

Genetic parameters of litter traits in three pig breeds in southern Brazil

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ABSTRACT

This paper reports estimates of genetic parameters for litter traits, obtained in three pig breeds in southern Brazil. A sample of 7064 Large White (LW), 4538 Landrace (LR), and 2400 Duroc (DC) litters was analyzed with a mixed model that included a set of fixed effects (farm, month and year of parity, and age of sow at parity) and the random effects of boar within farm, and daughter within boar. Each sow farrowed at least two litters. Heritability estimates and corresponding standard errors were: (1) total number of piglets born, 0.062 ± 0.023 (LW), 0.121 ± 0.033 (LR), and 0.078 ± 0.044 (DC); (2) number of piglets born alive, 0.060 ± 0.023 (LW), 0.119 ± 0.033 (LR), and 0.073 ± 0.043 (DC); (3) piglets alive at day 21, 0.075 ± 0.024 (LW), 0.101 ± 0.031 (LR), and 0.083 ± 0.044 (DC); (4) litter weight at birth, 0.151 ± 0.030 (LW), 0.155 ± 0.037 (LR), and 0.109 ± 0.048 (DC), and; (5) litter weight at day 21, 0.133 ± 0.028 (LW), 0.143 ± 0.035 (LR), and 0.174 ± 0.056 (DC). The LR breed had the greatest amount of genetic variability for litter size traits and in general, the heritabilities of litter weight traits had larger values than those of litter size traits. The genetic correlations among the five traits, with three exceptions, were high, suggesting the presence of favourable pleiotropic effects. These high correlations also reflect the part-whole relationships among traits.

INTRODUCTION

Improvement of sow reproductive performance reduces the costs of pork production (Tess *et al.*, 1983). Maintaining the breeding herd can account for up to one third of total production costs (Hall *et al.*, 1987). Most selection efforts in pigs have been made with the purpose of improving pig efficiency and carcass traits (Haley and Lee, 1992; Johnson, 1992). Some emphasis has been placed on improving fertility of pig stocks through selection, but it has not been very successful.

Selection for litter size in pigs is feasible (Johnson, 1992) and some experimental work has led to genetic progress (Tomes and Newman, 1982; Lamberson *et al.*, 1991; Neil and Irvin, 1992), mainly when litter size was standardized to a small number of piglets shortly after birth. Selection based on litter size in pigs has also led to negligible or no improvement in some populations (Rutledge, 1980; Johansson and Kennedy, 1985; Bolet *et al.*, 1989). An explanation for the lack of response to selection is the presence of negative maternal effects, causing sows born in large litters to farrow small litters, particularly the first one (Revelle and Robison, 1973; Vangen, 1980; Johansson and Kennedy, 1985).

Accurate estimation of genetic parameters is essential for predicting genetic progress and designing adequate selection strategies. The heritabilities of litter

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size and litter weight are low, ranging from 0.00 to 0.16 in both large field data sets and planned experiments (Legault, 1970; Revelle and Robison, 1973; Strang and Smith, 1979; Vangen, 1980; Johansson and Kennedy, 1985; McCarter *et al.*, 1987; Kaplon *et al.*, 1991; Haley and Lee, 1992; Ferraz and Johnson, 1993). Higher heritabilities have been reported (Irvin and Swiger, 1984; Ferguson *et al.*, 1985; some estimates of Alves *et al.*, 1987), but restricted sample sizes, highly unbalanced data structure or improper statistical models have led in many cases to confounding between genetic and environmental effects and inflated estimates.

Genetic correlations between litter size and litter weight, both at birth and at day 21, are normally positive and high, ranging from 0.58 to 0.99 in most large field data sets and planned experiments (Irvin and Swiger, 1984; Johansson and Kennedy, 1985; Alves *et al.*, 1987; Haley and Lee, 1992). High positive genetic correlations are desirable, since genetic progress in one trait would change the gene frequencies of other traits in a favourable direction.

The objective of this paper was to obtain estimates of heritabilities and genetic correlations among litter traits in three breeds of pigs, reared under commercial conditions in southern Brazil.

