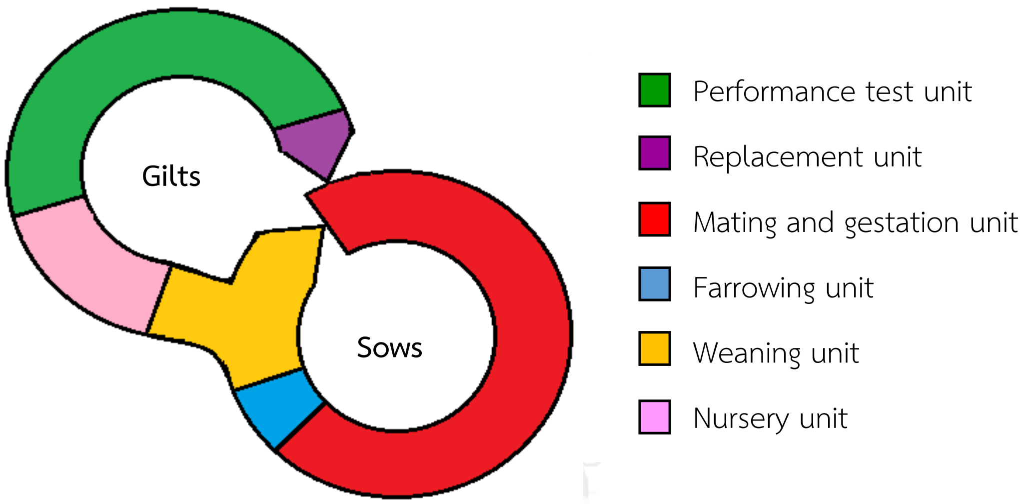

Figure 2 Production cycle of female pigs in breeding herd

1.2.1 Performance test unit

Gilts transferred to the performance test unit at 9 weeks of age were weighed individually for initial body weight of the performance test. The gilts were kept in groups (20 – 30 gilts per pen), and were given *ad libitum* access to diet. They were vaccinated against foot-and-mouth disease (FMD), Aujeszky's Disease (AD), and classical swine fever (CSF). In addition, they were treated against external and internal parasites between 17 and 18 weeks of age. At the end of the performance test, the gilts, approximately 22 to 23 weeks of age, were individually weighed and were ultrasonically measured for backfat thickness at the 10th rib and 6.5 cm off the midline. They were selected on the basis of their reproductive performance (total number of piglets born) and their production (average daily gain and backfat thickness) when they were around 24 to 25 weeks of age.

1.2.2 Replacement unit

The replacement gilts were moved from the performance test unit to the replacement unit where they stayed until 32 weeks of age. They were always recruited within the herd. The replacement gilts were kept in groups (20 to 30 gilts per pen) while they were in replacement unit. They were fed 2.0 kg/day/head. Vaccinations were performed to protect them against atrophic rhinitis (AR) and porcine parvovirus (PPV). Moreover, they had to stay in the same pen, together with removed sows for at least 2 weeks to acclimatize local immunity. The ratio of gilts and removed sow was 10 to 1. After that, replacement gilts were moved to the mating unit.

1.2.3 Mating and gestation unit

Owing to management strategies, the replacement gilts were mated on the second observed oestrus onwards at a minimum age of 32 weeks and body weight of 110 kg. Boars were used to check for oestrus exhibitions in both gilts and sows twice a day (morning and evening). Gilts were artificially inseminated three times per oestrus, while sows were performed two times per oestrus. The gilts which did not exhibit oestrus within 45 weeks of age, or failed to conceive after four consecutive mating were removed from herd. Also, the sows returning to oestrus after two consecutive mating were removed from herd.

Return to oestrus after mating was the method of pregnancy detection. The pregnant gilts and sows were housed in individual stalls (0.6 × 1.8 m^2), and were fed one time daily from mating to 83 days of gestation. Thereafter, they were moved to the wider individual stalls (0.7 × 1.8 m^2), and were fed two times daily from 84 days of gestation until farrowing. In addition, pregnant gilts and sows were moved to the farrowing unit at one week before the expected farrowing date.

1.2.4 Farrowing unit

One week prior to the expected farrowing date, the pregnant gilts and sows were moved from mating unit to farrowing unit where they stayed until weaning date. During farrowing and lactation, they were housed in individual farrowing pens (1.85 × 2.2 m^2).

The numbers of piglets born alive, stillborn piglets, mummified piglets, and piglets born alive but dead within 24 hours after birth (e.g., weak, crushed, and malformed piglets) were recorded. The husbandry procedures (i.e., needle teeth clipping, tail docking, ear tattooing, and iron injection) were performed once on the day after piglets born. If necessary, piglets born alive were cross fostered within one day after birth, but it was not recorded. Gilts and sows were fed 2.5, 4.5, and 6 kg/day/head during week1, week2, and week3 of lactation period, respectively.

1.2.5 Weaning unit

Due to farm routine work, piglets were weaned every Monday and moved to the nursery unit, whereas sows were returned to the mating unit. After weaning, sows were detected for oestrus exhibitions twice a day by technicians in conjunction with boar exposure. If weaned sows did not display oestrus within 7 days after weaning, they would be intensively stimulated for oestrus expression. Estrus stimulation consisted of relocation, transportation of sows to another stall, or grouping 3 to 4 sows together. After weaning, sows were fed once a day (2 kg/day) until the next mating.

1.3 Data

1.3.1 Structure of data

The raw data, recorded by pig producers, were obtained from a swine breeding farm, extracted from the computerized recording system, and retrieved from different files. Different variable names and data files used in this study are summarized in Table 5. The studied files consisted of pedigree, performance test, production, and removal files.

Table 5 Different variable names of four retrieved data files

Files	Variable used
Pedigree file	▪ Sow identification ▪ Sire of sow identification ▪ Dam of sow identification
Performance test file	▪ Average daily gain ▪ Backfat thickness ▪ Initial and final performance test age ▪ Initial and final performance test weight

Production file	▪ Breed ▪ Birth date, breeding date, farrowing date and weaning date ▪ Number of piglets born, stillborn piglets, mummified piglets, piglets born alive and piglets born alive but dead within 24 hours of birth (weak, crushed or malformed)
Removal file	▪ Date of removal ▪ Removal reasons ▪ Removal parity

1.3.2 Definitions of studied traits

The studied traits contained sow longevity, average daily gain, and backfat thickness. Sow longevity (days) was defined as the total number of days between first farrowing date and removal date. Average daily gain (ADG, g/day) over 9 to approximately 22-23 weeks of age was calculated by equation [2]. Backfat thickness (BF, mm) was measured at the 10th rib and 6.5 cm from the midline by using ultrasonic equipment.

$$\text{ADG (g/day)} = \frac{\text{(final performance test weight - Initial performance test weight)}}{\text{Days on performance test}} \qquad [2]$$

2. Methods

2.1 Edition of data

The analyses were based on purebred Landrace and purebred Yorkshire sows removed from a breeding herd from August 2008 to December 2013. The analyzed data set included 9,657 observations from 1,706 Landrace sows and 6,011 observations of 1,159 Yorkshire sows. The animals in pedigree files included 175 sires and 934 dams of Landrace sows and 149 sires and 615 dams of Yorkshire sows.

Data edition was to exclude incomplete records and/or outliers. According to farm guidelines and policies, the followings were criteria for outliers: average daily gain records <480 g/day or >1,300 g/day, and backfat thickness records <5 mm or >25 mm. The restriction of records considered in this study comprised age at first mating (between 196 and 345 days), age at first farrowing (between 300 and 600 days), gestation length (between 106 and 123 days), lactation length (between 0 and 30 days), and weaning-to-first-service interval, (between 0 and 45 days).

In the present study, the associations among sow longevity, average daily gain and backfat thickness were analyzed. First, gilts with missing records of average daily gain and backfat thickness were excluded from the performance test file. Second, exclusions of outlier records and records with values exceeding the restriction were performed in the production file. Third, production file was merged with removal file in order to calculate sow longevity. Missing records of first farrowing date and removal date were excluded because it affected the calculation of sow longevity. Moreover, combinations of first farrowing year and season that would be treated as contemporary group effects were created from first farrowing date. Likewise, contemporary group effects of birth year and season were created from sow's birth date.

The removal parity was defined as the last parity number before sows were removed. Those of parity 9 onwards were grouped into 9+ because of a small number of observations (0.2%). Thus, the removal parity consisted of nine groups, including parity 1, 2, 3, 4, 5, 6, 7, 8, and 9+. For each removal event, specific reasons for removal were recorded. Overall, the removal reasons were categorized into seven groups based (Table 6) on the physiological nature of sows and previous studies (Lucia et al., 2000b; Engblom et al., 2007). Seven removal categories consisted of reproductive disorders, low productivity, sick and/or disease, leg problems, dead, old age, and miscellaneous. The reproductive disorders included sows removed for abortions, discharge, dystocia, anoestrus, pseudopregnant, return to oestrus, and vaginal prolapse. For low productivity, the female would be removed if the number of piglets born alive in two consecutive farrowing events were less than the number of piglets born alive in standard of the breed. For sick and/or disease represented simply sows whose removal reason was sick and/or disease. Dog-sitting posture and lameness were two major reasons for grouping into the Leg problems category. Dead included all sows died in a herd. Old age was applied only to those with seven parities or more, and miscellaneous included accident, management, and general bad condition.

Table 6 Removal categories and removal reasons

Removal category	**Removal reasons**
Reproductive disorders	Abortion, dscharge, dystocia, anoestrus, pseudopregnancy, return to oestrus, and vaginal prolapse
Low productivity	Low productivity
Sick/disease	Sick and/or disease
Leg problems	Dog-sitting posture and lameness
Dead	Animals found dead
Old age	Old age (parity greater than or equal 7)
Miscellaneous	Accident, management or farm policy, general bad condition

2.2 Creation of survival curve

In order to establish survival curve, both data of removed sows and existing sows were used to construct a survival data file. It comprised 4,194 sows' records, including 2,865 (68.31%) records of removed sows and 1,329 (31.69%) records of existing sows. In addition, it consisted of three variables, i.e., sow identification, sow longevity, and dummy variable.

