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Impact of porcine epidemic diarrhea on herd and individual Berkshire sow productivity

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ABSTRACT

Porcine epidemic diarrhea (PED) is an emerging disease of pigs in several countries. In the present study, individual sow productivity of Berkshire sows exposed to PED virus at different stages of production was compared. On a commercial farrow-to-finish farm in Kagoshima Prefecture, Japan, the clinical presence of PED was observed in the farrowing barn on January 6, 2014, and all gilts and sows were immunized on January 9, except those in the farrowing barn. The sows were categorized into six groups based on the period in which they were exposed to PED virus: between days 0–30 (G1), 31–60 (G2), 61–90 (G3), or after 91 days of pregnancy (G4), during lactation (L), and after weaning (W). The control group was not exposed to PED during the period of PED outbreak. The study was based on 574 production records. The sows of the G4 and L groups had the fewest piglets weaned (4.8 ± 0.4, and 4.0 ± 0.3 pigs, respectively; $P < 0.05$) and the greatest pre-weaning mortality (33.1 ± 4.8%, and 39.7 ± 4.1%, respectively; $P < 0.05$). The number of piglets weaned and pre-weaning mortality, however, did not differ among the G1, G2, G3, and uninfected groups. The G4 and W groups had slightly lesser farrowing rates than the uninfected group ($P < 0.05$), however, similar subsequent piglet litter performance as the uninfected group. In conclusion, the effect of PED on individual sow productivity differed with the production stage in which sows were exposed to PED virus.

1. Introduction

Porcine epidemic diarrhea (PED) is caused by PED virus, an enveloped single-stranded RNA virus in the family Coronaviridae that is related to transmissible gas-troenteritis coronavirus (Pensaert and DeBouck, 1978; Hofmann and Wyler, 1989). The PED virus emerged as a global threat to the swine industry in 2013, when a number of epidemics were reported in many important swine-producing countries in North America and East Asia that were previously believed to be PED virus-free (Mole, 2013; Stevenson et al., 2013; Chen et al., 2014; Park et al., 2014; Hanke et al., 2015; Song et al., 2015). The PED virus was first reported in Japan in the 1990s, and a live PED vaccine was approved in 1996 (Sueyoshi et al., 1995). There have been only a few isolated outbreaks that had minimal effects on the pork production enterprises of Japan subsequently. In October 2013, however, a PED outbreak was reported in Japan (Okinawa Prefecture) after an interval of 7 years when there were no infestations reported (Sasaki et al., 2016). The epidemic of PED virus infection spread rapidly throughout Japan (Diep et al., 2017) and was also reported in Kagoshima prefecture, which has

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the largest number of pig farms in Japan. In Kagoshima, a numbers of farms produce pork from Kagoshima Berkshire pigs ('Kagoshima Kurobuta') which is one of the most sought pork brands in Japan. Approximately 25% of farms in Kagoshima Prefecture have Kagoshima Berkshire pigs (MAFF, 2012). Berkshire pork is an excellent quality meat, and the retail price for purebred Berkshire is 50% greater than that for a typical pig that has been developed to marketable size (LWD; Suzuki et al., 2003). Kagoshima Berkshire pigs reportedly have a lesser productivity, including litter size and fertility, compared with F_1 crossbred pigs (Matsumoto and Koketsu, 2003; Sasaki et al., 2014), and pre-weaning mortality of Berkshire sows before the PED outbreak was reported to be 5.0% (Sasaki et al., 2014). Productivity of Kagoshima Berkshire sows exposed to PED virus has not been, however, reported in Japan. In F_1 sows, the relationship between PED virus infection and productivity of sows reportedly differs when the sows are exposed to the virus at different stages of pregnancy (Olanratmanee et al., 2010). Compared with uninfected sows, infection with PED virus during the first 30 days of pregnancy significantly reduced litter size, but no reduction of litter size was observed as a result of infection with PED virus during the other stages of pregnancy (Olanratmanee et al., 2010).

The objectives of the present study, therefore, were to compare the herd productivity of Berkshire sows before and after an outbreak of PED, and to compare the individual productivity of Berkshire sows exposed to PED virus during different stages of production.

