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REGULAR ARTICLES

Climatic factors associated with reproductive performance in English Berkshire pigs and crossbred pigs between Landrace and Large White raised in a subtropical climate region of Japan

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Abstract Our objective was to characterize Berkshire female pigs associated with climatic factors by examining the interactions between two pig groups (pure English Berkshire females and crossbred females between Landrace and Large White) for reproductive performance in a humid subtropical zone. We analyzed 63,227 first-service records of 11,992 females in 12 herds. Climate data were obtained from four weather stations located close to the herds. Mean daily maximum temperatures (Tmax) and daily average relative humidity (ARH) for different time periods around servicing and farrowing of each female were coordinated with that female's reproductive performance data. Multilevel mixed-effects models were applied to the data. There were two-way interactions between the pig groups and either Tmax or ARH for weaning-to-first-mating interval (WMI) and number of total pigs born (TPB; $P<0.05$). The WMI in Berkshire sows increased by 0.64 days as Tmax increased from 20 to 30 °C ($P<0.05$), whereas in crossbred sows it only increased by 0.09 days over the same Tmax range. In contrast, WMI in Berkshire sows only increased by 0.01 days as ARH increased from 60 to 80 % ($P<0.05$), whereas in crossbred sows it increased by 0.32 days. In Berkshire females, TPB decreased by 0.3 pigs as Tmax increased from 20 to 30 °C ($P<0.05$), whereas that in crossbred females decreased by 0.4 pigs ($P<0.05$). Therefore, we recommend producers apply advanced cooling systems for Berkshire females.

Keywords Berkshire pigs · Climatic factors · Reproductive performance · Swine

Introduction

Berkshire breeding female pigs for pure Berkshire production account for approximately 6.4 % of the sow inventory of Japan (MAFF 2005), and have been mainly reared in the southern subtropical region in Kyushu. The quality of Berkshire meat is widely accepted in the Japanese pork market (Tomiyama et al. 2009), but Berkshire pigs reportedly have lower reproductive performance than crossbred pigs, such as total number of pigs born (TPB) and farrowing rate (McMullen 2006). Also, we have recently shown that Berkshire females have low lifetime performance and a lower probability of survival than crossbred females (Usui and Koketsu 2015). Furthermore, Berkshire sows in the state of Iowa in the USA have been reported to exhibit a seasonal breeding depression (McMullen 2006).

Climatic factors have been shown to affect reproductive productivity in pigs. For example, studies using climate data (measured at nearby meteorological stations or within herds) have shown that high ambient temperature and high humidity during peri-service events or during lactation decreased farrowing rate and TPB, and prolonged weaning-to-first-mating interval (WMI) of crossbred females (Suriyasomboon et al. 2006; Bloemhof et al. 2013; Iida and Koketsu 2014). Also, low parity (e.g., parity 0 and 1) has been shown to be associated with low reproductive performance in both Landrace × Large White crossbred females (Koketsu and Dial 1997) and Berkshire females (Sasaki et al. 2014). However, no studies have examined how subtropical climate factors affect pure English Berkshire or crossbred female reproductive performance characteristics, such as farrowing rates, TPB, and

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WMI. Nor have they studied the effects of parity on the reproductive factors in a subtropical climate zone. Therefore, the objective of our study was to clarify the reproductive characteristics of pure English Berkshire females in a subtropical zone by comparing the two female pig groups (pure English Berkshire pigs and crossbred pigs between Landrace and Large White) and examining interactions between the two pig groups and climatic factors or parity for reproductive performance.