Sow longevity measured from removed sows were determined as the number of days from first farrowing date to removing date. Sow longevity data of removed sows were called uncensored data, meanwhile those of existing sows were called censored data. Dummy variables were used to account for censored or uncensored data. The dummy variable was coded as 0 or 1 for censored or uncensored data, respectively.

The survival curve was created from survival data file using The LIFETEST procedure (SAS, 2002). The LIFETEST procedure could be used to compute the survivor function by the product limit method of Kaplan and Meier (1958).

$$\hat{S}(t) = \prod_{t_i<t}\left(1 - \frac{d_i}{n_i}\right) \qquad [3]$$

where

$\hat{S}(t)$ = the survivor function in time t

d_i = the number of sows at removal in i^{th} time

n_i = the total number of sows under risk at time t_i

$\prod$ = the symbol of product operator

2.3 Statistical analyses

2.3.1 Preliminary data analysis

Descriptive statistics, including the number of observations, means, standard deviations, minimum and maximum values of data and of sow longevity, average daily gain, and backfat thickness were obtained using MEANS procedure in the SAS program (SAS, 2002). The effects of breeds on the studied traits were analyzed by the least-squares method as applied in the GLM procedure. Frequency distributions were used to describe removal reasons, removal parity, and percentage of sows per removal reason within removal parity.

For the preliminary analysis, birth months and farrowing months were grouped into six classes (January/February, March/April, May/June, July/August, September/October, and November/December). Sow longevity, average daily gain, and backfat thickness were analyzed using GLM procedure in the SAS program (SAS, 2002). The statistical model for sow longevity included the effects of farrowing month. Multiple comparisons of sow longevity between different farrowing months were determined by using Duncan's Multiple Range Test. The statistical model for average daily gain and backfat thickness included the effects of birth month. Multiple comparisons among average daily gain and backfat thickness from different birth months were determined by using Duncan's Multiple Range Test. Statistical significance was set at $p < 0.05$ level.

2.3.2 Analysis of factors influencing studied traits

All possible fixed effects and covariates were tested for their significance ($P<0.05$) in univariate models using the MIXED procedure in the SAS program (SAS, 2002). Thereafter, only the significant influenced fixed effects and covariates were included in the final models. Fixed effects and covariates influencing the studied traits are presented in Table 7.

The final model for sow longevity included non - genetic effects of contemporary group (a combination of year and season of first farrowing), age at first mating, and the total number of piglets born alive over a sow's longevity. For average daily gain, a combination of birth year and season and the initial age of the performance test were included in the model. Moreover, a combination of birth year and season and the final weight at the performance test were included in the model for backfat thickness.

For the genetic analyses, seasons of birth and first farrowing were classified as hot (March - June), rainy (July - October), and winter (November - February). Age at first mating, total number of piglets born alive over a sow's longevity, initial age, and final weight of performance test were treated as covariates.

Table 7 Fixed effects and covariates used in the statistical models

Fixed effects	Traits[1]		
	Longevity	ADG	BF
Contemporary groups			
Year × Season of the birth	-	***	***
Year × Season of the first farrowing	***	-	-
Covariates			
Total number of piglets born alive[2]	***	-	-
Age at first mating	*	-	-
Initial performance test age	-	***	-
Initial performance test weight	-	ns	-
Final performance test age	-	-	ns
Final performance test weight	-	-	***

[1] Longevity (days) was estimated by the difference between the date of removal and the date of first farrowing, ADG = average daily gain, BF = backfat thickness

[2] total number of piglets born alive during sow's longevity

ns = not significant (P>0.05), * = significant on the level P<0.05, *** = significant on the level P<0.001, - = not considered in the model.

2.3.3 Estimation of variance-covariance components

The variance and covariance components were estimated by Restricted Maximum Likelihood (REML) estimation method using the REMLF90 program (Misztal, 2001). A multiple trait analysis under an animal model was used to estimate variances of studied traits and covariance among them. Thus, sow longevity, average daily gain, and backfat thickness were fitted simultaneously in the model. The (co)variance components were estimated using the following animal models:

$$y_1 = X_1b_1 + Z_1a_1 + e_1$$
$$y_2 = X_2b_2 + Z_2a_2 + e_2 \quad [4]$$
$$y_3 = X_3b_3 + Z_3a_3 + e_3$$

where

y_i = the vector of observations for i^{th} trait (i = 1, 2, 3)

X_i = the incidence matrix relating observations of i^{th} trait to fixed effects (i = 1, 2, 3)

Z_i = the associated incidence matrix relating observations of i^{th} trait to additive random genetic effects (animals) (i = 1, 2, 3)

b_i = the vector of fixed effects for i^{th} trait (i = 1, 2, 3)

a_i = the vector of additive random genetic effects (animals) for i^{th} trait (i = 1, 2, 3) (assume = $a \sim NID(0, A\sigma^2_a)$ A = the additive genetic relationship matrix between animals and σ^2_a = the additive genetic variances)

e_i = the vector of residual effects for i^{th} trait (i = 1, 2, 3) (assume = $e \sim NID(0, I\sigma^2_e)$ I = the identity matrix and σ^2_e = the residual variances)

The (co)variance matrices of random effect factors in ***a*** and ***e*** were assumed to be:

$$\text{var}\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ e \end{bmatrix} = \begin{bmatrix} A\sigma^2_{a_{11}} & A\sigma_{a_{12}} & A\sigma_{a_{13}} & 0 \\ A\sigma_{a_{21}} & A\sigma^2_{a_{22}} & A\sigma_{a_{23}} & 0 \\ A\sigma_{a_{31}} & A\sigma_{a_{32}} & A\sigma^2_{a_{33}} & 0 \\ 0 & 0 & 0 & I\sigma^2_e \end{bmatrix} \quad [5]$$

where

A = the additive genetic relationship matrix between animals

I = the identity matrix

σ^2_{ii} = the additive genetic variances of the studied trait i and

$\sigma_{a_{ij}}$ = the additive genetic covariances between traits i and j

σ^2_e = the residual variances

The estimation of variance-covariance components was performed using the Restricted Maximum Likelihood (REML) estimation method; a key assumption was that data of studied traits were normally distributed. From normality test, we found that data of sow longevity, average daily gain, and backfat thickness were normally distributed. In appendix, the distribution of sow longevity, average daily gain and, backfat thickness are shown in Figure 8, 9, and 10, respectively.

2.3.4 Estimation of genetic parameters

Variance and covariance components were used to estimate genetic parameters for sow longevity, average daily gain, and backfat thickness. The genetic parameters in this study consisted of heritability, genetic correlation, and phenotypic correlation.

1) Heritability

Heritability could be calculated from additive genetic variance and total phenotypic variance (the sum of additive and residual variances); this was referred as narrow-sense heritability. The variance components were used to calculate heritability for sow longevity, average daily gain, and backfat thickness according to the formula given by (Falconer and Mackey, 1996):

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2} \qquad [6]$$

where

h^2 = heritability of studied traits
(sow longevity, average daily gain, and backfat thickness)

σ_a^2 = the additive genetic variances

σ_e^2 = the residual variances

Standard errors (S.E.) of heritability estimate for the studied traits were calculated according to the formula given by Lo et al. (1992):

$$S.E. = 4\sqrt{\frac{2(N-1)(1-t)^2\left[1+(k-1)t\right]^2}{k^2(N-S)(S-1)}} \qquad [7]$$

where

N = the total number of observations

S = the number of sires

k = $\left(\frac{1}{S-1}\right) \times \left[N - \frac{\sum n_i^2}{N}\right]$

n_i = the number of observations of the i^{th} sire

t = the intraclass correlation (assume = $0.25h^2$)

2) Genetic correlation

Genetic correlations could be calculated from additive genetic variance of each trait and additive genetic covariances for pairs of the studied traits. The variance and covariance components were estimated by using REML analysis under a multivariate animal model. Those components were used to calculate genetic correlations among sow longevity, average daily gain, and backfat thickness according to the formula given by Falconer and Mackey (1996):

$$r_{12} = \frac{\text{cov } g_1g_2}{\sqrt{\text{var}(g_1)\text{var}(g_2)}} \qquad [8]$$

where

r_{12} = the genetic correlations between traits 1and 2

cov g_1g_2 = the additive genetic covariance between traits 1 and 2

var(g_1) = the additive genetic variance of traits 1

var(g_2) = the additive genetic variance of traits 2

Standard errors (S.E.) of genetic correlations of breeding value were calculated according to the formula given by Falconer and Mackey (1996):

$$S.E. = \frac{1-r_{12}^2}{\sqrt{2}}\sqrt{\frac{\sigma_{h_1^2}\sigma_{h_2^2}}{h_1^2 h_2^2}} \qquad [9]$$

where

r_{12} = the genetic correlation of breeding values between trait 1 and 2

$\sigma_{h_1^2}$ = the standard errors of heritability estimates of traits 1

$\sigma_{h_2^2}$ = the standard errors of heritability estimates of traits 2

h_1^2 , h_2^2 = the heritabilities of traits 1 and 2, respectively

3) Phenotypic correlation

Phenotypic correlations were calculated from phenotypic variance (the sum of additive and residual variances) of each trait and phenotypic covariance (the sum of the genetic and residual covariances) for pairs of the studied traits. The variance and covariance components estimated using REML analysis under a multivariate animal model were used to calculate phenotypic correlations among sow longevity, average daily gaind and backfat thickness according to the formula given by Falconer and Mackey (1996):

$$r_{12} = \frac{\mathrm{cov}\ p_1 p_2}{\sqrt{\mathrm{var}(p_1)\mathrm{var}(p_2)}} \qquad [10]$$

where

r_{12} = the phenotypic correlations between traits 1 and 2

$\mathrm{cov}\ p_1p_2$ = the phenotypic covariance between traits 1 and 2

$\mathrm{var}(p_1)$ = the phenotypic variance of traits 1

$\mathrm{var}(p_2)$ = the phenotypic variance of traits 2

CHAPTER IV

RESULTS

1. Survival curve for sow longevity

Survival curve were constructed from survival data using the product limit method of Kaplan and Meier (1958). Survival data included records of 4,194 sows with 2,865 (68.31%) uncensored and 1,329 (31.69%) censored records. Censored records were longevity of sows alive at the end of studied period. Survival curve for sow longevity is presented in Figure 3.

