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Productivity analysis of 70 farrow-to-finish swine farms in Japan from 2013 to 2018

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ABSTRACT. Improving productivity is an urgent issue in the swine industry if it is to compete internationally. However, lack of data about recent productivity transition obstructs stakeholder planning. This study investigated the yearly productivity trends among farrow-to-finish swine farms in Japan using annual productivity data from 2013–2018 obtained for 70 farms in Japan. The productivity parameters analyzed were pigs born alive per litter (PBA), preweaning mortality (PRWM), pigs weaned per litter (PWL), litters per mated female per year (LMFY), pigs weaned per mated female per year (PWMFY), post-weaning mortality (POWM) and marketed pigs per mated female per year (MP). Data were classified into three groups based on the size of the average female inventory and compared among groups. Results presented the mean PBA increased continuously over the 6-year period ($P<0.001$), and the PWL, PWMFY, and MP means began increasing after 2015 ($P<0.001$). These upward trends were particularly remarkable on large farms. The mean PRWM increased sharply in 2014, thus inhibiting the increases in PWL, PWMFY, and MP for the same year. The LMFY and POWM means did not change during the study period. Altogether, productivity in Japan improved markedly during the study period, indicating highly prolific sows were well utilized with suitable breeding techniques among farmers these days. Continued genetic improvement and sow management would aid further development in Japan.

KEYWORDS: benchmarking, farrow-to-finish, porcine epidemic diarrhea, production, swine

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The number of pig farms in Japan decreased from 575,000 to 4,470 between 1988 and 2018 [19], thus reducing the self-sufficiency rate of pork from 77% to 48%. Consequently, total pork importations had to be increased yearly to meet the increasing domestic demand [20]. Under these circumstances, existing producers experienced severe competition from the international market, particularly with Europe and North America. The limited land available for swine farming requires Japanese farmers to increase their productivity per area. Thus, the current productive efficiency on each farm must be properly evaluated [6, 12]. The data recording and analyzing systems used in Japan were PigCHAMP (PigCHAMP, Ames, IA, USA), which is also widely used in the United States, and PigINFO, which has been established through research between the National Institute of Animal Health and the Japan Association of Swine Veterinarians [27]. These systems are used to benchmark swine productivity. Pig productivity has been investigated in different countries. One of the most frequently used parameters is pigs weaned per mated female per year (PWMFY). Koketsu *et al.* [16] found mean PWMFYs of 22.2, 23.4 and 21.7 in the USA, Canada and Japan, respectively, in 2007. Other reports [1, 28] found much higher mean PWMFYs in EU than in Japan (23.0). Denmark, Spain, and the EU reported PWMFYs of 28.1, 24.0, and 24.4, respectively, in 2010. These findings indicated that Japanese producers had the potential to expand their productivity. More recent studies reported mean PWMFYs of 26.8, 33.6 and 27.8 in the USA, Denmark and the EU, respectively, in 2018 [1], thus demonstrating significant improvements in productivity in these countries. However, to our knowledge, limited information is available on the current status and yearly productivity trends for Japanese swine farms [26]. Therefore, we conducted this study to investigate the current status of these productivity trends and examine future directions for the Japanese swine industry.

MATERIALS AND METHODS

Data collection

We used the annual data from PigINFO for this study [27]. The study period was from January 2013 to December 2018. Farms

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with complete data throughout the 6-year study period were selected. Only farrow-to-finish herds were included. Farms that exchanged piglets with other farms were excluded. Farms that used purebred Berkshire pigs, which have low growth performance, were excluded. Seventy farms from 22 prefectures and who were clients of 16 veterinarians were included. Farmers submitted input data to the investigators every 3 months via their consulting veterinarians. Table 1 provides the definitions of all input data. All input data were recorded by the farm owners, their employees, or both. The names of individual farmers have been anonymized to maintain confidentiality. The annual productivity parameters (Table 2) were calculated based on the definitions, referring to Yamane *et al.* [27]. Most sows in this study were either homegrown crossbred Large White and Landrace sows or were purchased from breeding companies. Farm size was determined based on the average female inventory (AFI). The applied AFI for each farm was the mean for the study period. The farm classifications were small (AFI <300, n=23), medium (AFI ≥300 and <600, n=22), and large (AFI ≥600, n=25). Among the study farms, 28 farms were porcine epidemic diarrhea (PED)-positive in 2014, consisting of 5 small, 9 medium and 14 large groups. The PED classification was referred to the definition of Yamane *et al.* [29].