Materials and methods

Farms and animals

There are 12 pig herds located between latitude 31–33° N and longitude 130–132° E in the same subtropical region (Kyushu, Southern Japan) in the PigCHAMP database at Meiji University where the data has been maintained by using the PigCHAMP software (PigCHAMP, Ames, IA, USA). Based on the Köpper climate classification (Peel et al. 2007), the herds are located in a humid subtropical climate zone. Two of the herds were raising only purebred English Berkshire females. Their English Berkshire pigs were originally imported from the UK and have since been maintained in these two herds in Japan (KDF 2014). The remaining 10 commercial breeding herds comprised crossbred females between Landrace and Large White, which were either purchased replacement gilts from national or international breeding companies, or were replacement gilts home-produced through internal multiplication programs. The breeding stocks in the national breeding companies were originally imported from the USA or Europe. In the 12 herds, breeding was conducted by artificial insemination only, or by natural mating followed by artificial insemination, and pregnancy was confirmed by real-time ultrasound devices. Unlike Europe, artificial insemination followed by natural mating has not been commonly practiced in Japan. Mean (±SEM) herd sizes for Berkshire and crossbred breeding herds were 2311±241 and 464±110 females, respectively, and mean pigs weaned per mated female per year were 17.0±0.60 and 22.7±0.28 pigs, respectively. The range of herd size with crossbred females was between 162 and 1254 female inventories.

Female performance data, exclusion criteria, and definitions

Data for females entered into herds between 2005 and 2007 were extracted from the database. The data included service records of females mated between 2005 and 2010. The initial dataset contained 63,342 first-service records of 11,994 females in the 12 herds. Excluded data were records of sows with 0 pigs weaned or 0 pigs TPB (305 records), and also records of sows with WMI 61 days or higher (43 records; Tummaruk et al. 2010). In addition, the following records were treated as excluded data or missing values: records of sows with lactation length of 42 days or higher (1 record; Hoving et al. 2011) or lactation length of 13 days or shorter (17 records). Also, records with gilt age at first-mating of either 159 days or earlier or 401 days or later (174 records; Hoving et al. 2011) were treated as missing values. Hence, the final dataset included 62,993 first-serviced records of 11,992 females in the 12 herds.

A service included one or more matings in a 10-day time period of estrus. Female records were categorized into four parity groups: parity 0, 1, 2 to 5, and 6 or higher.

Climate data

Daily average temperatures and relative humidity data from 2005 to 2010 were downloaded from climate statistics of four weather stations of the Japan Meteorological Agency (JMA 2014). The weather stations were located in the prefectural government office cities of the four prefecture districts where the studied herds were located. Mean (±SEM) distance from each herd to the relevant weather station was 39.8±1.5 km, ranging from 18 to 61 km. Climate data from distant weather stations (3–160 km apart) have been used to examine climate data and sow performance (Freitas et al. 2006; Bloemhof et al. 2008; Iida and Koketsu 2014). Also, a previous study estimated a correlation of 0.9 between on-farm weather data and weather station data even for weather stations more than 300 km away from the farm (Freitas et al. 2006).

Mean daily maximum temperatures (Tmax) and daily average relative humidity (ARH) for different time periods for each female were coordinated with the relevant reproductive performance data for that female (farrowing rate, TPB, or WMI). The studied periods for Tmax and ARH were (1) the 21 days pre-service, (2) the period from 7 days pre-service to 12 days post-service, and (3) the first 25 days post-farrowing. The reproductive data comprised farrowing rate, TPB, and WMI. These three periods were chosen because previous reports have indicated that the climatic conditions in these three periods are critical for reproductive performance. For example, a recent study showed that heat stress during the 21-day pre-service period had the largest effect on farrowing rate, and that heat stress during the period from 7 days before successful service to 12 days afterwards had the largest effect on TPB (Bloemhof et al. 2013). Also, the 25-day post-farrowing period was chosen because mean lactation length in the 12 herds was approximately 25 days.

Statistical analysis

Two-level analysis with repeated measures was applied by using a herd at level 2 and an individual record at level 1, to

Table 1 Performance measurements for Berkshire and crossbred female pigs entered into 12 Japanese commercial herds

Measurements	Number	Mean±SEM	Range	
			Minimum	Maximum
62,993 first-service records for 11,992 females				
Age of gilts at first-mating, days	62,819	266.2±0.11	183	397
Parity	62,993	2.9±0.01	0	12
Farrowing rate, %	62,993	86.3±0.14	–	–
Number of total pigs born at subsequent parity, pigs	54,361	10.6±0.01	1	29
Lactation length, days	50,984	25.2±0.01	14	38
Number of pigs weaned, pigs	51,001	8.9±0.01	1	31
Weaning-to-first-mating interval, days	51,001	6.7±0.02	0	60

The remaining records (62,993- *N*) were regarded as missing records

take account of the hierarchic structure of females within a herd, and the correlations among repeated measures in the same sow (Singer 1998; Littell et al. 2006). This model was used to account for the fact that an individual female was reared or managed in an individual herd, and that the herd included some unique information such as herd management. The pig group (pure Berkshire females and crossbred females) was treated as farm-level information (Singer 1998). Pairwise multiple comparisons were performed using the Tukey-Kramer test. A natural log-transformation was used on WMI data to obtain a normal distribution for analysis, and then the data was back-transformed in order to present the results.