2. Materials and methods

2.1. Data collection

The present study was conducted on a commercial farrow-to-finish farm that had approximately 500 sows in the Kagoshima Prefecture of Japan. All the breeding gilts and sows on this farm were purebred Kagoshima Berkshire pigs that had been bred on the farm or purchased from the Livestock Research Institute of the Kagoshima Prefectural Institute for Agricultural Development. Pregnancy was confirmed with ultrasonography (Agroscan, Frontier International Co., Ltd.) 21 days after the first mating. The farm management included a 3-week batch production system, in which the sows were divided into seven reproductive groups, 3 weeks apart in stage of their reproduction (Fig. 1). Biosecurity measures practiced at the farm where the research was conducted were shower-in/shower-out for staff and visitors, changing clothes and footwear before entering the operation, rodent control, washing and disinfection of the chute floor after each loading/unloading, and washing and disinfection of the truck before loading. Both gilts and sows were housed in stalls on a partially slatted floor from the first mating and throughout gestation. In the lactation barns, crates with completely perforated floors made of cast iron or woven wire were used. The lactation and gestation diets were formulated from imported corn and soybean meal. The calculated composition of the gestation diet was 13.5% CP, 0.7% Ca, 0.5% P and 2.0% fat, whereas the nutrient constituency of the lactating diet was 15.0% CP, 0.7% Ca, 0.5% P and 5.0% fat.

2.2. Outbreak of PED

The first clinically validated case of PED in Kagoshima Prefecture was identified in December 2013, and the disease spread rapidly throughout the entire region. On the farm where the present study was conducted, the PED outbreak began in the gestation barn on January 6 and spread to the farrowing barn on January 9, 2014. The diagnosis of PED was confirmed with reverse transcription (RT) PCR and the immuno-histochemical analysis of fecal samples. The initial clinical signs on the farm where the research was conducted were diarrhea in the gilts and sows and the death of newborn piglets. The death of new born piglets attributed to PED ceased at the end of January. The animals on the farm were immunized with natural treatment methods with the PED virus. The feces of infected pigs were obtained, ground, mixed well and fed to the pregnant gilts and sows, sows from which pigs had been weaned, and gilts used for replacing culled sows within 2 weeks of the onset of clinical symptoms of PED. Intensive cleaning, disinfection, and early weaning programs were also instituted. All the gilts and sows were vaccinated with a live PED vaccine (Nisseiken Co., Ltd., Oume, Tokyo, Japan) from the end of March 2014.

2.3. Definition

Total pigs born was defined as the sum of pigs born alive and those born dead. Pigs born dead was defined as the sum of the number of stillborn pigs and the number of mummified fetuses. Pre-weaning mortality was calculated as the number of pigs that died

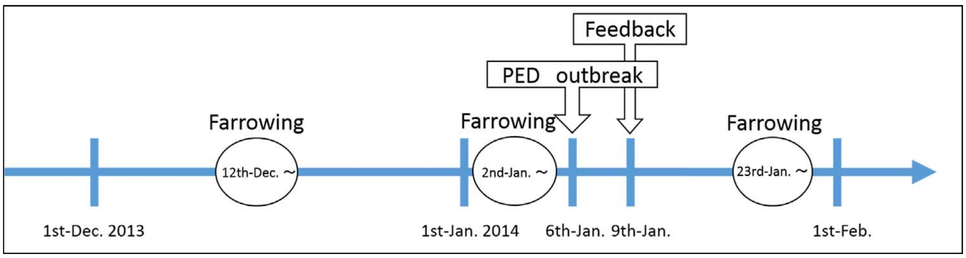

Fig. 1. Farrowing dates of sow groups on a farm that uses a 3-week batch production system.

before weaning divided by the number of pigs born alive, adjusted for the number of cross-fostered pigs. Farrowing was defined as ‘0′ when the sows were mated but aborted, were culled, did not become pregnant, or required repeated mating, and was defined as ‘1′ when the mating resulted in a farrowing that was consistent with the time of mating. The farrowing rate was calculated as the number of sows that farrowed divided by the number of mated gilts and sows, expressed as a percentage. Parity (number of deliveries) was classified into three groups: 1–2, 3–5, and ≥ 6.

