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Estimation of Genetic Parameters for Litter Traits in Taiwan Duroc, Landrace, and Yorkshire Pigs

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ABSTRACT

Selection for reproductive components in various pig populations in the world has been successfully performed. This study aimed to estimate the genetic parameters and genetic trends of reproductive traits of Taiwan Duroc, Landrace, and Yorkshire pigs. Data were extracted from the Taiwan Swine Registry Database from 2009 to June 2018. The number of farrowing records used in this study was 6,504, 6,398, and 2,178 for Duroc, Landrace, and Yorkshire, respectively. Litter traits measured were the number of piglets born alive (NBA), number of piglets at 21 days of age (N21D), litter weight at birth (LWB), and litter weight at 21 days of age (LW21D). Variances estimates obtained from univariate analysis with a repeatability model were used to estimate heritability and repeatability. Heritability estimates were 0.058±0.017, 0.037±0.014, and 0.101±0.032 for NBA; 0.086±0.018, 0.102±0.019, and 0.151±0.035 for N21D; 0.036±0.011, 0.111±0.021, and 0.330±0.05 for LWB; 0.119±0.020, 0.168±0.023, and 0.237±0.045 for LW21D in the Duroc, Landrace, and Yorkshire breeds, respectively. The genetic trends of NBA were 0.005 piglets/year for the Duroc and 0.002/piglets for the Landrace. In Yorkshire, conversely, there was no significant genetic improvement of NBA, but there was a 0.011 kg/year improvement of LWB. Among all genetic trends, it was shown that genetic gain in Taiwan pig populations was very low. In addition, it also suggested that genomic selection could be used in the Taiwan pig breeding program to push the rate of genetic gain.

Keywords: genetic parameters; genetic trend; litter traits; REML; pig

INTRODUCTION

The pig industry occupies an important place in the agriculture of Taiwan. In 2020, about 8.2 million pigs were slaughtered in Taiwan, contributing 42.3% of the economic value of livestock production and 14.2% of the total value of agricultural production (Statistic Office of C. O. A., 2020). Two-way crossbred (Duroc × Landrace, DL) and three-way crossbred (Duroc × Yorkshire × Landrace, DYL) pigs had become the major commercial lines in the pork market since the 1960s when Landrace, Duroc, Yorkshire, and Hampshire breeds were introduced into Taiwan for the crossbreeding experiments conducted by Taiwan Sugar Corporation and Taiwan Livestock Research Institute (NAIF, 2010a; NAIF, 2010b). Unfortunately, an outbreak of Foot and Mouth Disease (FMD) in 1997 caused the collapse of pig production and exports and a decrease of 48.5% in the total population size in 2020 in comparison to the population size in 1996 (Statistic Office of C. O. A., 1996; NAIF, 2020). Afterward, Taiwan obtained OIE's recognition as FMD-free in 2020 to create opportunities for overseas pork markets and pig farming businesses. Consequently, the improvement of reproductive efficiency should be the priority to meet the demand in the future.

The selection of reproductive traits in various pig populations worldwide has been successfully performed. Reproductive traits are also highly economically important in determining the profit of the pig industry (Nielsen *et al.*, 2013; Silalahi *et al.*, 2017). The sow reproductive efficiency of pigs is usually measured by the number of piglets produced by a sow per year (PSY) (Zhang *et al.*, 2023). The success of this selection goal is largely determined by the genetic parameters in the selected pig population. However, the genetic parameters of a population cannot be fully used in other populations because the differences between populations can cause a mismatch of the results with the expectation (Chen *et al.*, 2003). The genetic trend for reproductive traits in Taiwan pig populations has not been widely documented, and Taiwanese pig farmers still focus on the production traits such as body conformation, average daily gain, feed efficiency, and backfat thickness (Chen *et al.*, 2012; Tsou, 1993). The negative genetic correlation between production traits and reproductive traits in pigs may lower reproductive ability (Rutherford *et al.*, 2013; Lee *et al.*, 2015). Genetic parameters are also breed-specific as well as depend on the genetic model (Chen *et al.*, 2003). Thus, this study aimed to estimate genetic parameters and genetic trends of the reproductive performance of Taiwan Duroc, Landrace, and Yorkshire pigs. The results could determine further steps and future breeding strategies for Taiwan pig farming.

