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Analysis of Environmental Effects in Production and Reproduction Traits of Purebred Berkshire in Japan

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Abstract: The purpose of this study is to reveal environmental factors that affect production and reproduction traits of boars, sows and piglets and to add information regarding significant factors in pig production. Records of 2963 purebred Berkshire (1537 males, 1426 females) produced from December 1994 to January 2002 at Okayama prefectural animal husbandry and research center (Okayama Research Center) in Japan were analyzed. The number of Berkshire pigs maintained at Okayama Research Center was approximately 400 pigs each year. Animals from same litter were raised together in a pen from birth to 60 days of age; selection was then carried out based on their phenotypic performance. Among traits of sows, service sire effect (SSI) was not significant in any of the traits, whereas dam effect (DAM) was significant in all of traits, suggesting that both permanent environmental effects and maternal genetic effects have a marked effect on these traits. Management methods need to take into consideration the influence of seasons, which have a significant effect on the reproductive traits of boars and sows and as well as on all traits of body weight and weight gain except on Weaning Weight (WW), which was significant when birth year effect was excluded from the statistical model. The results indicated the necessity of including both the maternal genetic effect and the permanent environmental effect in analytical models.

Key words: Berkshire, reproduction traits, production traits, pigs

INTRODUCTION

At present, three-way cross is common in pork production in many countries because productive and reproductive capabilities are known to be higher in crossbred animals due to the effect of heterosis. Purebred Berkshire have shown inferior average daily gain, feed conversion ratio, back fat thickness and loin eye area compared with three-way crossbred animals of other breeds (Rothschild and Ruvinsky, 1998). Neverthless, demand for Berkshire meat is strong in Japan because of consumer preference for high quality pork, unlike in other countries. Products from Berkshire breeds satisfy Japanese consumers taste and flavor, making Berkshire the dominant breed in the premium pork market in Japan. Berkshire population in Japan, however, have not been analyzed in the context of animal breeding.

Economically, important traits such as growth, meat production and reproduction in animals are affected by a number of environmental factors. Some reproductive traits for sows were reviewed by Prunier *et al.* (1996). In the review, it was indicated that increase in light duration under the environment above 25°C should result in loss of live weight during lactation (Prunier *et al.*, 1994). Moreover, it was indicated that energy intake declined on average by 2.4 MJ DE day^{-1} (about 0.17 kg of feed) for each 1°C increase in ambient temperature above 16°C (Dourmad, 1988; Black *et al.*, 1993). Whereas, after acute exposure to cold condition, heat production was increased and this phenomenon was usually followed by an increase in energy intake and sometimes a change in body composition (Dauncey and Ingram, 1986). In addition to these reports, semen quantity and quality in Artificial Insemination (AI) reported to be affected by insemination technician, year, month and date of semen collection (Kennedy and Wilkins, 1984). Performance of pig is, thus, largely influenced by environmental conditions.

Analyses of feeding environment factors have been already conducted for Yorkshire, Landrace and Duroc (Kerr *et al.*, 2005; Tummaruk *et al.*, 2004). Whereas, Prunier *et al.* (1996) reviewed reproductive performance of sows. There is no report, however, for that of Berkshire under temperate climate such as in Japan.

The purpose of this study, is to reveal environmental factors that affect reproduction traits of Berkshire boars and sows and production traits of piglets.

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MATERIALS AND METHODS

Records of 2963 purebred Berkshire (1537 males, 1426 females) produced from December 1994 to January 2002 at Okayama Research Center were analyzed. Variables in the data structure are shown in Table 1.

The number of Berkshire pigs maintained at Okayama Research Center was approximately 400 pigs each year. Animals from the same litter were raised together in 1 pen from birth to 60 days of age, then selected according to their phenotypic performance at 60 days of age. The piglets were fed 4 g day^{-1} from day 0-7 days of age, 16 g day^{-1} (8-14), 48 g day^{-1} (15-20), 120 g day^{-1} (21-25), 160 g day^{-1} at 26 days of age, 200 g day^{-1} at 27 days of age, 240 g day^{-1} at 28 days of age, 244 g day^{-1} at 29 days of age, 320 g day^{-1} (30-34), 400 g day^{-1} (35-39), 0.5 kg day^{-1} (40-44), 0.7 kg day^{-1} (45-49), 0.9 kg day^{-1} (50-54), 1.1 kg day^{-1} (55-59), 1.5 kg day^{-1} (60-64), 1.6 kg day^{-1} (65-69), 1.7 kg day^{-1} (70-74), 1.8 kg day^{-1} (75-79), 1.9 kg day^{-1} (80-100) and 2.0 kg day^{-1} (101-120). The pigs were allowed free access to water. At 200 days of age, Back Fat Thickness (BFT) and Loin Eye Area (LEA) were measured by ultrasound (Super eye meat 500, Fujihira Industry Co. Ltd.) at the mid-point of the body and 2-3 cm down from the top of the median line.