A statistical model was constructed to examine interactions between the pig groups and climatic factors such as Tmax or ARH, or parity groups. Pig groups, climatic factors, parity groups, and a block of entry year were included in the model. Lactation length and number of pigs weaned were also included in the model when WMI was analyzed. Quadratic and cubic expressions of climatic factors in the model, and two-way interactions between the pig groups and significant explanatory variables, were examined and were then removed from the model if they were not significant ($P \geq 0.05$). The model included the herd as a random intercept. The normality of the residual in the final model was evaluated by using normal probability plots (Littell et al. 2006). Estimate statements were used for whether the slope of each variable was different from 0. To assess the variations in WMI, farrowing rate, and TPB that could be explained by the herd, intraclass correlation coefficients (ICC) were calculated by the ICC equations in Dohoo et al. (2009).

Results

Table 1 shows descriptive statistics of females in the 12 herds. Mean values (ranges) of daily maximum temperatures and relative humidity from 2005 to 2010 were 22.2 °C (2.0 to 37.8 °C) and 68.2 % (23.0 to 97.0 %), respectively (Fig. 1). The Berkshire females had 1.1 days higher WMI and 3.4 pigs fewer TPB than the crossbred sows ($P<0.01$), but there was no difference between the Berkshire and the crossbred females for farrowing rate ($P=0.37$).

There were three two-way interactions between the pig groups and Tmax for farrowing rate, TPB, and WMI, whereas there was only one two-way interaction between the pig groups and ARH for WMI ($P<0.05$; Table 2). Farrowing rates in the Berkshire and crossbred females decreased non-linearly by 4.8 and 2.3 %, respectively, as Tmax increased from 20 to 30 °C ($P<0.05$; Fig. 2). Also, farrowing rates of both the Berkshire and crossbred females decreased linearly by 0.01 %, as ARH increased from 60 to 80 % ($P<0.05$). There was no interaction between the pig groups and ARH for farrowing rate ($P=0.24$).

The TPB in the Berkshire females decreased non-linearly from 8.9 to 8.6 pigs (3.4 %) as Tmax increased from 20 to 30 °C ($P<0.05$; Fig. 3), whereas in the crossbred females TPB decreased non-linearly from 12.4 to 12.0 pigs (3.2 %) over the same Tmax range ($P<0.05$). However, there was no association between the pig groups and ARH for TPB ($P=0.42$).

The WMI of the Berkshire sows increased linearly by 0.64 days as Tmax increased from 20 to 30 °C ($P<0.05$;

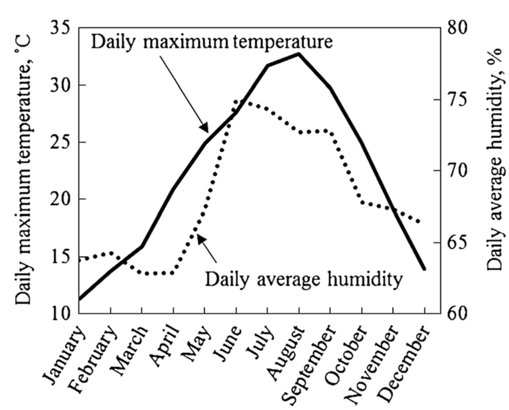

Fig. 1 Monthly values of daily average maximum temperatures (*solid line*) and humidity (*dotted line*) in the Kyushu area of Japan from 2005 to 2010