MATERIALS AND METHODS

Data

Data were extracted from the Taiwan Swine Registration Database System, and those records were collected from three commercial pig farms that have joined the On-Farm Performance Test Program for Duroc, Landrace, and Yorkshire pigs from 2009 to June 2018. The database includes information on the registration number of the purebred pigs, breed, parity, farm origin, birth date, mating date, farrowing date, date of piglet weaning, and litter size at birth and at 21 days postpartum. The number of farrowing records used in this study was 6,504, 6,398, and 2,178 for Duroc, Landrace, and Yorkshire, respectively. Pedigree data included 24,681 for Duroc, 24,020 for Landrace, and 7,610 for Yorkshire from 2004 to 2018. The structure of the data set is shown in Table 1.

Sow mating was done by artificial insemination (AI) two times at a 12-hour interval, followed by a pregnancy test with ultrasonography or behavior observation with boar exposure after 21-25 days of AI. Sow was penned individually with restricted feed and ad libitum access to water. Sow feed was given twice a day with commercial sow gestation feed. Litter traits measured were the number of piglets born alive (NBA), the number of piglets at 21 days of age (N21D), and individual piglet weight at birth and at 21 days after farrowing. The NBA was defined as the number of piglets found alive the next day (24 hours) after farrowing, while N21D is the number of piglets alive at 21 days of lactation, including cross-fostered piglets. The number of cross-fostered piglets was 3.16% and was carried out based on body weight, litter size, and age of the piglets. Litter weight was the sum of the individual piglet's live weight in a specific parity of the sow after 24 hours of farrowing (LWB) and at 21 days of age (LW21D).

Data used in the analysis were taken from the sows with the first to a maximum of the eighth parity records because the data integrity of higher parities was corrupt, such as the number of litter records at the ninth parity and above highly varied among the three farms. The considered farrowing seasons were summer (July-September), fall (October-December), winter (January-March), and spring (April-June). Year-season was created by concatenating the year and season of farrowing. Finally, the data set was analyzed without missing values.

Table 1. Number of animals in pedigree, farrowing records, sows, dams and sires of the sows, farms, parity[1], and year-season of each breed used

Items	Pig breeds		
	Duroc	Landrace	Yorkshire
Number of animals in pedigree	24,681	24,020	7,610
Litter record	6,504	6,398	2,178
Sow	1,722	2,045	670
Dam	937	1,007	321
Sire	343	244	119
Farm	3	3	3
Parity	8	8	8
Year-Season	38	38	38

Note: [1]The parity of the litter records was up to the eighth parity.

Statistical Analysis

The collected data were separately analyzed for each studied breed. Univariate analysis with a repeatability model was used to estimate the variance components of litter traits using MTDFREML software (Boldman *et al.*, 1995). In the preliminary model, the maternal genetic effect and also the service sire effect were used; however, some of the original data were incomplete and hard to be traced and confirmed, and it was decided to use animal model analysis with a univariate repeatability model without including service sires and maternal genetics. Variances estimates obtained from this analysis were used to estimate heritability and repeatability. The model used in the analysis was:

$$y = Xb + Za + Wpe + e$$

where y is a vector of observed field data including NBA, N21D, LWB, and LW21D; b is a vector of fixed factors including parity, farm, and year-season; a is a vector of random sow additive genetic effects; pe is a vector of random uncorrelated sow permanent environment effects; and e is residual effects. Incidence matrices, X, Z, and W, relate records to fixed, additive genetic, and permanent environmental effects, respectively. All random effects were assumed to be normally distributed. The variance matrices of random effect factors were assumed to be:

$$E\begin{bmatrix}a\\pe\\e\end{bmatrix}=\begin{bmatrix}0\\0\\0\end{bmatrix} \text{ and } V\begin{bmatrix}\propto\\pe\\e\end{bmatrix}=\begin{bmatrix}A\sigma_a^2 & 0 & 0\\0 & I_{pe}\sigma_{pe}^2 & 0\\0 & 0 & I_e\sigma_e^2\end{bmatrix}$$