MATERIAL AND METHODS

Data description

Reproductive performance records of Large White (LW), Landrace (LR), and Duroc (DC) gilts and sows were collected from 69 commercial pig farms in the state of Santa Catarina, southern Brazil. Data collection was supervised by the Brazilian Pig Breeders' Association (Associação Brasileira de Criadores de Suínos). Conditions imposed to include a farm in the sample were: (1) at least four sires of females and (2) at least six records per sire of female. The sample consisted of 2061 (LW), 1236 (LR), and 787 (DC) sows, which farrowed 7064 (LW), 4538 (LR), and 2400 (DC) litters between 1984 and 1987. Each sow farrowed two or more litters.

Under typical commercial conditions in southern Brazil, pregnant sows are fed *ad libitum* a diet containing about 13-14% crude protein, 3400 kCal/kg digestible energy, and 0.45% lysine. Piglets are kept with the sow up to at least 21 days of age. Litters in which crossfostering was practiced before piglets reached 21 days of age were not included in the sample.

Litter size and litter weight were measured at birth and at day 21. Symbols corresponding to the traits are: TOTB (total number of piglets born, except mummified), LIVB (piglets born alive), LIV21 (piglets alive at day 21), LWB (litter weight at birth), and LW21 (litter weight at day 21).

Statistical Methods

The model used to describe an observation was:

$$Y_{ijklmn} = \mu + F_i + Y_j + M_k + b_1 (X_{ijklmn} - \bar{X}) + b_2 (X_{ijklmn} - \bar{X})^2 + s_{il} + p_{ilm} + w_{ijklmn}$$

where:

- Y_{ijklmn} are the individual observations (TOTB, LIVB, LIV21, LWB, or LW21);
- μ is a constant that affects all observations;
- F_i is the fixed effect of the i^{th} farm;
- Y_j is the fixed effect of the j^{th} year of farrowing;
- M_k is the fixed effect of the k^{th} month of farrowing;
- b_1, b_2 are the partial regression coefficients (linear and quadratic) of age of female at farrowing (in days);
- X_{ijklmn} is the age of female at farrowing;
- s_{il} is the random effect of the l^{th} sire of females, in the i^{th} farm, $s_{il} \sim (0, \sigma_s^2)$, sires unrelated;
- p_{ilm} is the random effect of the m^{th} progeny (female) of the l^{th} sire, in the i^{th} farm, $p_{ilm} \sim (0, \sigma_p^2)$, progenies unrelated;
- w_{ijklmn} is the effect of the n^{th} observation (litter) in the m^{th} progeny of the l^{th} sire, in the i^{th} farm, $w_{ijklmn} \sim (0, \sigma_w^2)$, litters uncorrelated.

The analysis of variance corresponding to the model used is presented in Table I (Harvey, 1960). According to Method III described by Henderson (1953), the variance components σ_w^2 , σ_p^2 , and σ_s^2 are obtained by equating the observed to the expected mean squares. The calculation of the k_i values is presented in detail by Gates and Shiue (1962), and by Becker (1985). The genetic interpretations of the variance components are presented in Table II (Becker, 1985; Siewerdt, 1993).

RESULTS AND DISCUSSION

The variance components σ_w^2 , σ_p^2 , and σ_s^2 , the phenotypic variances, and the heritabilities estimated for LW, LR, and DC breeds are presented, respectively,

Table I - Analysis of variance for the model used.

Sources	Sums of squares	E (mean squares)
Fixed effects	$\mathbf{b}'\mathbf{Z}^{-1}\mathbf{b}$	-
Sires	$R(\mu, s, \mathbf{b}) - R(\mu, \mathbf{b})$	$\sigma_w^2 + k_2 \sigma_p^2 + k_3 \sigma_s^2$
Daughters w. sires	$R(\mu, s, p, \mathbf{b}) - R(\mu, s, \mathbf{b})$	$\sigma_w^2 + k_1 \sigma_p^2$
Within daughters	$\mathbf{y}'\mathbf{y} - R(\mu, s, p, \mathbf{b})$	σ_w^2

Table II - Estimated variance components and their contributions to phenotypic variance.