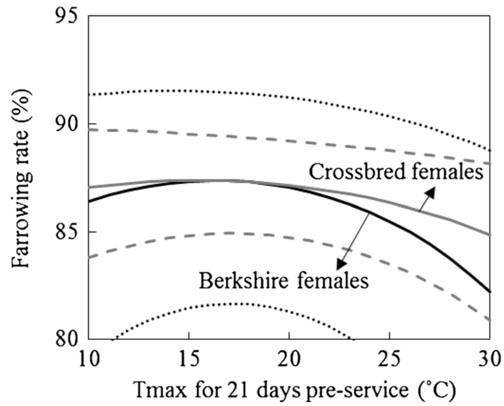

Fig. 2 Prediction lines for farrowing rate in gilts and sows by two pig groups with changing mean values of daily maximum temperatures (*Tmax*). *Dotted lines* represent 95 % confidence intervals of the Berkshire females and crossbred females

Fig. 4a), whereas in the crossbred sows it increased by only 0.10 days. Also, as ARH increased from 60 to 80 %, WMI in the Berkshire sows increased non-linearly by only 0.01 days ($P<0.05$; Fig. 4b), whereas in the crossbred sows it increased by 0.32 days.

There were two-way interactions between the pig groups and parity groups for farrowing rate, TPB, and WMI ($P<0.05$; Table 2). Parity 6 or higher Berkshire sows had a 5.7 % higher farrowing rate than those in parity 0 ($P<0.05$; Table 3), whereas in the crossbred sows there was no such difference ($P=0.88$). Also, parity 6 or higher Berkshire sows had 0.2 more TPB than those in parity 2–5 ($P<0.05$), whereas with the crossbred sows the greatest TPB was in parity 2–5 ($P<0.05$). Across parity, the Berkshire females had 1.1–1.2 days greater WMI than the crossbred females ($P<0.05$). Finally, the ICC indicated that the herd effect explained 2.9, 0.6, and 1.8 % of the total variation for farrowing rate, TPB, and WMI, respectively (Table 2).

Discussion

Our study showed that there was a stronger association between increased WMI and increased high ambient temperature in the Berkshire sows than in the crossbred sows. This result suggests that the reproductive function, via the hypothalamic pituitary axis, in Berkshire sows was impaired more than that in the crossbred sows due to high ambient temperature. One of the reasons why high ambient temperature could increase WMI is by suppressing lactational feed intake, which has been shown to be associated with low luteinizing hormone secretion resulting in prolonged WMI (Koketsu et al. 1996).

In contrast, our study also showed that the effect of increasing ARH on WMI was relatively larger in the crossbred sows than in the Berkshire sows, even though the Berkshire sows have consistently greater WMI. One possible reason why the crossbred sows might have been more sensitive to higher

Table 2 Estimates of fixed effects and random effect variance in the final model for reproductive performance

Fixed effects and variance	Farrowing rate		Number of total pigs born		Weaning-to-first-mating interval	
	Estimate (±SE)	*P* value	Estimate (±SE)	*P* value	Estimate (±SE)	*P* value
Intercept	1.6748 (0.1137)	<0.01	12.6840 (0.0888)	<0.01	1.6048 (0.0190)	<0.01
Berkshire females	0.2296 (0.2562)	0.37	−3.2568 (0.1818)	<0.01	0.2123 (0.0437)	<0.01
Tmax, °C	−0.0141 (0.0024)	<0.01	−0.0275 (0.0022)	<0.01	0.0017 (0.0004)	<0.01
Tmax-squared, °C	−0.0010 (0.0004)	<0.01	−0.0019 (0.0003)	<0.01		
Berkshire females×Tmax	−0.0128 (0.0033)	<0.01	0.0078 (0.0032)	0.01	0.0080 (0.0007)	<0.01
Berkshire females×Tmax-squared	−0.0012 (0.0006)	0.04				
ARH, %	−0.0099 (0.0026)	<0.01	0.0020 (0.0025)	0.42	0.0028 (0.0005)	<0.01
ARH-squared, %					0.0001 (0.0000)	<0.01
Berkshire females×ARH					−0.0047 (0.0008)	<0.01
Parity 0	−0.0757 (0.0566)	0.18	−1.5041 (0.0619)	<0.01		
Parity 1	0.2371 (0.0613)	<0.01	−0.9037 (0.0621)	<0.01	0.2476 (0.0084)	<0.01
Parity 2–5	0.3900 (0.0500)	<0.01	0.2026 (0.0514)	<0.01	0.0666 (0.0069)	<0.01
Parity 0 Berkshire females	−0.3325 (0.0754)	<0.01	−0.1402 (0.0852)	0.09		
Parity 1 Berkshire females	−0.3631 (0.0821)	<0.01	−0.1698 (0.0868)	0.05	−0.0474 (0.0118)	<0.01
Parity 2–5 Berkshire females	−0.2970 (0.0678)	<0.01	−0.3703 (0.0719)	<0.01	−0.0615 (0.0097)	<0.01
Herd variance	0.10 (0.05)		0.05 (0.02)		0.003 (0.001)	
Female and parity record variance	0.06 (0.01)		7.72 (0.05)		0.160 (0.001)	
ICC (records within the same herd), %	2.9		0.6		1.8	