where A is the numerator relationship matrix; I_{pe} is the identity matrix for sow permanent environmental effect; I_e is the identity matrix for residual; and σ_a^2, σ_{pe}^2, and σ_e^2 are animal additive genetic, sow permanent environmental, and residual variances, respectively. The covariance between random effects was assumed to be zero. The heritability (h^2) and repeatability (r) were calculated as $h^2 = \frac{\sigma_a^2}{\sigma_a^2+\sigma_{pe}^2+\sigma_e^2}$ and $r = \frac{\sigma_a^2+\sigma_{pe}^2}{\sigma_a^2+\sigma_{pe}^2+\sigma_e^2}$ respectively. In addition, the genetic trends of the litter traits from 2004 to 2017 were illustrated by averaging estimated breeding values of sows born in the same year.

RESULTS

Descriptive Statistics

Descriptive statistics of phenotypic NBA, N21D, LWB, and LW21D are shown in Table 2. The average NBA and LWB of the three breeds ranged from 7.3 to 9.6 piglets and 10.9 kg to 13.6 kg, respectively. The LW21D was higher in Landrace (58.1 kg) than in the Yorkshire breed (56.3 kg) even though N21D was smaller in the Landrace breed (9.0 piglets) in comparison to the Yorkshire breed

(9.2 piglets). The Duroc breed had the lowest performance among the traits analyzed.

Variance Components

Estimating variances components and genetic parameters were successfully carried out and shown in Table 3. The variance of additive genetic effect (σ_a^2) for NBA ranged from 0.284 up to 0.806 in which the σ_a^2 was highest in Yorkshire and lowest in Landrace. The σ_a^2 in Yorkshire was more than two times larger than in Duroc and Landrace. Similarly, the σ_a^2 for N21D, LWB, and LW21D were also highest in Yorkshire (1.224, 0.695, and 27.793, respectively) but lowest in Duroc (0.394, 0.177, and 9.242, respectively).

Heritability and Repeatability

The heritability (h^2) estimated in this study is shown in Table 3. The estimates of h^2 for NBA were 0.058±0.017 in Duroc, 0.037±0.014 in Landrace, and 0.101±0.032 in Yorkshire (Table 3). The estimated h^2 for N21D were 0.086±0.018 in Duroc, 0.102±0.019 in Landrace, and 0.151±0.035 in Yorkshire. For LWB, the estimated h^2 ranged from 0.036 to 0.330 in the three studied breeds, where the highest and the lowest were in Yorkshire and Duroc breeds, respectively. The h^2 for LW21D estimated in this study were 0.119±0.020 in Duroc, 0.168±0.023 in Landrace, and 0.237±0.045 in Yorkshire, respectively.

Repeatability is the strength of the relationship between records of repeated traits. The repeatability (r) was also estimated in this study (Table 3). The r estimates for NBA, N21D, LWB, and LW21D ranged from 0.135 to 0.160, from 0.115 to 0.151, from 0.056 to 0.400, and from 0.179 to 0.237, respectively. The lowest r for NBA and N21D were observed in Landrace, whereas the r estimates for LWB and L21D were the lowest in Duroc. In addition, the Yorkshire breed had the highest r for N21D, LWB, and L21D.

Realized Genetic Trend

Figure 1 illustrates the realized genetic trends across breeds from 2004 up to 2017 for NBA, N21D,

Table 2. Descriptive analysis of sow litter traits including number of live pigs born (NBA), number of piglets at 21 days of age (N21D), and litter weight at birth (LWB) and at 21 days of age (LW21D) in Duroc, Landrace, and Yorkshire sows