Component ¹	V _A	V _D	V _{AA}	V _{AD}	V _{DD}	V _{AAA}	V _{Ep}	V _{Et}
σ_s^2	1/4	0	1/16	0	0	1/64	0	0
σ_p^2	3/4	1	15/16	1	1	63/64	1	0
σ_w^2	0	0	0	0	0	0	0	1

¹V_A: additive genetic variance; V_D: dominance genetic variance; V_{AA}: additive x additive epistatic genetic variance; V_{AD}: additive x dominance epistatic genetic variance; V_{DD}: dominance x dominance epistatic genetic variance; V_{AAA}: additive x additive x additive epistatic genetic variance; V_{Ep}: permanent environmental variance; V_{Et}: temporary environmental variance.

in Tables III, IV, and V. For all traits, the largest V_p values were obtained in the LW breed and the smallest in the DC breed. However, in the LR breed the V_A estimates for litter size traits (TOTB, LIVB, LIV21) were larger than in the other two breeds. As a consequence, the heritability estimates of TOTB, LIVB, and LIV21 were larger in the LR breed than in the LW and in the DC breeds. In these same populations, higher heritabilities for average daily gain and for backfat thickness were obtained in the LR breed (Cardellino and Siewerdt, 1992).

The heritability estimates were in general low, in agreement with most estimates reported (Legault, 1970; Strang and Smith, 1979; Vangen, 1980; Johansson and Kennedy, 1985; Landrace breed in Alves *et al.*, 1987; McCarter *et al.*, 1987; Gu *et al.*, 1989; Kaplon *et al.*, 1991; Haley and Lee, 1992; Ferraz and Johnson, 1993). Litter size traits had smaller heritabilities than litter weight traits, which agrees with Strang and Smith (1979), and Ferraz and Johnson (1993).

The low heritabilities obtained would at first imply that the genetic progress obtained with phenotypic selection is expected to be small. The influence of environment on litter traits is the main cause of sow performance, so one could find some difficulty in identifying sows with favourable genotypes. However,

litter traits have high phenotypic variabilities, and thus high selection differentials can be achieved. As an example, under a selection intensity of $i=1$, the genetic progress, per generation, for TOTB would be 0.151 (LW), 0.286 (LR), and 0.171 (DC) piglets. A serious limitation to the effective realization of these genetic gains is that the analysis performed on the present data does not account for negative maternal effects (Avalos and Smith, 1987). Some previous reports (Eisen, 1970; Revelle and Robison, 1973; Rutledge, 1980; Vangen, 1980; Azzam *et al.*, 1984; Gama and Johnson, 1993) refer to maternal effects as a negative environmental effect on reproductive performance. Hill (1982) argues that in large litters there is a reduction of the share of maternal resources for each piglet, and therefore this negative environmental handicap may tend to reduce subsequent body and litter size. A consequence of a negative maternal effect is the existence of a negative genetic correlation between the litter sizes of dam and daughter (Avalos and Smith, 1987), although Revelle and Robison (1973) showed that the negative correlation only occurs for sows with very large litters.

The negative maternal effects appear to be more important in the gilt litter rather than in subsequent litters (Revelle and Robison, 1973; Vangen, 1980; Johansson and Kennedy, 1985), although results by Gama and Johnson (1993) disagree with this statement. According to the reports of Nelson and Robison (1976) and of Rutledge (1980), rearing replacement gilts in small litters can provide an extra piglet in the gilt litter. However, the structure of data used in the present paper did not allow fitting a model with maternal effects, which could lead to a great improvement of results.

Table VI presents the estimates of genetic covariances and of genetic, phenotypic, and environmental correlations among the five litter traits, for the LW, LR, and DC breeds. All genetic correlations (r_A) estimated were positive and different from zero ($P < 0.01$). The estimates agree with values previously reported (Young *et al.*, 1978; Bereskin, 1984; Irvin and Swiger, 1984; Kaplon *et al.*, 1991; Haley and Lee, 1992). Few r_A estimates deviated from the trend of high values: between TOTB and LW21, in the LW and DC breeds, and between LIVB and LW21, in the DC breed. These low correlation values could be due to a negative maternal effect in large litters, or a negative genetic correlation of litter size with mothering or milking ability. Another possible reason is the existence of a biological limit of milk production of the sow. It could cause each piglet of small litters to gain more weight than piglets from large litters, reducing the difference of weights between small and large litters and, in

Table III - Variance components, phenotypic variances (V_P), and heritability (h^2) of litter traits for Large White pigs.