Kaplan – Meier survival curve of all sows in this study reflected that older sows had more chance to be removed from the herd than younger sows. With this graph, equally spaced periods of the survival curve were due to a repeated decrease in the removal risk after weaning in each reproduction cycle. Nevertheless, the survival curve went severely down from longevity 580 days (parity 5) to 1,100 days (parity 8); this period showed the greatly increased risk of removal. In addition, the results for each breed are presented in appendix figure 11 and figure 12.

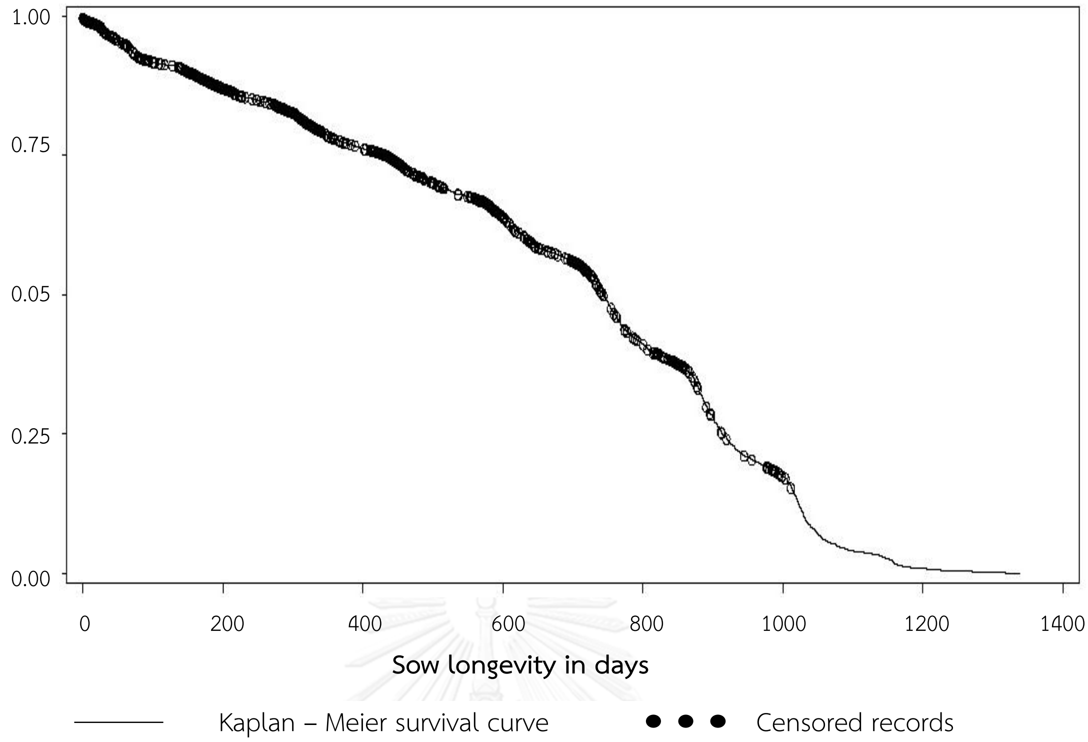

Figure 3 Survival curve of sow longevity

2. Preliminary analysis

2.1 Descriptive Statistics

Descriptive statistics for sow longevity, average daily gain, and backfat thickness in this study are shown in Table 8. The average sow longevity was 611 ± 337 days (ranged 0-1,339 days), counting from first farrowing date until culling date. A minimum sow longevity of zero day presented in Table 8 means that those were removed from the reproduction cycle after their first farrowing date. However, only 14 sows (0.49% of removal sows) were removed after their first farrowing date.

The results revealed that Landrace sows had higher longevity, average daily gain, and backfat thickness than Yorkshire sows. Average daily gain was almost 60 g higher in Landrace sows than in Yorkshire sows; nonetheless, backfat thickness was 0.1 mm less in Yorkshire sows than in Landrace sows.

Table 8 Number of records, mean, standard deviation (SD), minimum (Min), and maximum (Max) of the sow longevity, average daily gain, and backfat thickness in Landrace and Yorkshire sows

Traits	No. of records	Mean[2]	SD	Min	Max
Longevity, days[1]					
Landrace	1,706	633^{a}	341	0	1,339
Yorkshire	1,159	579^{b}	327	0	1,328
All sows	2,865	611	337	0	1,339
ADG, g/day					
Landrace	1,577	863^{a}	96	539	1,220
Yorkshire	1,094	805^{b}	89	505	1,184
All sows	2,671	839	97	505	1,220
BF, mm					
Landrace	595	11.8^{a}	3.4	5.0	24.0
Yorkshire	505	10.7^{b}	2.3	5.0	24.0
All sows	1,100	11.3	3.2	5.0	24.0

[1] Longevity (days) was estimated by the difference between the date of removal and the date of first farrowing, ADG = average daily gain, BF = backfat thickness

[2] [a,b] Means of each studied trait within a column with different superscript letters differ significantly at $P<0.0001$

2.2 Removal parity

On the average, sows in this study were removed at parity 5.1 ± 2.30. Landrace sows were removed from production cycle later than Yorkshire sows. The average parity at removal of Landrace and Yorkshire sows were 5.3 and 4.8, respectively.

The percentage of all sows removed after parities 1 to 9+ in this study are shown in Figure 4. It was similar from parity 1 to 4 (nearly 10%) and, thereafter, increased with the number of parities, reached a plateau in parity 6 and 7, and decreased in parity 8 and 9+. In parity 6 and 7, percentage of removed sows were greater than they were in other parities. In addition, the percentage of removed sows in each breed are presented in appendix Figure 13 and 14.

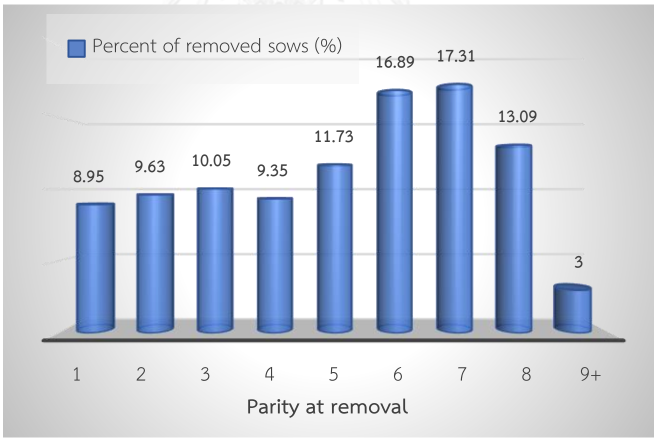

Figure 4 Percentages of sows removed after parities 1 to 9+

2.3 Removal reasons

Of seven removal reason categories, the most common reason for removal in this study were reproductive disorders (28.17%) and old age (26.25%), followed by sick/disease (14.80%), low productivity (13.75%), leg problems (13.33%), miscellaneous (2.13%) and dead (1.57%), respectively.

The different causes of reproductive disorders were return to oestrus (35.94%), anoestrus (26.15%), discharge (13.75%), abortions (11.90%), dystocia (7.06%), pseudo pregnant (3.10%), and vaginal prolapse (2.10%). As for leg problems, they included sows removed for lameness (78.53%) and dog-sitting posture (21.47%).

2.4 Removal reasons categorized by parity

Percentage of all removed sows in each category within removal parity are presented in Figure 5. From parity 1 to 4, most sows were removed owing to reproductive disorders, leg problems, and sick/disease. After the second parity, percentage of removed sows for reproductive disorders decreased linearly with increasing parity numbers. In parity 5, overall removal pattern was similar to those from parity 1 to 4, except an increase in percentage of those removed due to low productivity. In parity 6, sows removed from low productivity and sick/disease increased, while those removed owing to reproductive disorders decreased. Finally, most of the sows removed after parity 7 or higher were culled with old age. For more information, the reasons for removing sows and percentage of removals for each reason in each breed are presented in appendix Figure 15 and 16.

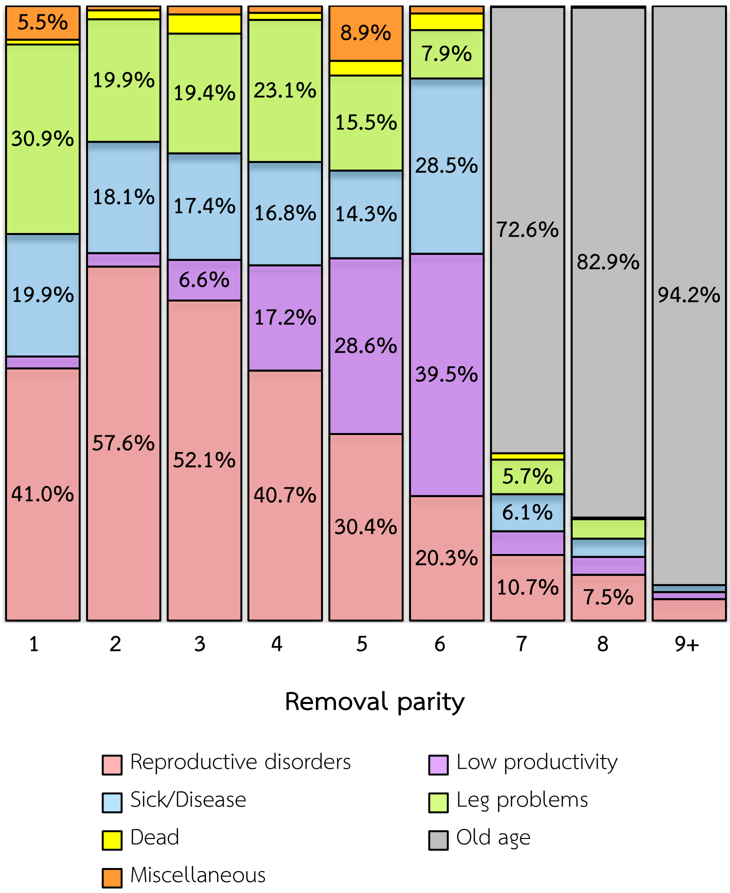

Figure 5 Percentage (%) of sows per removal reason category within removal parity (Only categories within parity with a percentage of at least 5% are shown in the figure)

2.5 Multiple comparisons of sow longevity between different farrowing months

Farrowing month significantly influenced sow longevity. The effect of month at first farrowing on sow longevity is shown in Figure 6. Sows farrowing in January/February had the highest longevity, meanwhile those farrowing between May and August had the lowest longevity. For further information, the effect of first farrowing month on sow longevity for each breed is shown in appendix Figure 17.