2.4. Study 1

In Study 1, herd productivity of sows was compared before the PED outbreak and after the PED outbreak relative to farrowing month. Data were obtained for the sows that farrowed between July 2013 and July 2014, which included the 6 months before and after the PED outbreak started. The data included those of results of 1325 matings and 1039 farrowing records for 516 sows. A month was defined as the period between the 9th day of one month and the 8th day of the next month. For example, the period for January was that between January 9 and February 8.

In Study 1, herd productivity included litter performance (total pigs born, pigs born alive, and pigs born dead), performance of weaned pigs (number of piglets weaned, pre-weaning mortality, lactation length, and adjusted 21-day litter weights), post-weaning performance (weaning-to-first-mating interval and farrowing rate), and litter performance at the subsequent parity.

Sows with records of weaning-to-first-mating intervals > 115 days (Hoshino and Kokestu, 2008; two sows) or records of weaning-to-conception intervals > 180 days (Koketsu and Dial, 1998; five sows) were excluded from the analysis of weaned pig and piglet litter performance at the subsequent parity.

2.5. Study 2

In Study 2, individual productivity of sows exposed to the PED virus at different stages of the production cycle was compared. The data collected from all sows that were on the farm on January 9, 2014 were assessed in this study. Sows were categorized into six groups (Olanratmanee et al., 2010) based on the period during which they were exposed to PED virus (January 9, 2014): exposed on days 0–30 (G1), 31–60 (G2), 61–90(G3), or after day 91 (G4) of pregnancy, or during lactation (L), or during the post-weaning (W) period. The control group was assigned based on the farrowing records extending from April 9, 2012, to March 8, 2013 (uninfected group). The data included records of results from 1585 matings and 1283 farrowing records for 575 sows.

In Study 2, individual sow productivity included litter performance (total pigs born, pigs born alive, and pigs born dead), weaning performance (number of piglets weaned, pre-weaning mortality of piglets, and adjusted 21-day piglet litter weights), post-weaning performance (weaning-to-first-mating interval and farrowing rate), and piglet litter performance at the subsequent parity.

Data from sows with records of weaning-to-first-mating intervals > 115 days (Hoshino and Kokestu, 2008; one sow) and records of weaning-to-conception intervals > 180 days (Koketsu and Dial, 1998; six sows) were excluded from the analysis of weaned pig and litter performance at the subsequent parity.

2.6. Statistical analysis

The data were analyzed statistically with SAS (SAS Institute Inc., Cary, NC, USA). A linear mixed-effects model using the MIXED procedure with the Tukey–Kramer multiple comparisons test was applied to the parametric data and a mixed-effects logistic regression model using the GLIMMIX procedure with contrasts was applied to the binomial data (farrowing rate; whether a sow had farrowed or not). In Study 1, productivity was a dependent variable, and farrowing month (July, August, September, October, November, December 2013, January, February, March, April, May, June, and July 2014) and parity (1–2, 3–5, and ≥ 6). Sow was included as a random effect in the statistical models. In Study 2, productivity was a dependent variable, and sow group (G1, G2, G3, G4, L, W, or uninfected group) and parity (1–2, 3–5, and ≥ 6) were independent variables. The data for L and W sows were excluded from the analysis of piglet litter performance. The data for W sows were also excluded from the analysis of weaning performance. Two-way interactions between independent variables were included in the statistical model for Study 2, but when there were insignificant interactions ($P > 0.05$) these terms were removed from the final models. Sow was included as a random effect in the statistical models. Lactation length was included in the analysis of weaning and subsequent litter performance. The weaning-to-first-mating interval was also included in the analysis of mating and subsequent litter performance. The data are shown as means ± SEM. P values < 0.05 were considered to indicate significant differences.

3. Results

3.1. Study 1

The descriptive statistics for the herd productivity of sows that farrowed between July 2013 and July 2014 are presented in Table 1. Pre-weaning mortality ranged from 0% to 100%, and the interquartile range was from 0% to 12.5%.