Traits analyzed: Semen Volume (SV, mL), Sperm Motility (SM) and Sperm Concentration (SC, 10^8 mL^{-1}) were measured in boars. The semen was collected in minimum volume that satisfies the requested quantity by customers of AI. The semen collection was performed every Monday and Thursday.

Total number of piglets born per L (TNB), Pre-Weaning Survival (PWS), Gestation Length (GL, day) and total weight of piglets born alive (TWB, kg) were measured in sows at each parity. TNB included stillbirths and culled animals.

For piglets, measurements were made of birth weight (BW, kg), body weight at 14 days of age (W14, kg), Weaning Weight (WW, kg), body weight at 60 days of age (W60, kg), Final Body Weight (FBW, kg), age in days at Final Body Weight (AFBW, day), daily gain from birth to final day (DG1, kg day^{-1}), from weaning to 60 days (DG2, kg day^{-1}), from 60 days to final day (DG3, kg day^{-1}), Back Fat Thickness (BFT, cm), Loin Eye Area (LEA, cm^2) and the number of teats (TEAT). BFT and LEA were also measured at about 200 days of age. LEA was an average of measurements of the right and left sides of the body. The basic statistics of the traits are shown in Table 2. The number of records varied because the selection was conducted at 60 days of age.

Table 1: Classification of records used in analysis

Class	No. of records
SIRE	24
DAM	70
Sex	
Male	1537
Female	1426
Birth year	
1994	310 (174)
1995	332 (174)
1996	340 (164)
1997	291 (150)
1998	271 (129)
1999	310 (163)
2000	291 (139)
2001	417 (226)
2002	401 (218)
Total records	2963

Numerals within parentheses indicate male animals

Statistical analysis: The significance of the effects was tested by PROC MIXED of SAS/STATS (1991) ver. 6.03 in information technology center at Okayama University.

The statistical model was as follows:

$$Y_{ijkl} = \mu + F_i + s_{j+m_k} + b_1 (A_{ijkl} - \bar{A}) + b_2 (A_{ijkl} - \bar{A})^2 + e_{ijk}$$

where:

- Y_{ijkl} = An observation in the ith animal.
- μ = The population mean.
- F_i = ith the fixed effects.
- S_j = Additive genetic effect of the jth sire.
- m_k = Additive genetic effect of the kth dam.
- b_1 and b_2 = Partial regression coefficients for linear (-L) and quadratic (-Q) regression.
- e_{ijkl} = Random error.

Table 2: Number of records (n), mean, Coefficient of Variation (CV) and Standard Deviation (SD), Minima (Min) and Maxima (Max) of traits analyzed

Trait	n	Mean	CV	SD	Min	Max
SV	346	164.30	0.48	79.60	20.00	420.00
SM	346	8.68	0.67	4.53	0.24	31.20
SC	301	6.79	0.09	0.75	25.00	95.00
TNB	350	9.60	0.26	2.49	1.00	17.00
PWS	297	0.89	0.14	0.12	0.00	1.00
GL	350	116.80	0.02	1.91	96.00	145.00
TWB	335	11.72	0.29	3.39	3.15	20.90
BW	2957	1.40	0.16	0.23	0.40	2.60
W14	2660	4.10	0.20	0.80	1.00	8.60
WW	2632	6.90	0.18	1.24	1.00	13.10
W60	2501	20.60	0.14	2.93	6.00	35.00
FBW	273	104.50	0.04	4.64	92.20	123.10
DG1	271	0.51	0.04	0.02	0.40	0.66
DG2	2123	0.59	0.17	0.07	0.01	0.78
DG3	269	0.41	0.06	0.03	0.42	0.79
BFT	273	1.76	0.17	030.00	1.05	4.25
LEA	253	25.08	0.10	2.47	17.97	37.14
TEAT	2932	14.20	0.07	0.93	7.00	18.00