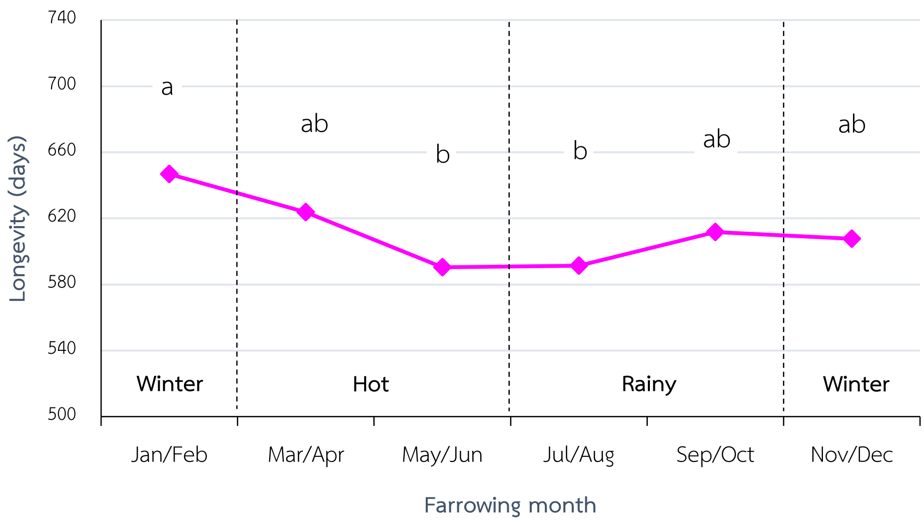

Figure 6 Effect of first farrowing month on sow longevity
Values with different letters on the same line differ significantly (P<0.05)

2.6 Multiple comparisons of average daily gain and backfat thickness between different birth months

Birth month significantly influenced average daily gain and backfat thickness. The effect of birth month on average daily gain and backfat thickness are shown in Figure 7. Gilts born between May and August had the lowest average daily gain. Gilts born between March and June had the highest backfat thickness, whereas those born in November/December had the lowest backfat thickness. In addition, the effect of birth month on average daily gain and backfat thickness in each breed is presented in appendix Figure 18 and 19, respectively.

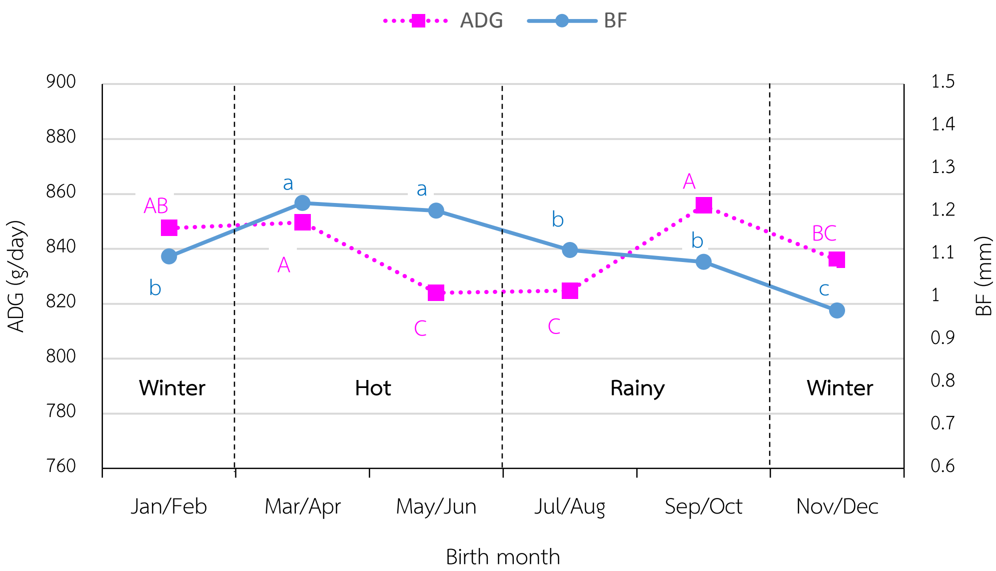

Figure 7 Effect of birth month on average daily gain and backfat thickness

Values with different letters on the same line differ significantly (P<0.05)

3. Factors influencing traits analyzed

The fixed effects for sow longevity were a combination of first farrowing year and season, age at first mating and total number of piglets born alive during sow's longevity. The combination of first farrowing year and season was treated as the contemporary group; 27 year and season combinations were observed. Age at first mating and total number of piglets born alive during sow's longevity were treated as covariates. Age at first mating was associated with sow longevity since longevity decreased with an increased age at first mating (P=0.04; regression coefficient = - 0.1840 ± 0.0936 (±SE)). This indicated that one day of age at first mating increased, sow longevity decreased by 0.184 day. Besides, an increased total number of piglets born alive during sow's longevity had a positive effect on sow longevity (P<0.01; regression coefficient = 11.4314 ± 0.0898 (±SE)). This indicated that those having one more piglets born alive during sow's longevity had an increased sow longevity by 11.43 days.

The fixed effects for average daily gain were a combination of year and season at birth and initial performance test age. That combination was treated as the contemporary group; 27 year and season combinations were found. Moreover, the initial performance test age was treated as covariate; it had a positive effect on average daily gain (P<0.01; regression coefficient = 1.6345 ± 0.2891 (±SE)). This indicated that the initial performance test age increased by one day, average daily gain increased 1.63 g/day.

The fixed effects for backfat thickness were a combination of year and season at birth and final performance test weight. Such combination was treated as the contemporary group; 27 year and season combinations were given. In addition, the final performance test weight was treated as covariate; it had a positive effect on backfat thickness (P<0.01; regression coefficient = 0.0079 ± 0.0008 (±SE)). This indicated that the final performance test weight increased by one kg, backfat thickness increased 0.0079 mm.

4. Genetic parameters

4.1 Heritability

Heritability estimates for sow longevity, average daily gain, and backfat thickness for Landrace and Yorkshire sows are presented on the diagonal in Table 9. Sow longevity heritability estimates for both breeds were low, whereas the estimates of heritability for average daily gain and backfat thickness were moderate to slightly high.

4.2 Genetic and phenotypic correlations

The estimates of genetic (above the diagonal) and phenotypic (below the diagonal) correlations among the studied traits for Landrace and Yorkshire sows are presented in Table 9. Unfavorable genetic associations of average daily gain and backfat thickness with sow longevity were found. Sow longevity were estimated to have moderate negative genetic correlations with average daily gain in both breeds (r_{gg} = -0.27 ± 0.12 in Landrace sows and r_{gg} = -0.36 ± 0.15 in Yorkshire sows) and moderate positive genetic correlations with backfat thickness in both breeds (r_{gg} =0.24 ± 0.10 in Landrace sows and r_{gg} = 0.30 ± 0.13 in Yorkshire sows). Additionally, a favorable association between average daily gain and backfat thickness was found only in Landrace sows. An average daily gain was estimated to have a significantly moderate negative genetic correlation with backfat thickness in Landrace sows (r_{gg} = -0.21 ± 0.10). However, genetic association between average daily gain and backfat thickness for Yorkshire was not significantly different from zero; but it tended to show a favorable genetic association. Additionally, phenotypic correlations among all traits were low for both breeds, ranging from -0.04 to 0.07.

Table 9 Heritabilities (± SE; on diagonal) and genetic (± SE; above the diagonal) and phenotypic correlations of sow longevity, average daily gain, and backfat thickness in Landrace and Yorkshire sows

Traits[1]	Longevity	ADG	BF
Landrace			
Longevity	**0.15 ±** 0.03	- 0.27 ± 0.12	0.24 ± 0.10
ADG	-0.02	**0.31 ±** 0.05	-0.21 ± 0.10
BF	0.07	-0.04	**0.57 ±** 0.07
Yorkshire			
Longevity	**0.11 ±** 0.03	-0.36 ± 0.15	0.30 ± 0.13
ADG	0.00	**0.23 ±** 0.05	-0.18 ± 0.12
BF	0.07	0.06	**0.46 ±** 0.07

[1] Longevity (days) was estimated by the difference between date of first farrowing and date of removal, ADG = average daily gain, BF = backfat thickness

CHAPTER V

DISCUSSION

1. Sow longevity

Sow longevities in the current study had large standard deviations. The average sow longevity for Landrace was slightly higher than that reported in earlier studies; 600 days in Poland by Sobczyńska et al. (2013), 615 days in Austria by Meszaros et al. (2010), and 617 days in Sweden by Yazdi et al. (2000). Surprisingly, average sow longevity from the finding of Yazdi et al. (2000) was lower than that in the current study, even though those sows were raised in a temperate climate country. The difference might partly depend on different data structures. Swedish data were recruited from 24 herds with more than 50 sows born, raised, and farrowed in the same herd, whereas our data were recruited from only one herd. Different managements among farms were included. Furthermore, extreme values for age at first farrowing were set lower than ours (≤250 and ≥480 days vs. ≤300 and ≥600 days). As a result, average sow longevity in the study of Yazdi et al. (2000) was slightly lower than that in the current study.

The average sow longevity for Yorkshire in the present study were within the range reported in other studies, ranging from 531 to 652 days (Tarres et al., 2006; Meszaros et al., 2010; Sobczyńska et al., 2013). The difference of average sow longevity seemed to depend on longevity measurement and removal strategies of each studied farm. For example, the study of Johnson and Nugent (2008) defined sow longevity as age at birth of the last recorded litter of each sow; all sows had the opportunity to produce at least three litters, while Sobczyńska et al. (2013) defined it as the number of days between the first and last farrowings. Additionally, different housing and management systems in each studied farm majorly impacted sow removal (Sobczyńska et al., 2013).

In the studied sows, survival probability decreased with greater parity number. The result was in accordance with other studies (Koketsu, 2000; Engblom et al., 2008) reporting that the risk for mortality increased with the parity number of sows. Moreover, the survival curve reflected that the survival probability of sows decreased, especially after weaning in each reproduction cycle. Our result was in agreement with the findings of Yazdi et al. (2000) who reported that the risk for removal was greater after weaning in parity 1-3. This incident might be explained by farm management system and breeding strategy since sows with poor performance were practically removed after weaning.