The data for productivity of the sows on the farms in the periods before and after the PED outbreak are presented in Tables 2 and 3. The PED outbreak was observed in January 2014. There was no difference in total pigs born, pigs born alive, or pigs born dead between the sows that farrowed in January 2014 and those that farrowed in the other months. The sows that farrowed in December (5.4 ± 0.2 pigs) and January (4.6 ± 0.4 pigs) had the least number of piglets weaned during these months of all the months in

Table 1
Descriptive statistics of the reproductive performance of sows that farrowed between July 2013 and July 2014.

	n	Mean ± SD	25%	75%
Litter performance				
Total pigs born, pigs	1039	8.4 ± 0.1	7	10
Pigs born alive, pigs	1039	7.3 ± 0.1	6	9
Pigs born dead, pigs	1039	1.1 ± 0.1	0	2
Weaning performance				
Number of piglets weaned, pigs	1020	6.8 ± 0.1	6	8
Pre-weaning mortality, %	1020	9.9 ± 0.6	0	12.5
Lactation length, days	1020	27.1 ± 0.1	27	28
Adjusted 21-day litter weights, kg	1015	6.1 ± 0.1	5.7	6.5
Post-weaning performance				
Weaning-to-first-mating interval, days	970	4.6 ± 0.1	4	4
Farrowing rate, %	1258	66.2 ± 1.3	–	–
Litter performance at subsequent parity				
Total number of pigs born	828	8.3 ± 0.1	6	10
Number of pigs born alive	828	7.3 ± 0.1	6	9
Number of pigs born dead	828	1.0 ± 0.1	0	2

Table 2
Comparison of the litter performance and weaning performance according to farrowing months.

Farrowing month	Litter performance				Weaning performance				
	Total number of pigs born		Number of pigs born alive	Number of pigs born dead	Number of piglets weaned		Preweaning mortality, %	Adjusted 21-day litter weights, kg	
	n	*Mean ± SEM*	Mean ± SEM	Mean ± SEM	*n*	Mean ± SEM	Mean ± SEM	*n*	Mean ± SEM
2013-*July*	99	9.2 ± 0.3[a]	7.6 ± 0.2	1.7 ± 0.1[a]	96	7.0 ± 0.2[a]	9.4 ± 1.7[c]	95	5.8 ± 0.1[e]
August	75	8.1 ± 0.4[ab]	7.0 ± 0.3	1.1 ± 0.2[ab]	75	6.8 ± 0.2[a]	7.3 ± 1.9[c]	74	5.9 ± 0.1[de]
September	62	8.8 ± 0.5[ab]	7.4 ± 0.4	1.4 ± 0.2[ab]	61	6.9 ± 0.2[a]	8.9 ± 2.0[c]	60	6.2 ± 0.1[bcde]
October	86	7.8 ± 0.3[ab]	6.7 ± 0.3	1.2 ± 0.2[ab]	84	6.7 ± 0.2[ab]	2.1 ± 0.6[c]	84	6.8 ± 0.1[a]
November	58	7.5 ± 0.4[b]	6.5 ± 0.4	0.9 ± 0.2[b]	55	6.5 ± 0.3[a]	5.2 ± 2.0[c]	55	6.6 ± 0.1[ab]
December	99	7.6 ± 0.3[b]	6.6 ± 0.3	1.0 ± 0.1[b]	98	5.4 ± 0.2[bc]	20.1 ± 2.7[b]	98	6.3 ± 0.1[bc]
2014-January*	71	8.0 ± 0.3[ab]	6.8 ± 0.3	1.2 ± 0.2[ab]	70	4.6 ± 0.4[c]	34.3 ± 4.7[a]	69	5.0 ± 0.2[f]
February	107	8.9 ± 0.3[ab]	7.9 ± 0.2	1.0 ± 0.1[ab]	106	7.6 ± 0.2[a]	5.8 ± 1.5[c]	106	5.8 ± 0.1[e]
March	69	9.2 ± 0.3[a]	8.1 ± 0.3	1.1 ± 0.2[ab]	68	7.4 ± 0.3[a]	8.9 ± 2.1[c]	68	6.3 ± 0.1[bcd]
April	64	8.4 ± 0.3[ab]	7.4 ± 0.3	1.0 ± 0.1[ab]	64	7.0 ± 0.3[a]	5.1 ± 1.6[c]	64	6.0 ± 0.1[cde]
May	77	8.1 ± 0.3[ab]	7.2 ± 0.3	1.0 ± 0.2[b]	75	7.2 ± 0.2[a]	3.7 ± 1.5[c]	75	6.5 ± 0.1[ab]
June	57	8.5 ± 0.4[ab]	7.7 ± 0.3	0.8 ± 0.2[b]	55	7.4 ± 0.2[a]	7.1 ± 1.5[c]	55	6.3 ± 0.1[bcd]
July	115	8.6 ± 0.3[ab]	7.7 ± 0.3	1.0 ± 0.1[b]	113	7.2 ± 0.2[a]	9.4 ± 1.5[c]	112	6.0 ± 0.1[cde]