SV: Semen Volume; SM: Sperm Motility; SC: Sperm Concentration; TNB: Total Number of piglets Born L^{-1}. PWS: Pre-Weaning Survival; GL: Gestation Length; TWB: Total Weight of piglets Born alive; BW: Birth Weight; W14: Body Weight at 14 days of age; WW: Weaning Weight. W60: Body Weight at 60 days of age; FBW: Final Body Weight. DG1: Daily gain birth to final; DG2: Daily Gain weaning to 60 days; DG3: Daily Gain 60 days to final; BFT: Back Fat Thickness. LEA: Loin Eye Area; TEAT: The number of Teats

Table 3: Factors included in the models

		BW	W14	WW	W60	FBW	AFBW	DG1	DG2	DG3	BFT	LEA	TEAT	SV	SM	SC	TLS	PWS	GL	TWB
Random	SIRE				x		x				x	x	x	x	x	x				
effect	DAM	x	x	x	x	x	x			x			x				x	x	x	x
	SIRE×DAM	x	x	x	x			x	x											
	SSI																			
	BY		x	x			x		x		x									
	BS	x	x		x	x	x	x	x	x										
	SEX	x	x	x	x	x	x	x	x	x	x		x							
Fixed	SCS													x		x				
effect	SSE																x	x	x	
	BY×BS		x		x				x		x									
	BY×SEX										x									
	BS×SEX											x								
	LS-L	x	x	x	x				x										x	x
	LS-Q				x															x
	PAR-L	x		x				x										x		
	PAR-Q	x	x	x	x															x
	W0A-L			x																
	WA-Q			x																
	AFBW-L					x		x	x	x		x								
	AFBW-Q					x			x											
Covariate	FBW-L						x													
	GL-L		x	x													x			
	GL-Q		x	x													x			
	SCA-L														x	x				
	SV-L															x				
	SV-Q															x				
	SM-L															x				
	SC-L													x	x					
	SC-Q													x						

SIRE: Sire effect; DAM: Dam effect; SSI: Service Sire effect; BY: Birth Year effect; BS: Birth Season effect; SEX: Sex Effect; SCS: Effect for semen Collection Season; SSE: Service Season Effect; LS: Regression for Litter Size effect after birth; PAR: Regression for parity effect; WA: Regression for Weaning Age effect; AFBW: Regression for age at the Final Body Weight effect; FBW: Regression for Final Body Weight effect; GL: Regression for Gestation Length effect; SCA: Regression for semen collection at the days of age effect; SV: Regression for Semen Volume effect; SM: Regression for sperm Motility effect; SN: Regression for Sperm Number effect; -L: Linear regression; -Q: Quadratic regression

Statistical models of traits and abbreviations for factors are shown in Table 3. Traits of boars and sows were measured repeatedly.

For GL, TWB, BW and TEAT, the effect of LS included stillborn and culled animals. For BS, the seasons were defined as spring from March to May, summer from June to August, autumn from September to November and winter from December to January.

RESULTS AND DISCUSSION

The results of the analysis of variance for boar traits are shown in Table 4. The sire effect was significant in all the traits. SCS was significant in SV ($p<0.01$) and SC ($p<0.05$). SCA were significant in SM ($p<0.05$) and SC ($p<0.001$), where regression coefficients were -0.002 and 0.004, respectively. For SCS, SC showed the highest value in autumn and the lowest in spring, whereas SV was highest in spring and lowest in autumn.

Semen quality in summer is generally inferior to that in the other seasons in Spanish Landrace and large white (Corcuera *et al*., 2002) because adverse environment conditions may have a negative influence on the production, quantity and quality of semen (Wettemann *et al*., 1976; Cameron and Blackshaw, 1980). The effect of thermal stress on sperm production, that elevated ambient temperatures had a negative effect on semen quality, was also reviewed by Kunavongkrit *et al*. (2005). The season effect in our study, however, is different from those results. This difference seems to be caused by photoperiod because effect of photoperiod and photo phase light intensity was significant on sperm