2. Removal reason

In low parity (parity 1 to 4), the most category for removal was reproductive disorders. This finding was in accordance with earlier studies (Lucia et al., 2000a; Dhliwayo, 2007; Engblom et al., 2007). Reproductive disorders accounted for the largest proportion of the overall removal category. Return to oestrus (36%) and anoestrus (26%) were the main removal reasons within reproductive disorders category. The result was in agreement with other studies, which reported that return to estrus and anoestrus were the most common reasons for reproductive disorders (Koketsu et al., 1997; Engblom et al., 2007; Segura-Correa et al., 2011a).

Both return to oestrus and anoestrus after weaning could be influenced by management practices. For instance, return to oestrus could be due to insufficient oestrus detection (Vargas et al., 2009), improper boar stimulation (Segura-Correa et al., 2011a), and poor artificial insemination techniques (Engblom et al., 2007). In addition, improper timing of artificial insemination was important to an increase the risk of return to oestrus (Bortolozzo et al., 2005) because older sows showed longer oestrus than gilts and primiparous sows (Nissen et al., 1997). As for postweaning anoestrus, it could be due to the effect of stress from translocation (Engblom et al., 2007) and low feed intake capacity (Koketsu and Dial, 1997). When the sows had lower feed intake capacity during lactation, it resulted in high weight loss and poor body condition; the incidence of anoestrus after weaning increased (Tantasuparuk et al., 2001a; Vargas et al., 2009).

Leg problems came in second category for removal at low parity numbers. Leg problems comprised approximately 13% of the overall removal category. Within Leg problems category, sows were removed for lameness (80%), which was in association with with the findings of Lucia et al. (2000a) and Segura-Correa et al. (2011a), followed by dog-sitting posture (20%). The results in the current study agreed with those of Segura-Correa et al. (2011a), who observed that gilts and sows at parity 1 to 4 were more likely to be removed as a result of locomotor problems than old parity sows. In general, females would be selected for structural soundness in the early period of their lifetime production. Therefore, gilts and primiparous sows having leg problems were removed immediately in the early parities (D'Allaire et al., 1987; Masaka et al., 2014), bringing the higher proportion of sows removal with leg problems in low parity sows than those in high parity.

In medium parity (parity 5 to 6), it was found that both reproductive disorders and leg problems decreased with higher parity numbers, whereas low productivity category clearly increased in medium parity. Considering the ratio of sows removed with sick and/or disease, those in parity 6 had the highest ratio when compared to those in other parities. Low productivity and sick and/or disease categories, in this study, comprised approximately 14% and 15% of the overall removal category, which agreed with the findings of Lucia et al. (2000a) and Segura-Correa et al. (2011a). Litter size and body size of sows generally increased with the parity number (Lawlor and Lynch, 2007); however, older sows were often unable to eat enough feed in order to meet the body requirements, especially during lactation. Consequently, this might also lead to a loss of body weight (Kruse et al., 2011) and an increased sickness and/or disease problems in high parity sows. In addition, the lower feed intake and the loss of body weight in sows were associated with smaller litter size at subsequent farrowing (Koketsu and Dial, 1997; Thaker and Bilkei, 2005).

In high parity, most of the sows were removed due to old age which accounted for the second rank (26%) of overall removal category; this was consistent with earlier studies (Engblom et al., 2007; Hughes et al., 2010; Segura-Correa et al., 2011a). In this study, only sows in parity ≥ seven were removed due to old age. The proportion of sows removed with old age increased with greater parity numbers (72.6%, 82.9%, and 94.2% in parity 7, 8 and 9+, respectively). This result was supported the studies of by Lucia et al. (2000b) and Segura-Correa et al. (2011a). They reported that the sows removed due to old age increased with higher parity numbers. According to a study of Sasaki and Koketsu (2008), those removed as a result of old age had both high longevity and high number of lifetime pigs born alive. Similarly, Lucia et al. (2000b) reported that sows removed with old age had the longest longevity, the greatest numbers of piglets per sows, and the shortest nonproductive days.

3. Fixed effects

Fixed effects on longevity

Farrowing month (seasonal) was a factor associated with sow longevity. The present study showed that sows farrowing in late hot and early rainy months had the shortest longevity. High mortality of sows in summer was probably because of the greater ambient temperature in summer and climatic change during late hot to early rainy months (Chagnon et al., 1991; D'Allaire et al., 1996; Koketsu, 2000; Engblom et al., 2008). In addition, the former study reported that body temperature of sows increased around farrowing in the high temperature conditions (Prunier et al., 1997);

this might lead to a greater hazard for heart failure in sows (Chagnon et al., 1991). Additionally, Koketsu and Dial (1997) found that sows farrowing in summer had the lightest litter weight at weaning and longer weaning-to-first-service interval than those farrowing during any other season. Finally, sows with poor performance would be culled earlier than those with standard or good performance.

Results of the present study showed a negative relationship between sow longevity and age at first mating. The younger the sows were first mated, the longer the longevity of the sows was. This might be explained by the findings of Schukken et al. (1994) and Hoge and Bates (2011) that age at pubertal, age at first mating or farrowing of first litter of gilts at a younger age may be an indicator of fertility and good body condition for piglet production. In agreement with previous studies, gilts first observed oestrus, mated, and farrowed at younger age had a greater sow longevity than gilts attaining those events at an older age (Schukken et al., 1994; Koketsu et al., 1999; Engblom et al., 2008; Knauer et al., 2010; Hoge and Bates, 2011; Saito et al., 2011). Furthermore, annualized lifetime PBA and the number of parities at removal significantly increased with decreased age at first mating or age at first farrowing as reported by Le Cozler et al. (1998) and Saito et al. (2011). In addition, these gilts would subsequently be sows to produce litter, so they should have had lower probability of being culled, contributing to an increases sow longevity (Koketsu et al., 1999).

Total number of piglets born alive during sow's longevity had a positive effect on sow longevity. This finding confirmed the results of other studies, which indicated that the greater the number of piglets born alive were produced, the longer the sow longevity was (Yazdi et al., 2000; Engblom et al., 2008; Knauer et al., 2010; Hoge and Bates, 2011). In Addition, the preceding studies reported that genetic and phenotypic correlations between the number of lifetime piglets born alive and sow longevity or parity at removal were high and positive (Tholen et al., 1996; Sasaki and Koketsu, 2008; Sobczyńska et al., 2013). The results indicate that selection for increased number of lifetime piglets born alive might result in an increased sow longevity. It could be explained by the autocorrelation on the grounds of the fact that sows were removed due to small litters had automatically lower longevity.

Fixed effects on average daily gain

Birth month (seasonal) was a factor associated with average daily gain. The present study showed that gilts born in late hot and early rainy months had the lowest average daily gain. An effect of stress under an elevated ambient temperatures resulted in a reduction of appetite, feed intake, consequently, milk production of the sows in lactation periods (Prunier et al., 1997). Thus, sows producing insufficient milk might cause problems with a decrease in pre-weaning growth rate of their piglets (Quiniou and Noblet, 1999; Renaudeau and Noblet, 2001). It was reported that a decrease in weaning weight of piglet resulted in a decreased average daily gain after weaning (Smith et al., 2008; Leliveld et al., 2013). Thus, average daily gain of sows born during late hot and early rainy seasons might be affected by a relatively high ambient temperature.

Average daily gain in the current study was measured from 9 to 22 weeks of age. The initial performance test age of the studied sows ranged from 53 to 84 days (appendix table 11). It was found that the initial performance test age had a positive effect on average daily gain. This was in accordance with the study of Dritz et al. (1997) that older and heavier pigs would have greater average daily gain than lighter and younger pigs in the same stage of growth since maximum weight would improve the competitiveness between pigs. The effect of initial performance test age could somewhat be explained by the growth curve of the pigs which was created by plotting body weight against age, giving a sigmoidal shaped curve. During early life stage, growth was exponential up to the peak of growth rate; rate then slowly decreased towards zero when the pig matured. The initial performance test age in this study was measured in the early life stage. On average, sows tested at the older age had higher weight than those tested at the younger age. As a result, the older could gain weight more than the younger ones.

Fixed effects on backfat thickness

Birth month (seasonal) was a factor associated with backfat thickness. Gilts born in hot months had the highest backfat thickness. According to age at performance test, gilts born in hot months were measured ultrasonically for backfat thickness during rainy and winter months. Since feed intake tended to increase in cold weather to compensate the great metabolic demand for heat production as reported by Dube et al. (2011), an increased feed intake in cool temperature conditions would increase backfat thickness of gilts (García-Valverde et al., 2008).

Nevertheless, gilts born in winter month had the lowest backfat thickness. This was confirmed by Tummaruk et al. (2000), who reported that gilts born in winter had a lower backfat depth than those born in summer. Considering farming system, gilts born in winter months were measured ultrasonically for backfat thickness during hot and rainy months. Gilts were stressed to an increase in ambient temperature during hot months, resulting in a decrease of appetite, feed intake, and fat deposition; these, hence reduced backfat thickness (Trezona et al., 2004).

The final performance test weight had a positive effect on backfat thickness. The higher the final performance test weight was weighed, the higher the backfat thickness of the sows was. In this study, backfat thickness was measured at approximately 22 to 23 weeks of age. The average final performance test age and weight of all sow were 157 ± 15 days and 102 ± 14 kg, respectively (appendix table 11). Sow’s body weight increased generally in those of increasing age. At the higher weight, sows increased backfat deposition, leading to an increased backfat thickness.

4. Genetic parameters

4.1 Heritability

The heritability estimates for sow longevity in this study were low for both breeds. However, genetic variation existed for selection in order to increase sow longevity. The heritability estimate for sow longevity, in this study, was in agreement with earlier studies, ranging from 0.10 to 0.11 for Yorkshire sows and from 0.11 to 0.19 for Landrace sows (López-Serrano et al., 2000; Johnson and Nugent, 2003; Sobczyńska et al., 2013). The estimates of heritability were slightly lower in Yorkshire than in Landrace sows.