[a,b,c,d,e]Values without the same superscript letters within a column differ (P < 0.05).
*Porcine epidemic diarrhea outbreak observed this month.

which data were collected (P < 0.05; Table 2). Pre-weaning mortality was also greatest in the sows that farrowed in January (34.3 ± 4.7%; P < 0.05; Table 2), and the second greatest pre-weaning mortality was in the sows that farrowed in December (20.1 ± 2.7%; P < 0.05; Table 2). There was no other month-to-month differences in pre-weaning mortality. The adjusted 21-day litter weights were least in the sows that farrowed in January (5.0 ± 0.2 kg; P < 0.05; Table 2). The weaning-to-first-mating interval was longer in the sows that farrowed in January than in those that farrowed in October 2013, and et al., 2014February, March, and July 2014. The farrowing rates of sows that farrowed in December and January were less than those of sows that farrowed in September. There was no difference in litter performance at subsequent parities, however, between sows that farrowed in December 2013 or January 2014 and sows that farrowed in the other months (Table 3).

3.2. Study 2

Data for comparisons of the productivity data for the different sow groups are presented in Table 4. For litter performance, there was a difference between the sow groups for total pigs born and pigs born alive. The G4 sows gave birth to fewer live pigs than the uninfected sows (P < 0.05), however, there was no difference between the sows in G1, G2, G3, and uninfected groups for piglets born alive. For piglet performance to the time of weaning, there was a difference between the sow groups for number of piglets weaned, pre-weaning mortality, and the adjusted 21-day litter weights (P < 0.05). The sows of the G4 and L groups had the fewest

Table 3
Comparison of post weaning performance and litter performance at subsequent parity according to farrowing months.

Farrowing month	Post-weaning performance				Litter performance at subsequent parity			
	Weaning-to-first-mating interval, days		Farrowing rate, %		Total number of pigs born		Number of pigs born alive	Number of pigs born dead
	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	Mean ± SEM	Mean ± SEM
2013-July	92	5.1 ± 0.6^{abcd}	139	56.8 ± 4.2^{b}	79	7.7 ± 0.3^{ab}	6.4 ± 0.3^{b}	1.3 ± 0.1
August	69	6.0 ± 1.1^{a}	94	64.9 ± 4.9^{ab}	61	7.6 ± 0.4^{b}	6.8 ± 0.4^{ab}	0.8 ± 0.1
September	56	8.5 ± 3.6^{abcd}	62	85.5 ± 4.5^{a}	53	9.0 ± 0.4^{ab}	8.0 ± 0.4^{ab}	1.0 ± 0.2
October	84	4.4 ± 0.3^{cd}	97	78.4 ± 4.2^{ab}	76	9.2 ± 0.3^{a}	8.0 ± 0.3^{a}	1.2 ± 0.2
November	55	4.4 ± 0.4^{abcd}	77	59.7 ± 5.6^{ab}	46	8.7 ± 0.4^{ab}	7.5 ± 0.3^{ab}	1.2 ± 0.2
December	95	5.4 ± 1.3^{abcd}	132	60.6 ± 4.3^{b}	80	8.2 ± 0.4^{ab}	7.1 ± 0.3^{ab}	1.1 ± 0.2
2014- January*	67	5.9 ± 0.8^{ab}	86	55.8 ± 5.4^{b}	48	8.0 ± 0.4^{ab}	7.4 ± 0.3^{ab}	0.6 ± 0.2
February	103	4.0 ± 0^{cd}	120	75.0 ± 4.0^{ab}	90	8.6 ± 0.3^{ab}	7.7 ± 0.3^{ab}	1.0 ± 0.1
March	68	4.1 ± 0.1^{d}	85	71.8 ± 4.9^{ab}	61	7.8 ± 0.3^{b}	6.9 ± 0.3^{ab}	0.9 ± 0.2
April	60	4.9 ± 0.6^{abc}	73	71.2 ± 5.3^{ab}	52	8.0 ± 0.4^{ab}	7.0 ± 0.4^{ab}	1.0 ± 0.2
May	71	4.0 ± 0.1^{bcd}	93	65.6 ± 5.0^{ab}	61	8.6 ± 0.3^{ab}	7.6 ± 0.3^{ab}	1.0 ± 0.2
June	54	4.1 ± 0.1^{abcd}	70	62.9 ± 5.8^{b}	44	7.6 ± 0.5^{b}	7.0 ± 0.4^{ab}	0.6 ± 0.2
July	98	4.0 ± 0.1^{cd}	130	63.1 ± 4.2^{b}	82	8.1 ± 0.4^{ab}	7.0 ± 0.3^{ab}	1.1 ± 0.2