Table 4: Significant level of boar traits

	Trait		
Factor	SV	SM	SC
SIRE[1]	***	**	***
SCS	**	ns	*
SCA	ns	*	***
SV-L	-	ns	ns
SV-Q	-	ns	ns
SM-L	ns	-	ns
SM-Q	ns	-	ns
SN-L	***	***	-
SN-Q	**	ns	-

SV: Semen Volume; SM: Sperm Motility; SC: Sperm Concentration; SIRE: Sire effect; SCS: Effect for semen Collection Season; SCA: Regression for semen collection at the days of age effect; SV: Regression for Semen Volume effect; SM: Regression for Sperm Motility effect; SN: Regression for Sperm Number effect; -L: Linear regression; -Q: Quadratic regression; ***$p<0.001$, **$p<0.01$, *$p<0.05$; ns: Not significant; -: Not analyzed; [1]The statistical significance was tested by the likelihood ratio test production (Kunavongkrit *et al*., 2005). Whereas the breed effect was reported to be significant in all the semen traits by Kennedy and Wilkins (1984) and Kuo *et al*. (1997). Therefore, it is suggested that semen quantity and semen quality are influenced mostly by season effect and breed effect. These results indicated that management of climatic condition for AI boar is important for the semen quantity and quality.

The analysis of variance for sows is shown in Table 5. SSI was not significant in any of the traits, whereas DAM was significant in all of the traits, suggesting that permanent environmental effects and maternal genetic effects exert marked influences on these traits.

In sows, SSE was significant in all the traits, except in TWB. The Least Square Means (LSM) of SSE showed the highest TNB value in autumn, the lowest PWS value in autumn and the highest GL value in autumn, whereas the LSM of SSE showed the lowest TNB value in summer. This result may be due to the quantity and quality of semen which deteriorate because of high temperatures (Wettemann *et al*., 1976; Cameron and Blackshaw, 1980) also, sows tend to produce not only smaller litters but also lighter piglets in warm seasons (Tomes and Nielsen, 1979; Lui *et al*., 1981). These results are consistent with our results, suggesting that animals born in winter have the lowest PWS.

In our study, PAR had no statistically significant effect on TNB and GL. The capability for reproductive performance such as litter size is, however, highest at the third or fourth parity in some pig breeds (Xue *et al*., 1997; Koketsu *et al*., 1997; Wang and Lee, 1999; Tantasuparuk *et al*., 2000). Prunier *et al*. (1996) showed that reproduvtive performance of sows in the first parity was inferior to that in the later parity. Moreover, Lawlor and Lynch (2007) showed that the weight loss of piglet during lactation was observed at early parity. Thus our result was inconsistent with these reports. We should investigate the difference further with more records.

Table 5: Significant level of sow traits

	Trait			
Factor	TNB	PWS	GL	TWB
SSI[1]	ns	ns	ns	ns
DAM	***	***	***	***
SSE	*	**	*	ns
BY	ns	ns	ns	ns
BS	ns	ns	ns	ns
BY×BS	ns	ns	ns	ns
LS-L	-	ns	**	***
LS-Q	-	ns	ns	***
PAR-L	ns	***	ns	ns
PAR-Q	ns	ns	ns	**
GL-L	***	-	-	ns
GL-Q	***	-	-	ns

TNB: Total number of piglets born per litter; PWS: Pre-weaning survival; GL: Gestation length; TWB: Total weight of piglets born alive; SSI: Service sire effect; DAM: Dam effect; SSE: Service season effect; BY: Birth year effect; BS: Birth season effect; LS: Regression for litter size effect after birth; PAR: Regression for parity effect; GL: Regression for gestation length effect; -L: Linear regression; -Q: Quadratic regression; ***p<0.001, **p<0.01, *p<0.05; NS: not significant; -: not analyzed; [1]: The statistical significance was tested by the likelihood ratio test

The reproductive traits of sows reported to be largely influenced by quantity and quality of boar semen, the breed effect, however, was reported small (Swierstra and Dyck, 1976; Kim *et al*., 2002). SSI for traits of sows in our study was inconsistent with the reports. It seems that difference between our results and reported results is caused by using AI because sperm concentration of AI semen is quite stable.