Breed	Variable	N	Mean	SD	Min.	Max.
Duroc	NBA	6504	7.3	2.31	1	19
	N21D	6504	6.9	2.21	1	17
	LWB	6504	10.9	3.59	1	31
	LW21D	6504	40.9	14.65	3	112.6
Landrace	NBA	6398	9.5	2.84	1	20
	N21D	6398	9.0	3.01	1	20
	LWB	6398	13.6	4.16	0.9	33.2
	LW21D	6398	58.1	18.17	3.5	129.1
Yorkshire	NBA	2178	9.6	2.98	1	21
	N21D	2178	9.2	3.08	1	20
	LWB	2178	13.6	4.24	0.9	33
	LW21D	2178	56.3	17.51	3.5	123.3

Note: NBA= number of piglets born alive (in head); N21D= number of piglets alive at 21 days old (in head); LWB= litter weight at birth (in kg); LW21D= litter weight at 21 days of lactation (in kg); N= number of observations; SD= Standard deviation; Min.= the minimum value; Max.= the maximum value.

Table 3. Estimates of (co)variance components and genetic parameters from univariate analyses for the number born alive (NBA), the number of piglets at 21 days of age (N21D), and litter weight at birth (LWB) and at 21 days of age (LW21D) by breed

Parameter	Pig breeds											
	Duroc				Landrace				Yorkshire			
	NBA	N21D	LWB	LW21D	NBA	N21D	LWB	LW21D	NBA	N21D	LWB	LW21D
σ_a^2	0.302	0.394	0.177	9.242	0.284	0.790	0.435	22.695	0.806	1.224	0.695	27.793
σ_{pe}^2	0.528	0.266	0.101	4.695	0.758	0.102	0.191	3.512	0.324	0.000	0.147	0.012
σ_e^2	4.343	3.916	4.636	63.801	6.704	6.847	3.301	109.005	6.812	6.865	1.261	89.649
σ_P^2	5.174	4.576	4.915	77.738	7.747	7.740	3.927	135.212	7.942	8.089	2.104	117.454
h^2	0.058	0.086	0.036	0.119	0.037	0.102	0.111	0.168	0.101	0.151	0.330	0.237
SE(h^2)	0.017	0.018	0.011	0.020	0.014	0.019	0.021	0.023	0.032	0.035	0.055	0.045
pe^2	0.102	0.058	0.021	0.060	0.098	0.013	0.049	0.026	0.041	0.000	0.070	0.000
r	0.160	0.144	0.056	0.179	0.135	0.115	0.159	0.194	0.142	0.151	0.400	0.237

Note: NBA= number of piglets born alive (in head); N21D= number of piglets alive at 21 days old (in head); LWB= litter weight at birth (in kg); LW21D= litter weight at 21 days of lactation (in kg); N= number of observations; σ_a^2= additive genetic variance; σ_{pe}^2= permanent environment variance of the sow; σ_e^2= residual variance; σ_P^2= phenotypic variance; h^2= heritability; SE= standard error; pe^2= fraction of variance due to sow permanent environment effects; and r= repeatability.

LWB, and LW21D, while Table 4 shows the overall genetic trend. A positive genetic trend for litter size in Duroc is indicated in Figure 1 as well as Table 4 shows that the annual genetic gain was 0.005 piglets for both NBA and N21D. The Landrace also had a positive genetic trend for NBA (Figure 1), with 0.002 piglets per year, whereas the genetic gains for N21D were not different from zero (Table 4). In a contrary manner, for Yorkshire, the genetic trends for NBA and N21D from 2004 up to 2010 underwent a slow decrement while a faster degradation of genetic gain was observed from 2010 to 2014 and finally reversed the direction to be positive until 2017 (Figure 1). However, the overall genetic gain for litter size (NBA and N21D) in Yorkshire was not different from zero (Table 4). The current study showed that there was no significant genetic improvement for N21D observed in Landrace and Yorkshire breeds, even though both breeds are known and raised as maternal lines.

Genetic changes for LWB and LW21D in Duroc and Landrace breeds were not clearly shown in Figure 1 because of a tiny change and no fluctuation gain each year. The genetic gain for LWB and L21D in Landrace was not different from zero (Table 4). Similarly, there was no genetic change for LWB in Duroc but had a small positive genetic gain for LW21D. A significant decline of genetic gain for LW21D in Yorkshire started from 2011 to 2017, although a positive genetic trend for LW21D increased from 2004 to 2011 (Figure 1). The overall genetic gain of LW21D in Yorkshire was negative at about 0.122 piglets per year (Table 4).