[a,b,c,d]Values without the same superscript letters within a column differ ($P < 0.05$).
[*]Porcine epidemic diarrhea outbreak observed this month.

piglets weaned (4.7 ± 0.4 − G4 sows, 4.0 ± 0.3 − L sows; $P < 0.05$) and the greatest pre-weaning mortality (34.2 ± 4.8% − G4 sows, 39.7 ± 4.1% − L sows; $P < 0.05$). There was no difference among the sows of the G1, G2, G3, and uninfected groups for number of piglets weaned and pre-weaning mortality rate. The piglets from the sows of the G4 group had the least adjusted 21-day litter weights ($P < 0.05$). For post-weaning performance, there were differences among the sow groups for farrowing rate ($P < 0.05$). The sows of the G4 and W groups had lesser farrowing rates than the uninfected sows. The sows of the G4 group had numerically longer weaning-to-first-mating intervals than the sows of the other groups. For pig litter performance at subsequent parities, total pigs born differed between the sows in the G2 and uninfected groups ($P < 0.05$). The sows of the G4, L, and W groups gave birth to similar total numbers of pigs and similar numbers of live pigs as the uninfected sows exposed to PED virus.

There was a two-way interaction between the sow groups and parity for pigs born alive, number of piglets weaned, pre-weaning pig mortality, and adjusted 21-day litter weights. In each sow group, the effects of parity were similar to the main effects.

4. Discussion

In the present study, the impact of a PED outbreak on both herd and individual sow productivity was evaluated. The PED outbreak decreased herd productivity as a result of greater pre-weaning mortality. The impact of PED on individual sow productivity, however, differed depending on the stage of production in which the sows were exposed to PED virus. These findings indicate that it is important to investigate the productivity of sows based on when they were infected with PED to accurately assess the impact of a PED outbreak on their productivity.

The number of pigs born alive to the Kagoshima Berkshire sows in the present study was similar to the number of pigs born alive to Berkshire pigs in the United Kingdom (McMullen, 2006). This is an interesting finding because the Kagoshima Berkshire pigs originated from Berkshires in the United Kingdom. The productivity of the sows in the present study was similar to that in a previous study that investigated the productivity of Berkshire sows in Japan. In the present study, pigs born alive were 7.8 compared with 8.2 pigs or 8.4 pigs in previous studies (Matsumoto and Koketsu, 2003; Sasaki et al., 2014) and farrowing rate was 77.3% in the present study compared with 82.0% in a previous study (Sasaki et al., 2014).

When compared with the entire herd from which the animal data in the present study were analyzed, results of the present study indicate that the sows that farrowed in December 2013 (1 month before the PED outbreak) and January 2014 (month of the PED outbreak) had the least number of piglets weaned, and a greater pre-weaning mortality than the sows that farrowed in the other months, because they farrowed when the epidemic was most prevalent. In the present study, 5.4 ± 0.2 pigs were weaned in December and 4.6 ± 0.4 pigs were weaned in January, and the pre-weaning mortality rates were 20.1 ± 2.7% and 34.3 ± 4.7%, respectively. The PED infection, therefore, resulted in greater mortality of piglets, which is consistent with the findings of previous studies (Huang et al., 2013; Alvarez et al., 2015; Yamane et al., 2016; Sasaki et al., 2017).