The analysis of variance for piglet traits is shown in Table 6. SIRE was significant in W60, AFBW, BFT, LEA and TEAT. DAM was significant in all piglet traits, except in DG1, DG2, BFT and LEA. The interaction between sire and dam (SIRE×DAM) was significant in BW, W14, WW, W60, DG1, DG2 and TEAT. These results demonstrate that both the maternal genetic effect and permanent environmental effects might strongly influence the growth of piglets, except in BFT and LEA.

BS was significant in all piglet traits except in WW, BFT and LEA. The LSM of BS for BW, W14, W60 and FBW (Fig. 1) showed that low temperatures had a negative influence on the body weight of piglets, suggesting that the weight of animals born in winter was lowest such as in BW, W14 and W60; however, in summer it was lowest in FBW. Critical temperature for finishing pigs is assumed to be about 15-18°C (Suzuki *et al*., 2003) and the average daily gain reduced by 14-22 g due to decrease in 1°C ambi,ent temperature if feed intake is assumed to be same (Agriculture, Forestry and Fisheries Research Council Secretariat, 1998). At the loctation of Okayama Research Center, average temperature in January was about 4°C. Therefore, lowest LSM of BS for BW, W14 and WW in winter is caused by difference between the critical temperature and actual temperature because feeding quantity for Berkshire in this study was no change by season. Lowest LSM of BS for FBW of the animals born in summer is also thought influence by low temperature because the season of finishing period was winter. Consequently, the marked influence of ambient temperature on piglets needs to be reduced in the management of animals: The termal control for fattening pig in winter and the change of feeding management by season. No significant effect of the farrowing season on litter weight at birth and at weaning is observed in Danish Landrace in China because the difference in temperature between spring and autumn

Table 6: Significant level of piglet traits

	Trait											
Factor	BW	W14	WW	W60	FBW	AFBW	DG1	DG2	DG3	BFT	LEA	TEAT
SIRE[1]	ns	ns	ns	***	ns	***	ns	ns	ns	***	***	***
DAM[1]	***	***	***	***	***	***	ns	ns	***	ns	ns	***
SIRE×DAM[1]	***	**	***	***	ns	-	***	***	ns	ns	ns	***
BY	ns	*	*	ns	ns	***	ns	ns	ns	***	ns	ns
BS	***	**	ns	***	***	**	*	***	***	ns	ns	***
SEX	***	**	**	***	*	***	**	**	*	*	ns	***
BY×BS	ns	***	ns	***	ns	ns	ns	***	ns	***	ns	ns
BY×SEX	ns	ns	ns	ns	ns	ns	ns	ns	ns	***	ns	ns
BS×SEX	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
LS-L	***	***	***	***	ns	ns	ns	*	ns	ns	ns	***
LS-Q	ns	ns	ns	*	ns	ns	ns	**	ns	ns	ns	ns
PAR-L	***	ns	**	ns	ns	ns	*	ns	ns	ns	ns	**
PAR-Q	***	***	***	***	ns	ns	ns	ns	ns	ns	ns	***
WA-L	-	-	***	-	-	ns	-	-	-	-	-	-
WA-Q	-	-	**	-	-	ns	-	-	-	-	-	-
FBW-L	-	-	-	-	-	***	-	-	-	-	-	-
FBW-Q	-	-	-	-	-	ns	-	-	-	-	-	-
AFBW-L	-	-	-	-	***	-	***	-	***	ns	*	-
AFBW-Q	-	-	-	-	**	-	ns	-	ns	ns	ns	-
GL-L	ns	**	***	ns	ns	ns	ns	ns	ns	-	-	ns
GL-Q	ns	**	***	ns	ns	ns	ns	ns	ns	-	-	ns

BW: Birth Weight; W14: Body Weight at 14 days of age; WW: Weaning Weight; W60: Body Weight at 60 days of age; FBW: Final Body Weight; DG1: Daily Gain birth to final; DG2: Daily Gain weaning to 60 days; DG3: Daily Gain 60days to final; BFT: Back Fat Thickness; LEA: Loin Eye Area; TEAT: The number of teats; SIRE: SIRE effect; DAM: DAM effect; BY: Birth Year effect; BS: Birth Season effect; SEX: SEX effect; PAR: Regression for parity effect; WA: Regression for Weaning Age effect; AFBW: Regression for age at the final body weight effect; FBW: Regression for Final Body Weight effect; GL: Regression for Gestation Length effect; ***$p<0.001$, **$p<0.01$, *$p<0.05$; ns: Not significant; -: Not analyzed; [1]The statistical significance was tested by the likelihood ratio test