Indeed, the heritability estimates for sow longevity seemed to differ depending on genetic makeup of breeds, populations, and method of analysis in each study (Serenius and Stalder, 2004). Heritability estimates for sow longevity were presented by Serenius and Stalder (2004) and Yazdi et al. (2000) indicating that linear model estimates of heritability were lower than those estimated using survival analysis (Serenius and Stalder, 2006b; Engblom et al., 2009). In this study, the heritability for sow longevity was not estimated by using survival analysis since the survival analysis software is unavailable in Thailand.

Sow longevity heritability estimates ranged between 0.05 and 0.10 from linear model analysis and between 0.16 and 0.19 from survival analysis for Finnish Landrace and Large White sows (Serenius and Stalder, 2004). In addition, the heritability estimates for Swedish Landrace sows ranged from 0.11 to 0.27, obtained by survival analysis (Yazdi et al., 2000). Typically, sow longevity data should be analyzed using survival analysis, but multiple-trait analysis was not possible when using the survival analysis software (Serenius and Stalder, 2006a).

The heritability estimates for average daily gain and backfat thickness were moderate to slightly high for both breeds. Estimate of heritability for average daily gain of Landrace sows was consistent with an heritability of 0.31 estimated from growth rate during 9 to 22 weeks of age reported by Imboonta et al. (2007a). As for backfat thickness, the estimate of heritability of Landrace sows was in accordance with those of earlier studies ranging from 0.45 to 0.61 for an ultrasonic measure of backfat thickness at the 10^{th} rib and 6.5 cm from the midline and adjusted to 100 kg (Imboonta et al., 2007a; Imboonta et al., 2007b).

The estimates of heritability for average daily gain and backfat thickness of Yorkshire sows were in the range of those from earlier studies. Johnson et al. (2002) used Landrace, Yorkshire, Duroc, and Hamshire from USA to study and reported that heritability estimates of 0.17 to 0.25 for average daily gain at approximately 100 kg of live weight and heritability estimates of 0.30 to 0.46 for backfat thickness at 12^{th} rib using B-mode ultrasound equipment were observed. Moreover, Johnson and Nugent (2003) reported that the estimates of heritability for backfat thickness ranged from 0.32 to 0.47 based on Landrace, Yorkshire, Duroc, and Hamshire sows.

4.2 Genetic correlations

Genetic correlations between sow longevity and average daily gain

The genetic correlation between sow longevity and average daily gain were moderate negative. The results from the present study appeared to suggest that selection for an increased average daily gain might result in decreased sow longevity. This was in agreement with the findings of Hoge and Bates (2011) who reported that gilts growing faster had an increased risk of being culled from herd.

Moreover, these results were supported by the study of López-Serrano et al. (2000). They found negative genetic correlation between stayability and daily gain at approximately 105 kg live weight, ranging from -0.28 to -0.32 and positive genetic correlation, ranging from 0.22 to 0.27, between stayability and backfat thickness measured at three different points on the back of gilts. Similarly, Sobczyńska et al. (2013) reported that the length of productive life had weakly negative correlation with growth rate (-0.11 in Polish Yorkshire sows) and weakly positive correlation with backfat thickness at P_2 and P_4 (3 and 8 cm), adjusted to 110 kg (0.16 in Polish Landrace sows). They summarized that the fattest and the slowest growing gilts might have better sow longevity.

These results were supported by Tholen et al. (1996), who reported that the genetic correlation between average daily gain and fertility trait (interval between weaning and conception following the first farrowing) were negative. This indicated that selection for gilts with a high growth rate might increase fertility problem. Moreover, the faster growing gilts could laed to structural problems (Tholen et al., 1996). In the study of Serenius and Stalder (2004), average daily gain was estimated to have moderately negative genetic correlation with overall leg score, ranging from 1 (severe leg problems) to 5 (free of leg problems) (r_{gg} = -0.33 ± 0.13). Furthermore, overall leg scores were estimated to have moderately positive genetic correlation with sow longevity (r_{gg} = 0.32 ± 0.17). These results indicated that selection for high growth rate was associated with high leg conformation problems and short sow longevity.

Besides, the results of Stalder et al. (2005) supported those of the present study; they showed that gilts from slow growing group (>210 days to 113.4 kg of body weight) had higher number of pigs weaned during their lifetime than those from the fast growing group (150 to 165 days, 166 to 180 days, 181 to 195 days, and 196 to 210 days). As a result, the slow growing gilts having more weaned pigs should have lower risk of culling.

Genetic correlations between sow longevity and backfat thickness

The genetic correlations between sow longevity and backfat thickness were moderately positive genetic correlation in both Landrace and Yorkshire sows. These correlation suggested that the selection for a reduced backfat thickness might result in short sow longevity. These results were supported by the study of Hoge and Bates (2011) who reported that gilts possessing less backfat thickness adjusted to 113 kg body weight had an increased risk of being culled from herd.

Additionally, Stalder et al. (2005) also found that gilts from the highest backfat thickness groups (>25 mm) had more lifetime number of piglets born alive and the number of parities than those from lower three backfat thickness groups (<9 mm, 17 to 21 mm and 22 to 25 mm). Moreover, those from the highest backfat thickness group had the best probability of surviving to last litter than those from other groups, according to Kaplan – Meier survival curve. Due to the fact that gilts from group with highest backfat thickness had the ability to produce a greater number of piglets, they, consequently, were retained in the herd for a greater number of parities. Furthermore, Chen et al. (2002) reported the genetic correlation between backfat thickness and number born alive ranging from 0.18 to 0.20 based on Duroc, Hamshire, Landrace, and Yorkshire. Thus, selection for high backfat thickness is beneficial for improving litter size and sow longevity.

However, no clear genetic correlation among average daily gain, backfat thickness, and sow longevity was observed in the study of Tholen et al. (1996). They found that genetic correlation between stayability and growth rate ranging from -0.31 to 0.02, together with that between stayability and backfat thickness ranging from -0.03 to 0.36. Nevertheless, estimates of genetic correlation were mostly unfavourable. In addition, neither average daily gain nor backfat thickness was reported to have significantly genetic association with sow longevity in Swedish Landrace sows (Yazdi et al., 2000), as well as Finnish Landrace and Large White sows (Serenius and Stalder, 2004).

Genetic correlations between average daily gain and backfat thickness

According to the results from the present study, genetic correlation between average daily gain and backfat thickness for Yorkshire was not significantly different from zero. The only favorable and significant genetic correlation was between average daily gain and backfat thickness in Landrace sows. The result indicated that the selection for increased average daily gain might result in decreased backfat thickness. Similarly, in a study from Korea, Kim et al. (2004) reported that the day to 90 kg had negatively genetic correlation with the backfat measurement at the 3 different sites, ranging from -0.19 to -0.30 in Duroc, from -0.04 to -0.17 in Landrace, and from -0.10 to -0.13 in Large White sows. Besides, Dube et al. (2013) found that the genetic correlation between test period gain (average daily gain form 27 kg to 86 kg of live weight) and backfat thickness was -0.26 for Large White sows.

On the other hand, Serenius and Stalder (2004) reported that positive genetic correlations between daily gain and backfat thickness at approximately 100 kg live weight were 0.32 in Finnish Landrace and 0.39 in Finnish Large White sows. The difference of the estimated genetic correlations seem to be dependent on the population, model used, and methodology of analyses (Yazdi et al., 2000; Serenius and Stalder, 2004). In addition, the difference of results might be due to then difference of measurements, such as weight at measure, age at measure, and site of measurement. It depended on data and objectives of the project.

CHAPTER VI

CONCLUSIONS

1. The average sow longevity of all studied sows was 611 days, being counted from first farrowing to culling dates. On average, parity number of the sows at removal was 5.1. The average parity at removal of Landrace was higher than that of Yorkshire sows. According to breed difference, it was found that Landrace sows had higher longevity, higher average daily gain, and thicker backfat depth than Yorkshire sows.

2. Sows removed after parity 1-4 were around 38% of all removals. Almost 46% were removed after parity 5 to 7; and only 16% of them were removed after parity 8 to 9+. The most common reasons for removal were reproductive disorders (28.17%) and old age (26.25%).

3. Young sows, parity 1-4, were predominantly removed due to reproductive disorder followed by leg problems. An increase in percentage of sows removed owing to low productivity were found in parity 5. In parity 6, low productivity was the main reason of removal. Most of the sows removed after parity 7 or higher were from old age.

4. Farrowing month significantly influenced sow longevity. Sows farrowing in winter had the highest longevity while those farrowing in summer and rainy season had the lowest longevity. Covariates affecting sow longevity were age at first mating and total number of piglets born alive during sow's longevity. Birth month significantly influenced average daily gain and backfat thickness. Gilts born in summer and rainy season had the lowest average daily gain. Gilts born in summer had the highest backfat thickness, while those born in winter had the lowest backfat thickness.

Covariate affecting average daily gain was initial performance test age, while final performance test weight was a covariate for backfat thickness.

5. Heritabilities of sow longevity were low whereas those of average daily gain and backfat thickness were moderate to slightly high for two breeds. These confirmed that sow longevity was lowly heritable trait. However, genetic variation obtained is sufficient to be utilized for increasing sow longevity by selection. However, average daily gain and backfat thickness were moderately to highly heritable traits.

6. Sow longevity genetically correlated with average daily gain and backfat thickness in both Landrace and Yorkshire sows. These correlation suggested that selection for improved average daily gain and reduced backfat thickness could have unfavorable consequences for sow longevity. A favorable genetic correlation was found between average daily gain and backfat thickness only in Landrace sows. Thus, in Landrace sows, selection for increasing average daily gain would result in reduced backfat thickness.