In contrast, in individual sows, the number of piglets weaned and the pre-weaning mortality rate differed with the stage of production in which the sow was exposed to PED virus. The G4 and L sows had the fewest piglets weaned and the greatest pre-weaning mortality rate: 2.5 fewer piglets weaned for the sows of the G4 group and 3.3 fewer piglets weaned for the sows of the L group, and increases in pre-weaning mortality to 27.4% for G4 and 34.0% for sows of the L group compared with the sows of the uninfected group. The fewer number of piglets weaned and the increase in pre-weaning mortality could be attributable to the lack of antibodies against PED virus in the colostrum of the sows in the G4 and L groups. A reduction of number in the piglets weaned and an increase in pre-weaning mortality reduces the efficiency of pork production, causing economic losses. In particular, a reduction in

Table 4
Comparison of reproductive performance according to sow group[1].

	Uninfected group		G1		G2		G3		G4		Lactating		Weaning	
	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM	n	Mean ± SEM
Litter performance														
Total number of pigs born	949	8.8 ± 0.1ab	53	8.6 ± 0.3ab	103	9.3 ± 0.2a	67	8.8 ± 0.3a	67	7.9 ± 0.3b	.	.	.	.
Number of pigs born alive	949	7.8 ± 0.1a	53	7.6 ± 0.3ab	103	8.1 ± 0.2a	67	7.7 ± 0.3a	67	6.7 ± 0.3b	.	.	.	.
Number of pigs born dead	949	1.0 ± 0.1	53	1.0 ± 0.1	103	1.1 ± 0.1	67	1.1 ± 0.2	67	1.2 ± 0.2	.	.	.	.
Weaning performance														
Number of pigs weaned	937	7.5 ± 0.1a	53	6.9 ± 0.3a	102	7.8 ± 0.2a	66	7.5 ± 0.3a	66	4.7 ± 0.4b	49	4.0 ± 0.3b	.	.
Pre-weaning mortality, %	937	5.5 ± 0.4b	53	9.9 ± 2.9b	102	6.0 ± 1.4b	66	6.0 ± 1.8b	66	34.2 ± 4.8a	49	39.7 ± 4.1a	.	.
Adjusted 21-day litter weights, kg	933	6.9 ± 0.1a	53	5.8 ± 0.1c	102	6.2 ± 0.1b	66	5.8 ± 0.1c	65	4.9 ± 0.2d	49	6.9 ± 0.1a	.	.
Post-weaning performance														
Weaning-to-first-mating interval, days	915	4.4 ± 0.1	50	5.1 ± 0.7	99	4.1 ± 0.1	65	4.0 ± 0.1	63	5.8 ± 0.9	46	4.4 ± 0.3	51	4.2 ± 0.1
Farrowing rate, %	1136	77.3 ± 1.2a	61	73.8 ± 5.7ab	122	72.1 ± 4.1ab	78	71.8 ± 5.1ab	79	57.0 ± 5.6b	62	62.9 ± 6.2ab	73	60.3 ± 5.8b
Litter performance at subsequent parity														
Total number of pigs born	870	8.9 ± 0.1a	45	8.2 ± 0.4ab	88	7.8 ± 0.3b	56	8.7 ± 0.4ab	45	8.4 ± 0.4ab	38	8.4 ± 0.4ab	43	8.0 ± 0.6ab
Number of pigs born alive	870	7.7 ± 0.1	45	7.1 ± 0.5	88	6.9 ± 0.3	56	7.7 ± 0.4	45	7.7 ± 0.3	38	7.4 ± 0.4	43	6.9 ± 0.5
Number of pigs born dead	870	1.1 ± 0.1	45	1.1 ± 0.2	88	0.9 ± 0.1	56	1.0 ± 0.2	45	0.6 ± 0.2	38	1.0 ± 0.2	43	1.1 ± 0.2

[a,b,c,d]Values without the same superscript letters within a rows differed ($P < 0.05$).

1Sows were categorized classified into six groups based on the period in which they were exposed to porcine epidemic diarrhea virus (9th of January 9, 2014): being exposed during at 0–30 of pregnancy (G1), being exposed during at 31–60 of pregnancy (G2), being exposed during at 61–90 of pregnancy (G3), being exposed during at day 91 days or later of pregnancy (G4), being exposed during lactating (L), and being exposed during post-weaning (W).

piglet numbers of Berkshire breeding resulted in a greater economic loss compared with what occurred in pork production enterprises producing pork from other breeding, because the Berkshire pork is of greater value when marketed because of its excellent quality meat. The retail price of purebred Berkshire pigs is 50% greater than that of typical market weight pigs (LWD; Suzuki et al., 2003).