DISCUSSION

Brief Selection History in Taiwan Pig Populations

Selection history in Taiwan pig populations was started in 1975 by establishing the Central Performance Test Station as well as the Swine Registry System. Later in 1980, the On-Farm Performance Test Program was also adopted. However, the On-Farm Performance Test

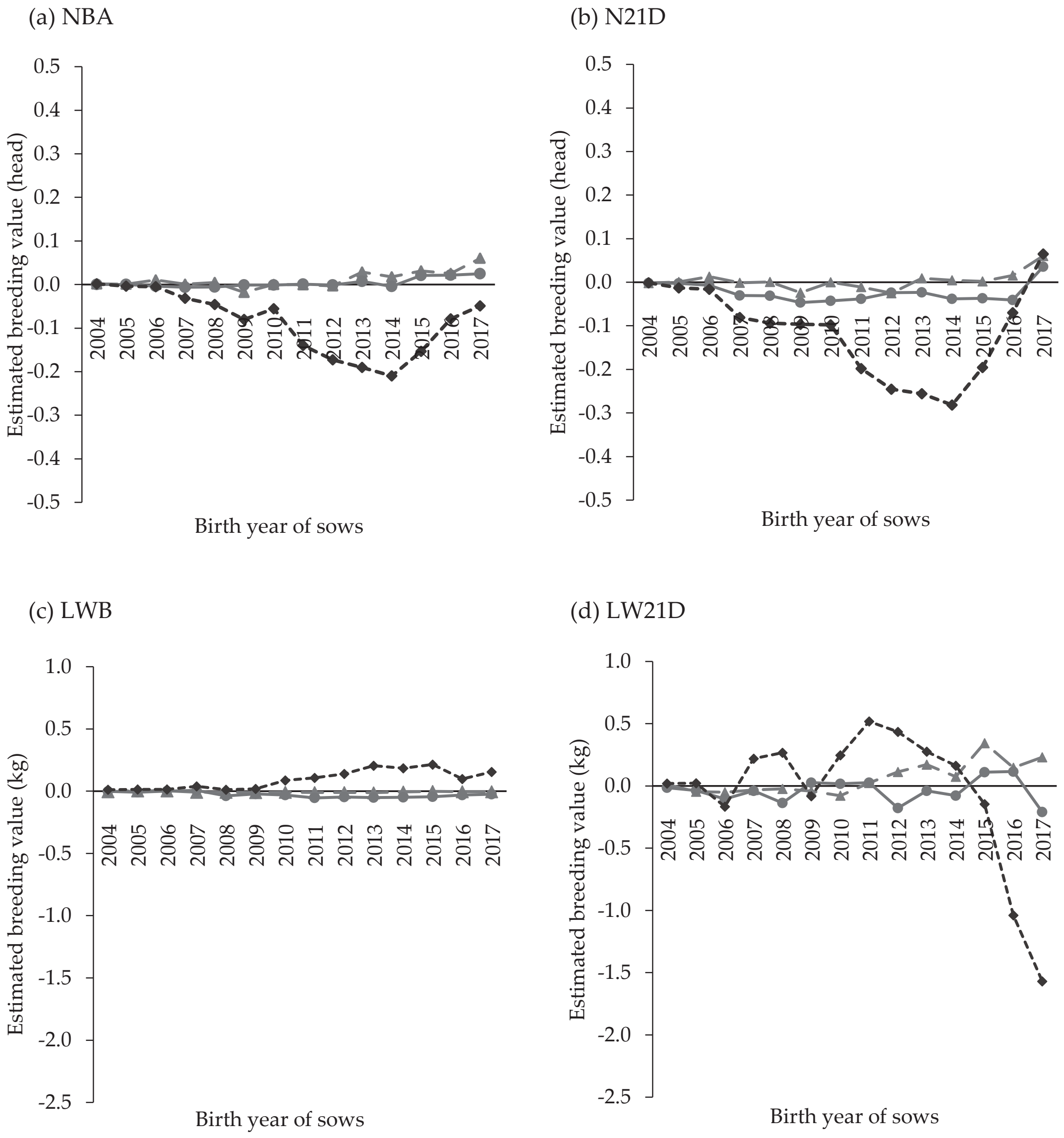

Figure 1. Genetic trends of each breed from 2004 to 2017 for (a) number born alive (NBA), (b) number of piglets at 21 days of age (N21D), (c) litter weight at birth (LWB), and (d) litter weight at 21 days of age (LW21D). Duroc= -▲-; Landrace= -•-; Yorkshire= ---◆---

Table 4. Overall regressions of estimated breeding value (EBV) for number born alive (NBA), number of piglets at 21 days of age (N21D), litter weight at birth (LWB), and litter weight at 21 days of age (LW21D) on birth year of sow by breed

Traits	Pig breeds		
	Duroc	Landrace	Yorkshire
NBA, piglet/year	0.005 ± 0.0008*	0.002 ± 0.0005*	-0.004 ± 0.0030^{ns}
N21D, piglet/year	0.005 ± 0.0015*	0.003 ± 0.0027^{ns}	0.005 ± 0.0053^{ns}
LWB, kg/year	-0.0001 ± 0.0004^{ns}	-0.002 ± 0.0020^{ns}	0.011 ± 0.0053*
LW21D, kg/year	0.017 ± 0.0083*	-0.015 ± 0.0183^{ns}	-0.122 ± 0.0312*

Note: ns=non-significant (genetic gain = zero); * = significant (genetic gain ≠ 0).

Program was suspended in 2000 due to the outbreak of FMD in 1997 and restarted in 2014 until now. In addition, to evaluate the carcass database, the Central Progeny Performance Test station was established in 1989 but closed in the 2000s. The selection index used in the Central and On-Farm Performance Test was initially adopted from the Iowa Swine Test Station and NLC Index of the UK. Finally, the selection indexes of boars evolved through a change in the economic weight of each trait in the selection index and adjusted to meet the rearing scheme, which referred to average daily gain (ADG), feed conversion ratio (FCR), backfat thickness (BF), and loin eye area (LEA). Body conformation is evaluated in the Central Performance Test Station