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APPENDIX

Table 10 Summary of the percentage of sows removed within each category of removal reasons

Reference	Country	Breed[1]	No.[2]	Removal reasons (%)						
				Reproductive disorders	Low productivity	Old age	Leg problems	Death	Disease	Others
Lucia et al. (2000)	USA	Crossbred	7,973	33.6	20.6	8.7	13.2	7.4	3.1	13.4
Tarres et al. (2006)	Spain	Duroc	353	20.0	56.0	NR	7.0	14.0	NR	3.0
Engblom et al. (2007)	Sweden	LR x YS	14,234	26.9	9.5	18.7	8.6	4.4	28.3	3.6
Dhliwayo (2007)	Zimbabwe	Crossbred	1,961	16.4	36.8	NR	26.3	6.9	2.6	11.0
Sasaki et al. (2008) [3]	Japan	LW x LR	3,000[4]	6.2	1.1	81.9	1.4	NR	NR	9.4
			3,379[5]	10.6	4.3	67.2	3.1	NR	NR	14.8
			7,407[6]	39.3	5.9	4.3	14.7	NR	NR	35.8
Hughes et al. (2010)	Australia	LW x LR	2,154	42.9	19.1	20.6	12.2	NR	5.2	NR
Segura-correa et al. (2011a)	Mexico	Crossbred	7236	26.9	12.8	24.1	15.5	NR	13.0	7.7
Soltesz and Balogh (2013)	Hungary	LW x LR	4,359	29.6	26.8	NR	20.6	13.8	NR	9.2

[1] Crossbred = Crossbred sow, LR x YS = Crossbred (Landrace x Yorkshire) sow, LW x LR = Crossbred (Large White x Landrace) sow

[2] No. = Number of sow *removed*

[3] *Sows were divided into three sow group*: [4] A group of sow having both high lifetime efficiency and high longevity [5] A group of sow having ordinary lifetime efficiency and high longevity [6] A group of sow having low longevity. (NR = not reported)

Table 11 Mean, standard deviation (SD), minimum (Min), and maximum (Max) for initial and final performance test of age and weight

Traits	Mean	SD	Min	Max
Initial performance test age, days	72	8	53	84
initial performance test weight, kg	30	6	17	70
Final performance test age, days	157	15	118	232
Final performance test weight, kg	102	14	68	165