Tmax mean values of daily maximum temperatures, *ARH* daily average relative humidity, *ICC* intraclass correlation coefficient

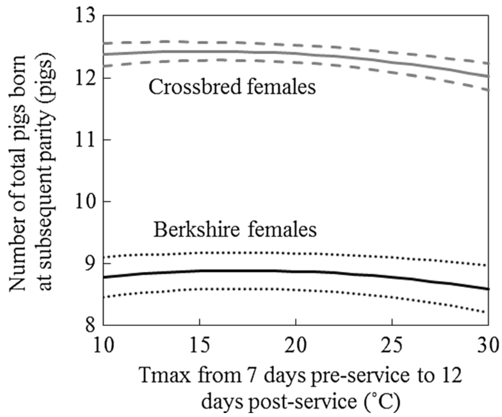

Fig. 3 Prediction lines for number of total pigs born at subsequent parity in gilts and sows by two pig groups with changing mean values of daily maximum temperatures (*Tmax*). *Dotted lines* represent 95 % confidence intervals of the Berkshire females and crossbred females

ARH is because they could have more piglets for milking and more reduction in lactational feed intake.

Our study showed that there was a two-way interaction between pig groups and Tmax for TPB, but that the effect of high temperature during the 7-day pre-service to 12-day post-service time period on TPB did not differ much between the Berkshire and the crossbred females. In both pig groups, high ambient temperature appears to be similarly associated with a decrease in TPB, probably by affecting estrus, follicle development, ovulation, fertilization, implantation of embryos, or embryo survival (Hansen et al. 2001; Bertoldo et al. 2012).

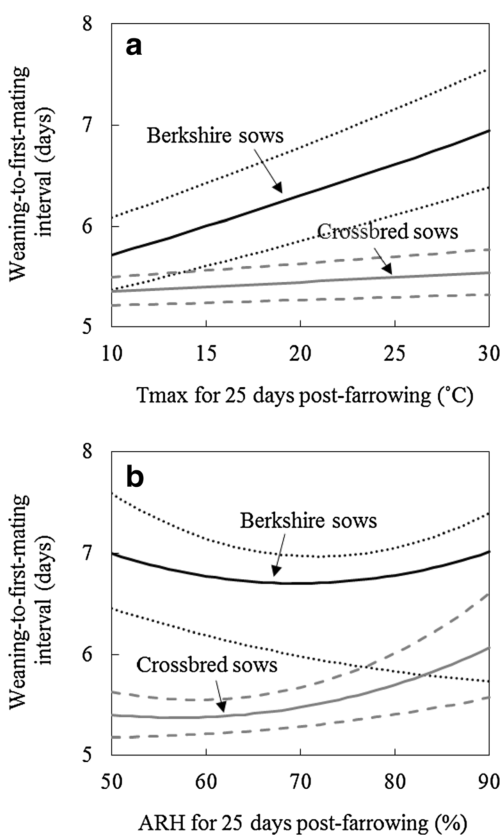

Fig. 4 Prediction lines for weaninig-to-first-mating interval for females by two pig groups with changing mean values of daily maximum temperatures (*Tmax*; **a**) and average relative humidity (*ARH*; **b**). *Dotted lines* represent 95 % confidence intervals of the Berkshire females and crossbred females