because conformation or appearance is one of the major determinants of market pricing. In 1985, a selection index was also implemented to evaluate sow performance by adopting the Sow Productivity Index (SPI) from U.S. National Swine Improvements Federation (Tsou, 1993). It was observed that reproductive phenotypic trends of litter size at birth and 21 days and litter weight at 21 days increased from 1987 to 1992 (Tsou, 1993). However, both the central test and rebooted on-farm tests focus on production traits, including ADG, FCR, ultrasonic BF, and ultrasonic LEA, whereas less effort was put into the reproductive traits. Thus, we attempted to infer the genetic progress of the reproductive traits in Taiwan pig populations from the records of the official database, the Swine Registry System. In addition, more attention was also given to genetic evaluation using Best Linear Unbiased Prediction Animal Model (BLUP-AM) to estimate genetic parameters and genetic trends for sow reproductive traits from 2004 to 2018.

Except for the NBA and N21D in Duroc, the phenotypic performance of NBA, N21D, and LW21D in this present study showed that there was an improvement in comparison with those reported by Tsou (1993), 6.5-9.4 piglets for NBA, 6.1-8.5 piglets for N21D, and 29.7-46.9 kg for LW21D. The higher LW21D in Landrace and Yorkshire breeds could indicate better milk production and maternal ability during lactation (Table 2). However, these performance of litter traits were inferior to those of the Duroc, Landrace, and Yorkshire breeds in the USA (Chen *et al.*, 2003), Korea (Lopez *et al.*, 2017; Alam *et al.*, 2021) and China (Zhang *et al.*, 2020), and of the Landrace and Large White in Japan (Ogawa *et al.*, 2019). On some farms in Taiwan, the replacement rate of sows is low because the farmers keep the sows up to a parity of 10 or even more if the sows have good health conditions, regardless of their performance. However, the reproductive records of the sows included in the present study were limited until parity 8.