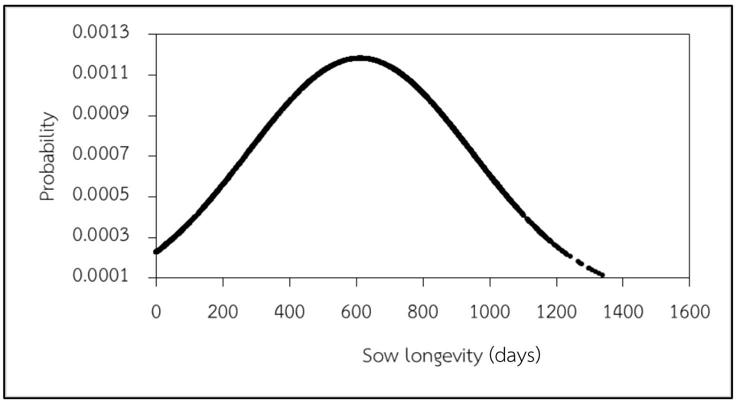


Figure 8 Distribution of sow longevity

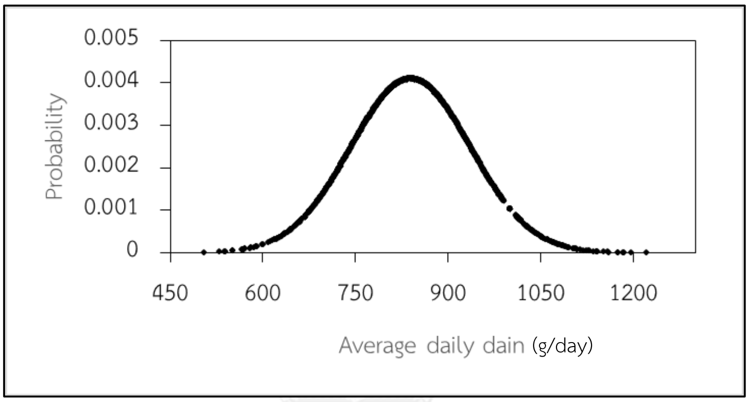


Figure 9 Distribution of average daily gain

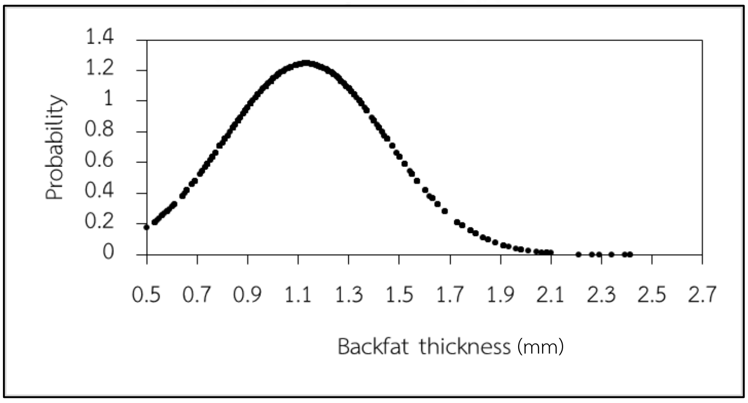


Figure 10 Distribution of backfat thickness

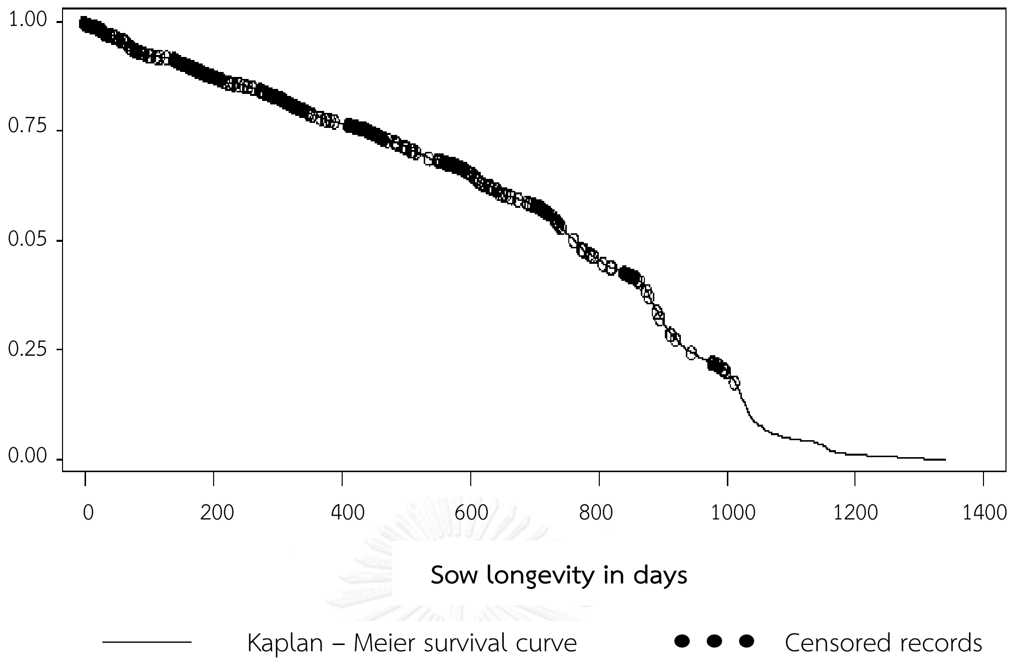


Figure 11 Survival curve of sow longevity for Landrace

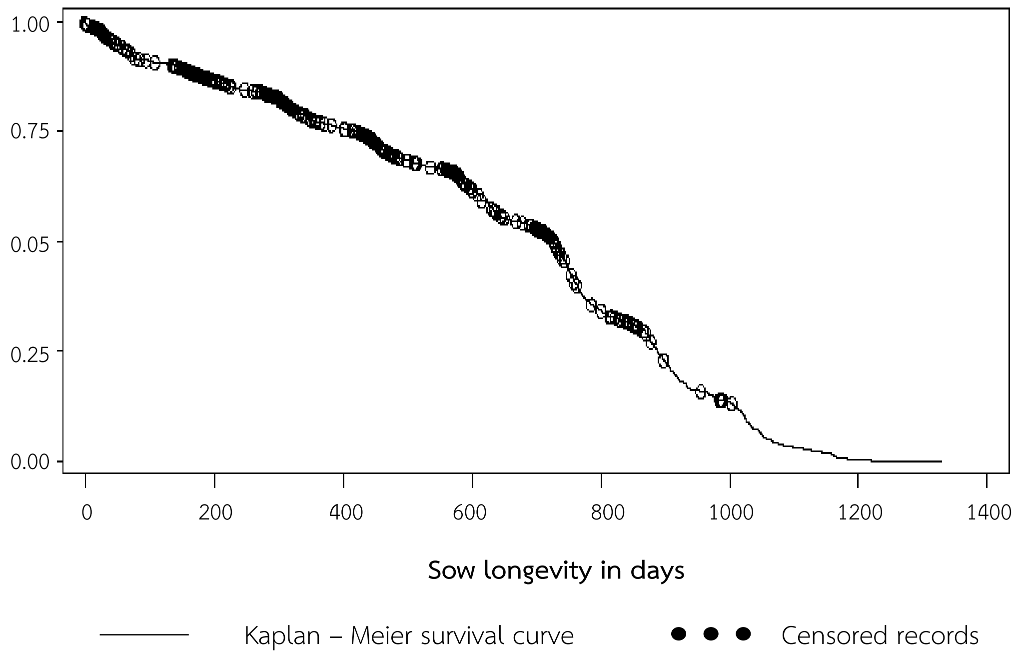


Figure 12 Survival curve of sow longevity for Yorkshire

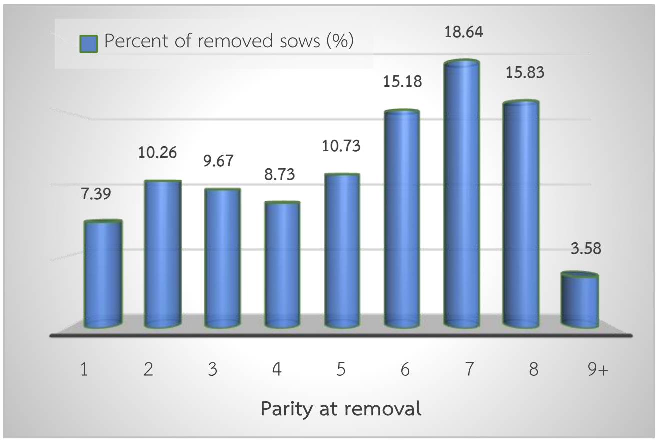


Figure 13 Percentages of sows removed after parities 1 to 9+ for Landrace

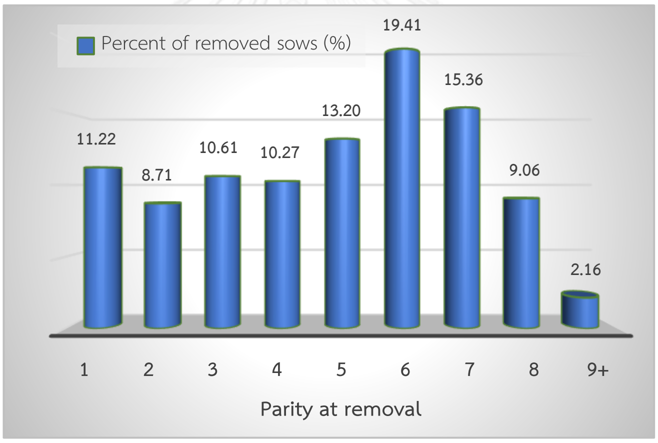


Figure 14 Percentages of sows removed after parities 1 to 9+ for Yorkshire

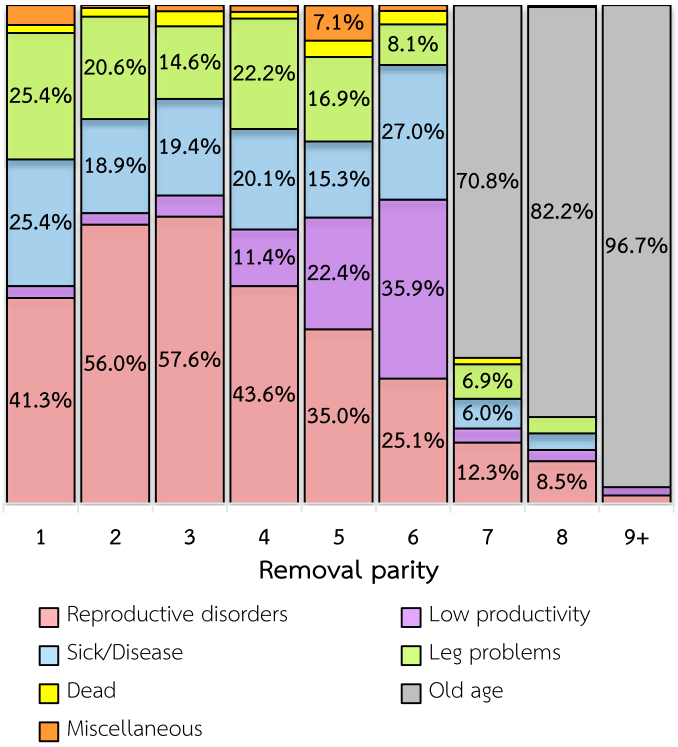


Figure 15 Percentage of sows per removal reason category within parity for Landrace

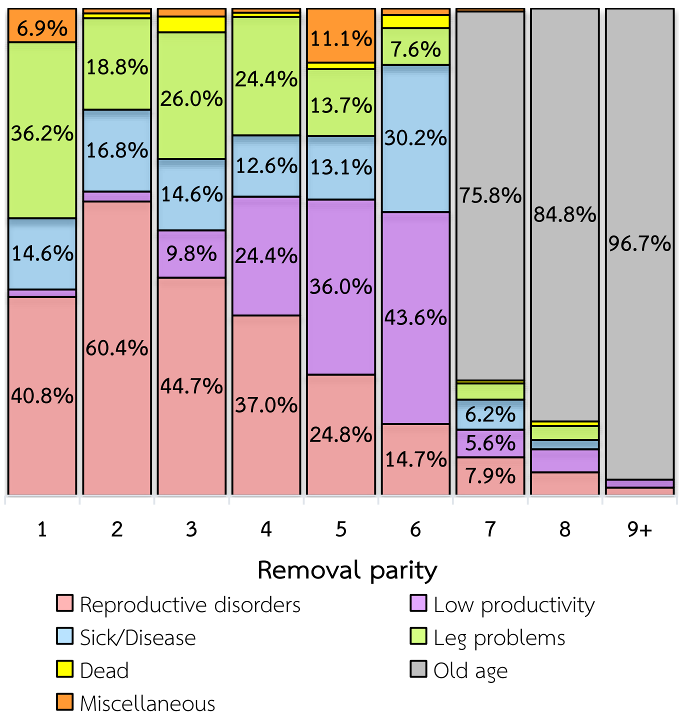
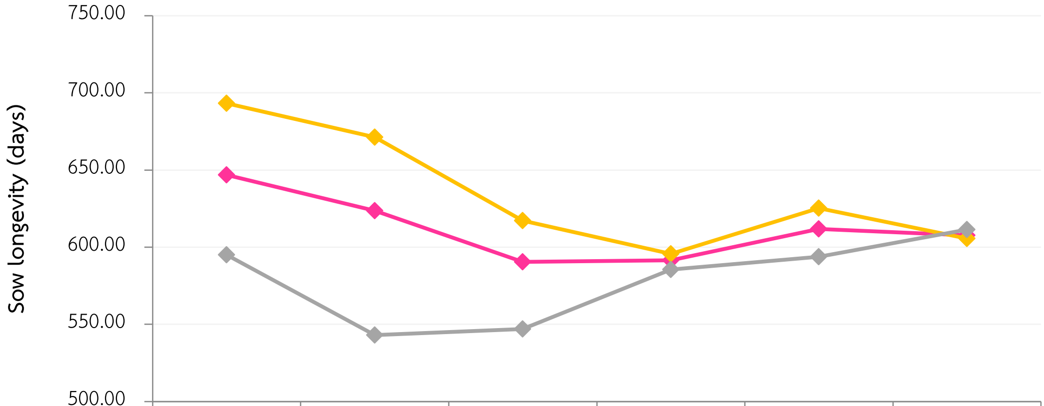


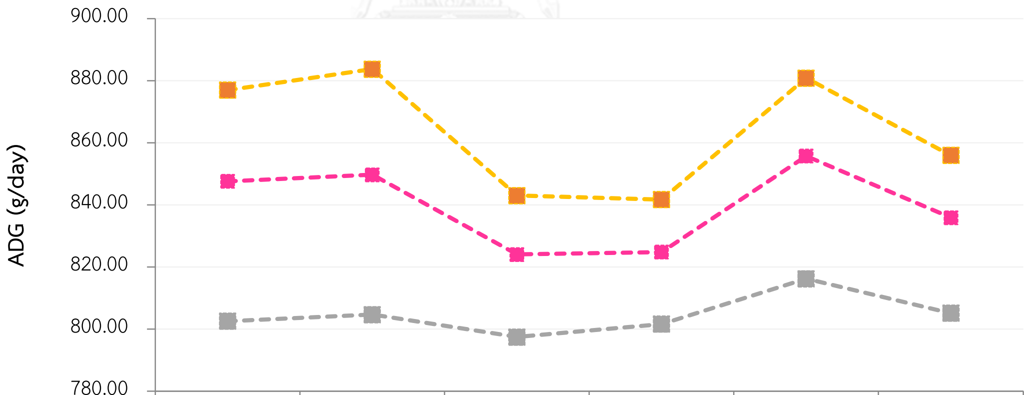
Figure 16 Percentage of sows per removal reason category within parity for Yorkshire



	Jan/Feb	Mar/Apr	May/Jun	Jul/Aug	Sep/Oct	Nov/Dec
All sows	646.87	623.72	590.38	591.45	611.82	607.59
LR	693.32	671.16	617.15	595.66	625.21	605.50
YS	594.95	543.12	546.96	585.60	593.71	611.31

Farrowing month

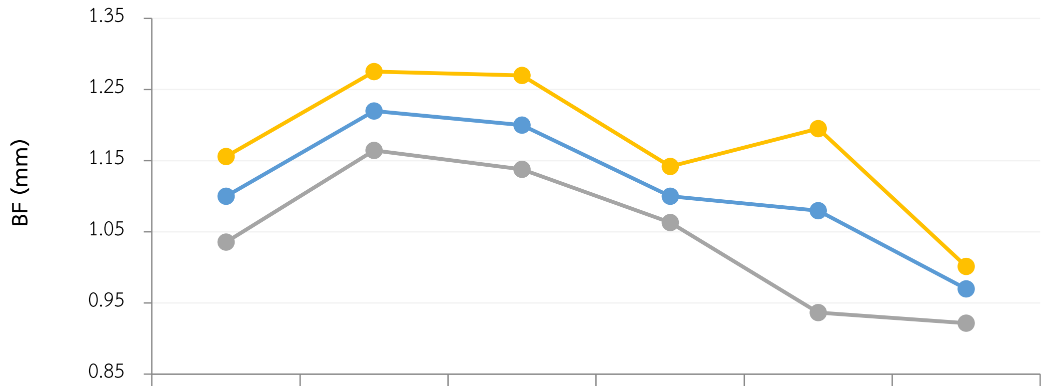
Figure 17 Effect of first farrowing month on sow longevity for all sows, Landrace (LR) and Yorkshire (YS)



	Jan/Feb	Mar/Apr	May/Jun	Jul/Aug	Sep/Oct	Nov/Dec
All sows	847.57	849.67	824.03	824.80	855.71	835.89
LR	876.96	883.69	842.98	841.72	880.81	855.92
YS	802.52	804.68	797.46	801.62	816.20	805.09

Birth month

Figure 18 Effect of birth month on average daily gain (ADG) for all sows, Landrace (LR) and Yorkshire (YS)



	Jan/Feb	Mar/Apr	May/Jun	Jul/Aug	Sep/Oct	Nov/Dec
All sows	1.10	1.22	1.20	1.10	1.08	0.97
LR	1.16	1.28	1.27	1.14	1.20	1.00
YS	1.04	1.16	1.14	1.06	0.94	0.92

Birth month

Figure 19 Effect of birth month on backfat thickness (BF) for all sows, Landrace (LR) and Yorkshire (YS)

VITA

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Publications:

Nuttha Wongsakajornkit and Nalinee Imboonta. 2014. Percentage of factor affecting on sow culling at different parity number. In: Thai Journal of Animal Science. The 3rd National Animal Science Conference of Thailand, ISSN 2351-0188 Vol.1 Supplement 2 April 8-10, 2014. p 115 - 118.

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