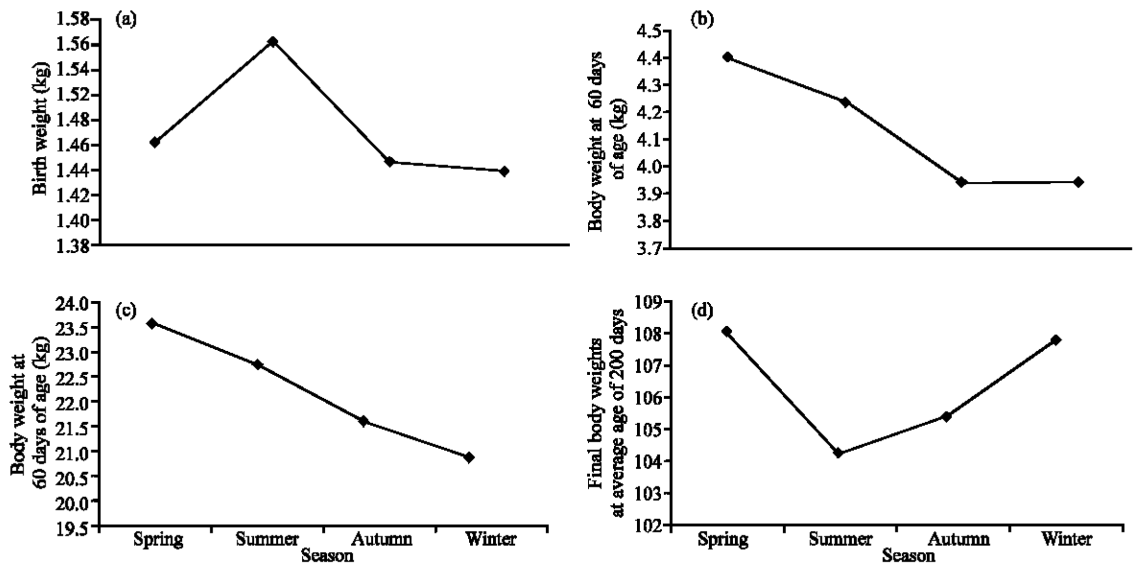

Fig. 1: (a) influence of birth season on birth weight (b) body weight at the 14 days of age (c) body weight at 60 days of age and (d) final body weight at average age of 200 days

in the subtropical environment is very small (Wang and Lee, 1999). The climatic difference may be the reason for the inconsistency between their study and ours. Further studies on temperature control are needed, because the attempts for reducing the incidence of seasonal infertility of sows by introduction of cooling systems has generally failed (Stork, 1979; Hurtgen and Leman, 1980).

The LSM of parity effect in W60 showed a hill-like trend where the body weight at the sixth parity was the highest and that at the ninth parity was as same as at the first parity (Fig. 2). A similar tendency has been reported

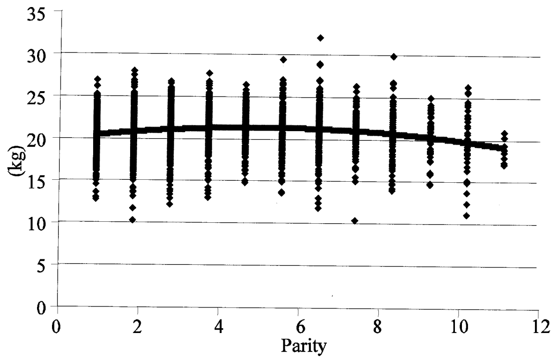

Fig. 2: Influence for parity effect on W60

for litter weight at the birth and at 45 days of age of Danish Landrace in China, with a peak at the fourth parity (Wang and Lee, 1999). The parity at the heaviest litter weight in their report was, however, earlier than that of our study. This difference between the two studies might be due to breed differences.

DAM was significant in all sow traits and in BW, W14, WW, W60, FBW, AFBW, DG3 and TEAT of piglets. Also, SIRE×DAM was significant in BW, W14, WW, W60, DG1, DG2 and TEAT in piglet traits. The results indicated the necessity of including both the maternal genetic effect and the permanent environmental effect in the analytical models for any traits.

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