Univariate analysis with a repeatability model was used in this present study to estimate the variance components and heritability for important reproductive traits in the purebred pig populations in Taiwan. The σ_a^2 for NBA in this study was lower than the previous studies with the same genetic model (Putz *et al.*, 2015; Lopez *et al.*, 2017). With a more complex genetic analysis and a larger database, Chen *et al.* (2003) showed that the σ_a^2 for NBA was lower but the σ_a^2 for N21D was higher than those in this study. The present study showed that the σ_a^2 for LWB and LW21D were highest in Yorkshire while lowest in Duroc (Table 3). The σ_a^2 for LWB was lower than that in Ogawa *et al.* (2019), whereas the higher σ_a^2 for LW21D than that reported by Chen *et al.* (2003). The genetic model used in this present study did not consider maternal genetic and service sire effects. Similarly, Ogawa *et al.* (2019) reported the genetic evaluation of litter traits in Japanese Large White and Landrace using the same model with only additive genetic and permanent environmental effects. In addition, Lopez *et al.* (2017) also suggested that the model with additive genetic and permanent environment effects was the most suitable for Korean pig evaluation considering that maternal genetic effect contributed only 0.4% and 0.8% of the total variability of NBA in Yorkshire and Landrace breeds and also service sire effect contributed 0.8% and 0.5% of the phenotypic variance. The same report also showed that the correlation of estimates with and without service sire effect ranged from 0.98 to 0.99 for all farrowing traits (Lopez *et al.*, 2017). Chen *et al*. (2003) compared the EBV of the animal with and without maternal genetic effect in the model and resulted in no difference in animal ranking. However, Chen *et al*. (2003) also showed that the contribution of the service sire effect ranged from 2%-5% of the total variance. Bidanel (2011) reviewed that litter traits were mostly affected by sow genes than maternal, paternal, or piglet effects.

The h^2 estimates in this study for NBA in Yorkshire breed corresponded to the estimated h^2 of 0.10 and 0.11 reported by Chen *et al*. (2003) and Lopez *et al*. (2017), respectively, but the estimated h^2 for Landrace and Duroc breeds were considerably lower. The differences in both Landrace and Duroc breeds were mainly due to the lower σ_a^2. In addition, Chen *et al*. (2003) found that the estimated h^2 for NBA was 0.08 in Landrace, 0.10 in Yorkshire, and 0.09 in Duroc, with the model including the service sire effect. Furthermore, the estimate of

h^2 for NBA in Yorkshire in this study was higher than the estimated h^2 of 0.07-0.091 in Chinese Yorkshire (Li *et al.,* 2017; Zhang *et al.,* 2020), 0.06 in Chinese Large White (Ye *et al.,* 2018), and 0.07 in South African Large White (Dube *et al.,* 2012), but lower than those of 0.11 in Finnish Large White (Sevón-Aimonen & Uimari, 2013). In a meta-analysis of genetic parameters for reproductive traits in tropic pigs, the combined weighted h^2 for NBA of 0.08±0.008 (Akanno *et al.,* 2013). Conversely, the h^2 for N21D of this study showed that the h^2 of Duroc, Landrace, and Yorkshire were higher than American breeds (Chen *et al.,* 2003). The present study showed that the h^2 for NBA was lower than that for N21D (Table 3). This result was in agreement with Putz *et al.* (2015) by using the same genetic model, indicating that h^2 for litter size from birth to weaning was positively increased. Su *et al.* (2007) estimated h^2 by using a more complex genetic model and found that h^2 for the total number of piglets born was lower than the number of weaned piglets.