In contrast to the sows of the G4 and L groups, there was no difference between the G1, G2, G3, and uninfected groups in the numbers of piglets weaned and the pre-weaning mortality rate in the present study. These results suggest that the sows in the G1, G2, and G3 groups acquired immunity against the PED virus through herd immunization. On the farm where the data for the present study was collected, the immunization technique used involved feeding the sows the feces and minced intestines of infected piglets. The piglets delivered from seropositive sows might acquire passive immunity from their mothers (Olanratmanee et al., 2010), reducing their mortality as a result of immune resistance to the PED virus (Song et al., 2007). In addition, previous studies reported that passive lactogenic immunity to PED virus is important for suckling piglet protection due to an immature immune system of the neonatal suckling piglet (Langel et al., 2016), and antibody provided in colostrum and milk protects the piglet in the interval between birth and development of a functional immune system (Poonsuk et al., 2016). Further research into the immunization technique and productivity, however, is required to determine if these findings are relevant to all production settings. Cleaning and sterilization of facilities would also reduce the residual PED virus in the farrowing barn. On the farm where the data for the present study were collected, batch farrowing was used, in which the sows were classified into seven groups (a 3-week system), so there was enough time to ensure a sufficient disinfection regimen.

In addition to weaning performance, no reduction of piglet litter performance was detected among the G1, G2, G3 and uninfected groups. This finding indicates that there was no negative effect on piglet litter performance of sows in the present study. Fewer pigs born alive in the G4 group compared with uninfected sows in the present study could be explained by the period during which inseminations occurred, which was during hot season that reportedly has negative effects on number of pigs born alive (Wegner et al., 2016).

In the present study, a slightly lesser farrowing rate was observed in the sows that farrowed in December 2013 and January 2014 compared with those that farrowed in September 2013 at the herd level, and in the G4, L, and W groups compared with the uninfected sows at the individual sow level. These findings are consistent with a previous study that reported a lesser farrowing rate during the 4-month period after a PED outbreak compared with the same period the previous year (Olanratmanee et al., 2010). The lesser farrowing rates in the G4 and L groups of the present study might be associated with a lesser suckling stimulus and feed intake caused by the fewer piglets weaned. A lesser sucking stimulus could affect the hormonal milieu (Poleze et al., 2006) affecting ovulation rate, which will reduce the farrowing rate. An inadequate nutrient intake during lactation also influences the metabolic state of sows before the final growth of the pre-ovulatory follicles which is an important determinant of subsequent fertility (Poleze et al., 2006). The lesser farrowing rate of sows in the W group could have been associated with an inadequate body condition arising from anorexia and watery diarrhea at the time of mating, which can cause early pregnancy loss (Dial et al., 1992). The effect of the PED outbreak on post-weaning performance was not severe compared with its effect on weaning performance.

In the present study, there was no difference in pigs born alive at the subsequent parity between the sows that farrowed in December 2013 or January 2014 and the other months at the herd level, or among the sows of the G4, L, W, and uninfected groups at the individual level. These results indicate that the PED outbreak had no negative effect on litter performance at subsequent parity both at the herd and individual sow level. These findings may be attributable to the prolonged weaning-to-conception interval arising from the reduced farrowing rate in these sows. A prolonged weaning-to-conception interval reportedly increases piglet litter size (Koketsu and Dial, 1998), and this could provide enough time for severely PED-infected sows to recover their body condition.

In general, the reproductive performance including the number of piglets weaned, pre-weaning mortality, farrowing rate and pigs born alive differed among parities (Koketsu et al., 2006). The lack of an interaction between the sow group and the parity group on productivity in the present study, however, suggests that the effect of the PED outbreak on productivity is independent of the effect of parity on productivity in Berkshire sows.

In conclusion, results of the present study indicate that a PED outbreak reduced the herd productivity of Berkshire sows. The impact of PED on individual sow productivity differed according to the stage of production in which the sows were exposed to PED virus.

Conflict of interest

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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