Trait ¹	σ_s^2	σ_p^2	σ_w^2	V_P	$h^2 \pm \text{s.e.}$
TOTB	0.091415	0.765162	5.026308	5.882884	0.062 \pm 0.023
LIVB	0.085797	0.737910	4.898475	5.722181	0.060 \pm 0.023
LIV21	0.101350	0.556989	4.732866	5.391205	0.075 \pm 0.024
LWB	0.517238	1.578117	11.628318	13.723672	0.151 \pm 0.030
LW21	5.481430	16.036908	143.805627	165.323965	0.133 \pm 0.028

¹TOTB: total number of piglets born, except mummified, LIVB: piglets born alive, LIV21: piglets alive at day 21, LWB: litter weight at birth, and LW21: litter weight at day 21.

$k_1 = 3.3506$, $k_2 = 3.3786$, $k_3 = 20.2578$.

Table IV - Variance components, phenotypic variances (V_P), and heritability (\pm s.e.) of litter traits for Landrace pigs.

Trait ¹	σ_s^2	σ_p^2	σ_w^2	V_P	$h^2 \pm \text{s.e.}$
TOTB	0.169638	0.748438	4.702119	5.620195	0.121 \pm 0.033
LIVB	0.156380	0.688494	4.424360	5.269233	0.119 \pm 0.033
LIV21	0.125863	0.614881	4.229491	4.970236	0.101 \pm 0.031
LWB	0.495649	1.869915	10.447412	12.812976	0.155 \pm 0.037
LW21	5.238080	16.383945	124.748492	146.370518	0.143 \pm 0.056

¹TOTB: total number of piglets born, except mummified, LIVB: piglets born alive, LIV21: piglets alive at day 21, LWB: litter weight at birth, and LW21: litter weight at day 21.

$k_1 = 3.5780$, $k_2 = 4.1340$, $k_3 = 25.3322$.

Table V - Variance components, phenotypic variances (V_P), and heritability (\pm s.e.) of litter traits for Duroc pigs.

Trait ¹	σ_s^2	σ_p^2	σ_w^2	V_P	$h^2 \pm \text{s.e.}$
TOTB	0.093061	0.609968	4.047925	4.750955	0.078 \pm 0.044
LIVB	0.084438	0.597148	3.936973	4.618559	0.073 \pm 0.043
LIV21	0.092128	0.590913	3.781196	4.464237	0.083 \pm 0.044
LWB	0.306815	1.157680	9.793073	11.257568	0.109 \pm 0.048
LW21	5.771390	15.124420	111.544336	132.440146	0.174 \pm 0.056

¹TOTB: total number of piglets born, except mummified, LIVB: piglets born alive, LIV21: piglets alive at day 21, LWB: litter weight at birth, and LW21: litter weight at day 21.

$k_1 = 2.9951$, $k_2 = 3.1423$, $k_3 = 18.2398$.

consequence, reducing the genetic correlation between the two traits.

The high and positive values of most of the genetic correlations among litter traits suggest that one could obtain favourable and high correlated responses in traits not included in the selection criteria. As an example, if selection is performed based on litter size (TOTB, LIVB, or LIV21), the litter weight (LWB or LW21)

would be simultaneously improved. Gains in litter weight would also be high, and that could be achieved without reducing selection intensity for litter size.

The phenotypic correlations were all positive and significantly different from zero ($P < 0.01$) (Table VI). The r_P values were similar for the three breeds, suggesting that the biological relationships between the traits follow a similar trend in the three breeds.

Table VI - Genetic covariances (Cov_A), genetic (r_A), phenotypic (r_P), and environmental (r_E) correlations among litter traits.