The h^2 estimates for LWB in this study were 0.330 in the Yorkshire breed and 0.036 in the Duroc breed (Table 3). The estimated h^2 for LWB in the Landrace (0.102±0.019) (Table 3) was lower than the estimated h^2 for LWB of 0.18 in the Japanese Landrace, while the estimated h^2 for LWB in Yorkshire (0.330±0.055) (Table 3) was higher than the estimated h^2 for LWB of 0.18 in Japanese Large White in the same study (Ogawa *et al.,* 2019). In addition, the estimated h^2 for LWB in the present study was higher than those in Chinese Duroc, Landrace, and Yorkshire, which ranged from 0.07 to 0.11 (Zhang *et al.,* 2020; Yu *et al.,* 2022). The present study showed that the estimated h^2 for LW21D ranged from 0.119 to 0.237 (Table 3). Chen *et al.* (2003) showed that the estimated h^2 for LW21D were 0.07, 0.09, and 0.08 in USA Duroc, Landrace, and Yorkshire, respectively, considering service sire effects in the model. Akanno *et al.* (2013) reviewed that, through meta-analysis methodology, the h^2 for LW21D in the tropical region was 0.13. The erratic results were observed in the estimated h^2 for LWB, which was 0.33 in Yorkshire but 0.03 in Duroc and 0.11 in Landrace, and then the estimated h^2 for LW21D were less different, which were 0.12 in Duroc, 0.23 in Yorkshire, and 0.16 in Landrace. Due to their superior reproductive performances, Yorkshire and Landrace are used as maternal breeds. One possible reason for the higher additive genetic variance and lower phenotypic variance of LWB in Yorkshire was that about 44.6% of the sows used in this study were reared in one of the three commercial farms, indicating those sows were managed more similarly. In contrast, a nearly equal ratio of Landrace sows attributed from the three commercial farms (32.2%, 37.7%, and 30.1%). Finally, the results of this study revealed that there was sufficient genetic variability of the traits of interest to perform selection to genetically improve the next generation.

Among the traits studied in the present study, the lowest r was observed for LWB in the Duroc breed (0.056), and the highest was observed for LWB in the Yorkshire breed (0.400) (Table 3). The estimated r for NBA, N21D, and LW21D ranged from 0.115 to 0.237 (Table 3). The results were slightly higher than those of 0.08-0.17 reported by Chen *et al.* (2003) in the same breeds in the USA. In addition, the results of this study were in agreement with Ogawa *et al.* (2019) using records from first parity to sixteenth and seventeenth for NBA and LWB in Japanese Large White and Landrace pigs.

Selection evaluation can be carried out to find out whether a selection has resulted in significant genetic changes or not (Bidanel *et al.,* 2020). Silalahi (2017) showed that selection evaluation could be carried out using frozen semen, where frozen semen can be stored for quite a long time, where selection evaluation for 21 years in French Yorkshire pigs showed genetic improvements in production traits but decreased immunity traits. In this study, several litter traits, such as NBA in Yorkshire, LWB in Duroc, and LW21D in Landrace, showed no genetic changes from 2004 to 2017 in the pig population in Taiwan. The similar results of Camargo *et al.* (2020) showed that litter traits, such as litter size at three weeks of age, were not improved from 2009-2016 in Brazilian Landrace pigs. This indicates that it is necessary to carry out a selection with a higher selection intensity or use more advanced selection methods, such as BLUP animal models or genomic selection (Samorè & Fontanesi, 2016; Silalahi *et al.,* 2016).

CONCLUSION

The estimates of variance components and genetic parameters from the current study indicated sufficient genetic variability for selection to improve reproductive performance in Taiwan pig populations. The heritability range for NBA was 0.037-0.101, 0.086-0.151 for N21D, 0.036-0.330 for LWB, and 0.119-0.237 for LW21D. The low genetic gain, 0.02-0.05 for NBA, 0.005 for N21D, 0.011 for LWB, and -0.112-0.017 for LW21D, were observed for those three-pig breeds. The genetic trends of NBA were 0.005 and 0.002 piglets/year in the Duroc and Landrace breeds, respectively. In Yorkshire, conversely, there was no significant genetic improvement of NBA, but there was a 0.011 kg/year improvement of LWB. The results suggested that further reproductive trait selection must be more intense.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the manuscript's material.

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