Table 3 Comparisons between pig groups and parity groups for farrowing rate, number of total pigs born at subsequent parity, and weaning-to-first-mating interval

	Berkshire females		Crossbred females	
Parity groups	*N*	Mean±SE	*N*	Mean±SE
Farrowing rate, %				
Parity 0	6716	80.1±3.63^{c}	5276	82.5±1.56^{b}
Parity 1	5093	84.2±3.04^{b}	4696	86.6±1.29^{a}
Parity 2–5	15,471	86.9±2.58^{a}	15,209	88.2±1.09^{a}
Parity 6 or higher	5325	85.8±2.79^{ab}	5207	83.6±1.52^{b}
Number of total pigs born at subsequent parity, pigs				
Parity 0	5348	7.7±0.16^{dy}	4440	11.1±0.08^{dx}
Parity 1	4292	8.2±0.16^{cy}	4135	11.7±0.08^{cx}
Parity 2–5	13,421	9.1±0.16^{by}	13,646	12.8±0.08^{ax}
Parity 6 or higher	4554	9.3±0.16^{ay}	4525	12.6±0.08^{bx}
Weaning-to-first-mating interval, days				
Parity 1	5093	7.6±1.04^{ax}	4696	6.5±1.02^{ay}
Parity 2–5	15,471	6.3±1.04^{bx}	15,209	5.4±1.02^{by}
Parity 6 or higher	5325	6.2±1.04^{bx}	5207	5.0±1.02^{cy}

Mean and SE were estimated by mixed-effects multivariable models. Different superscripts within a column (a–d) and within a row (x, y) represent significant differences in means ($P<0.05$)

The present study showed the slope of high temperature on farrowing rate was slightly higher in the Berkshire females than in the crossbred females, but the confidence interval of the predicted line in the Berkshire females overlapped the predicted line in the crossbred females (Fig. 2). The results for farrowing rate were similar to those for TPB, showing little difference between the Berkshire and crossbred females for the effect of high temperature during the pre-service event on farrowing rate. Additionally, there was no difference in the effects of ARH on TPB or farrowing rate between the two pig groups. Therefore, there would appear to be a little effect of ARH on processes from ovulation to embryo survival, and farrowing in both the two pig groups.

The interactions between the pig groups and parity groups for farrowing rate, TPB, and WMI indicate that there is a difference in the effects of parity on reproductive performance between the Berkshire and the crossbred females. For Berkshire females, reproductive performance, including parameters such as farrowing rate and TPB, was the highest at parity 6 or higher, whereas for crossbred females, reproductive performance reached a maximum in sows at parities 2–5. In a related study, we showed that Berkshire females were culled due to reproductive failure at an earlier stage than crossbred females (Usui and Koketsu 2015). Also, analysis of these herds' culling data in a previous study (Usui and Koketsu 2015) suggests that the Berkshire females were culled due to low TPB from low to mid-parity, and so only the more fertile sows survived until parity 6 or higher. Additionally the prolonged WMI in the Berkshire sows across all parities indicates that the resumption of ovarian cyclicity after weaning in Berkshire sows is delayed regardless of parity.

Finally, in the present study, the relatively low ICC of 0.6–2.9 % for herd variance suggests that there were few unexplained effects of the herd on the analyzed reproductive performance parameters of WMI, farrowing rate, and TPB. It appears that management of individual pigs is more critical than herd management.

In conclusion, WMI in the Berkshire females appeared to be more susceptible to high temperature than that in the crossbred females. Furthermore, TPB and farrowing rate were affected by high ambient temperature in both the Berkshire and crossbred females. Therefore, we recommend that producers apply advanced cooling systems (e.g., cool cell systems or automated drip coolers) and ventilation systems to prevent a reduction of reproductive performance due to high ambient temperature.

A limitation of this study is that it was an observational study performed using commercial herd data and climate data recorded at meteorological stations. Herd health, nutrition, genotype, and boar fertility were not taken into account in the analyses. However, even with such limitations, this research provides valuable information for swine producers and veterinarians about the quantitative relationship between climate factors and reproductive performance in Berkshire females.

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Conflict of interest The authors declare that they have no competing interests.

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