Traits ¹	Breeds	Cov_A	$r_A \pm$ s.e.	r_P	r_E
TOTB, LIVB	LW	0.31163	0.880 \pm 0.050	0.931	0.934
	LR	0.63434	0.974 \pm 0.014	0.933	0.928
	DC	0.31767	0.896 \pm 0.071	0.925	0.927
TOTB, LIV21	LW	0.25861	0.672 \pm 0.116	0.790	0.799
	LR	0.50714	0.868 \pm 0.050	0.843	0.841
	DC	0.19612	0.530 \pm 0.248	0.745	0.764
TOTB, LWB	LW	0.49800	0.573 \pm 0.110	0.802	0.836
	LR	0.90901	0.784 \pm 0.063	0.814	0.820
	DC	0.33824	0.500 \pm 0.231	0.822	0.856
TOTB, LW21	LW	0.99061	0.350 \pm 0.158	0.669	0.706
	LR	3.00373	0.797 \pm 0.070	0.714	0.702
	DC	0.45684	0.156 \pm 0.288	0.625	0.696
LIVB, LIV21	LW	0.33023	0.885 \pm 0.054	0.872	0.871
	LR	0.53743	0.958 \pm 0.021	0.916	0.912
	DC	0.27018	0.766 \pm 0.149	0.821	0.826
LIVB, LWB	LW	0.59324	0.704 \pm 0.081	0.872	0.901
	LR	0.90949	0.817 \pm 0.052	0.885	0.897
	DC	0.37830	0.588 \pm 0.199	0.895	0.928
LIVB, LW21	LW	1.51594	0.553 \pm 0.122	0.751	0.777
	LR	3.21985	0.889 \pm 0.047	0.788	0.773
	DC	1.02709	0.368 \pm 0.244	0.698	0.750
LIV21, LWB	LW	0.68315	0.746 \pm 0.072	0.810	0.824
	LR	0.80181	0.803 \pm 0.061	0.838	0.846
	DC	0.32033	0.476 \pm 0.237	0.763	0.794
LIV21, LW21	LW	2.33917	0.785 \pm 0.060	0.891	0.908
	LR	3.11958	0.961 \pm 0.025	0.884	0.876
	DC	2.34296	0.803 \pm 0.092	0.887	0.908
LWB, LW21	LW	4.98406	0.740 \pm 0.062	0.778	0.785
	LR	5.37002	0.833 \pm 0.052	0.802	0.797
	DC	2.24455	0.422 \pm 0.200	0.717	0.786

¹TOTB: total number of piglets born, except mummified, LIVB: piglets born alive, LIV21: piglets alive at day 21, LWB: litter weight at birth, and LW21: litter weight at day 21.

The environmental correlations were also all positive and high (Table VI). The environmental effects seem to act in synergy, in all the litter traits, and show similar trends for the three breeds, since differences observed in r_E values were small.

CONCLUSIONS

The heritabilities of litter traits were small. The largest values were found in the Landrace breed. The heritabilities of litter weight traits were in general

greater than those of litter size traits. The genetic correlations among all litter traits were high and positive. Phenotypic selection could be efficient because of the high phenotypic variances found in all traits. Favourable correlated responses are expected for litter traits not considered in the selection criteria.

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RESUMO

Apresenta-se estimativas de parâmetros genéticos do tamanho e peso de leitegada, em três raças de suínos criadas no estado de Santa Catarina. Dados de 7064 leitegadas da raça Large White (LW), 4538 da raça Landrace (LR) e 2400 da raça Duroc (DC) foram analisados. Ajustou-se um modelo misto com os efeitos fixos de granja, mês e ano de nascimento da leitegada e idade da fêmea ao parto e os efeitos aleatórios de pai (da fêmea), dentro de granja e de filha dentro de pai. As filhas produziram duas ou mais leitegadas. As estimativas de herdabilidade (\pm erros padrão) foram: (1) total de leitões nascidos, $0,062 \pm 0,023$ (LW), $0,121 \pm 0,033$ (LR) e $0,078 \pm 0,044$ (DC); (2) número de leitões nascidos vivos, $0,060 \pm 0,023$ (LW), $0,119 \pm 0,033$ (LR) e $0,073 \pm 0,043$ (DC); (3) número de leitões vivos aos 21 dias, $0,075 \pm 0,024$ (LW); $0,101 \pm 0,031$ (LR) e $0,083 \pm 0,044$ (DC); (4) peso da leitegada ao nascer, $0,151 \pm 0,30$ (LW), $0,155 \pm 0,037$ (LR) e $0,109 \pm 0,048$ (DC); (5) peso da leitegada aos 21 dias, $0,133 \pm 0,028$ (LW), $0,143 \pm 0,035$ (LR) e $0,174 \pm 0,056$ (DC). A raça LR possui maior variabilidade genética no tamanho da leitegada e, de modo geral, as herdabilidades dos caracteres de peso de leitegada foram maiores do que as dos caracteres de tamanho de leitegada. As correlações genéticas entre os cinco caracteres foram altas (exceto em três casos), sugerindo a presença de efeitos pleiotrópicos favoráveis.

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