Data analysis

Productivity parameters were subjected to the Shapiro-Wilk test for normality and Bartlett's test for equal variances. Log-transformation was performed for post-weaning mortality (POWM) to adjust for the normal distribution. One-way analysis of variance (ANOVA) with repeated measures was used to analyze the means of the parameters for different years. If significant differences were detected, Bonferroni's test was applied for multiple comparisons among years. If the parameter means were not normally distributed, Friedman's and Wilcoxon's signed rank tests were used to compare the means for the different years. To analyze the means of the farm sizes within the same year, ANOVA was used if the data were normally distributed; the Kruskal-Wallis test was used if they were not. $P<0.05$ was considered statistically significant. All statistical analyses were performed with EZR (Saitama Medical Centre, Jichi Medical University, Saitama, Japan), a graphical user interface for R (version 2.13.0; R Foundation for Statistical Computing, Vienna, Austria) [9].

RESULTS

General

The mean AFI of the population was 903.6 (Standard deviation: 1,265.10, range: 76–7,088), with a total of 63,254 females, accounting for approximately 7.68% of the 2018 Japanese sow population [19]. The mean and sum of AFI in each year of farm-size are summarized in Table 3.

Productivity trends between 2013 and 2018

Figure 1 shows the means of the productivity parameters per year. Many of the parameters, including the means of the pigs born alive per litter (PBA; Fig. 1A), pigs weaned per litter (PWL; Fig. 1C), PWMFY (Fig. 1E), and marketed pigs per mated

Table 1. Definitions of the input data

Input data	Definition
Total number of marketed pigs (TNMP)*	Total number of fattening pigs sold (sows and boars sold were excluded)
Total number of pigs born alive (TNPB)	Total number of pigs born alive at farrowing
Total number of pigs weaned (TNPW)	Total number of pigs weaned
Average female inventory (AFI)	Includes sows and mated gilts but not maiden gilts (numbers were counted monthly; AFI was defined as the mean of the 12-month values)
Total number of litters (TNL)	Total number of litters
Total number of deaths at postweaning stage (TND)	Total number of deaths and euthanized animals at the growing stage

*Data were collected mainly through carcass reports from slaughterhouses. If a farm replaced sows with farm-born pigs, the data were adjusted, and the farm-born pigs were regarded as being sold to the slaughterhouse.

Table 2. Definitions of productivity parameters

Productivity parameter	Definition
Pigs born alive per litter	TNPB/TNL
Preweaning mortality, %	1-TNPW/TNPB
Pigs weaned per litter	TNPW/TNL
Litters per mated female per year	TNL/AFI
Pigs weaned per mated female per year	TNPW/AFI
Post-weaning mortality, %	TND/TNPW
Marketed pigs per mated female per year	TNMP/AFI

TNMP=Total number of marketed pigs, TNPB=Total number of pigs born alive, TNPW=Total number of pigs weaned, AFI=Average female inventory, TNL=Total number of litters, TND=Total number of deaths at postweaning stage.

Table 3. Mean and sum of average female inventory (AFI) in each year of farm-size

Index	Farm size	n	Year						Period average
			2013	2014	2015	2016	2017	2018	
Mean of AFI	All	70	879.5	894.4	901.7	897.8	918.1	930.4	903.6
	Small	23	187.4	186.5	180.5	179.9	184.0	186.2	184.1
	Medium	22	387.4	388.2	400.3	407.5	424.5	431.8	406.6
	Large	25	1,949.3	1,991.0	2,006.4	1,989.7	2,027.7	2,053.8	2,003.0
Sum of AFI	All	70	61,566	62,607	63,118	62,845	64,264	65,126	63,254
	Small	23	4,310	42,90	4,152	4,138	4,232	4,283	4,234
	Medium	22	8,522	8,540	8,806	8,965	9,339	9,498	8,945
	Large	25	48,734	49,776	50,160	49,742	50,693	51,345	50,075

female per year (MP; Fig. 1G) increased during the study period (PBA, PWL, PWMFY: $P<0.001$; MP: $P=0.03$). The mean PBA increased continuously throughout the study period, while the PWL, PWMFY, and MP means increased only after 2015. The mean preweaning mortality (PRWM; Fig. 1B) did not differ throughout the study period ($P>0.05$) except for a rapid increase in 2014 ($P=0.02$). The mean litters per mated female per year (LMFY; Fig. 1D) remained mostly constant with minimal change. Similarly, the mean post-weaning mortality (POWM; Fig. 1F) stayed constant except in 2014, where it increased from the previous year ($P>0.05$). Supplementary Table 1 summarizes these values.

Trends in productivity parameters classified by farm size

Figure 2 compares the means of the investigated parameters classified by farms size. For PBA, PWL, PWMFY, and MP, large farms had higher means than did medium and small farms for all years. The annual rates of increase for these parameters were also highest on the large farms throughout the study period (Fig. 2A, 2C, 2E and 2G). The small farms had the lowest mean PRWM among the groups, although no significant differences were observed (Fig. 2B). Between 2013 and 2014, the PRWM of the medium and large farms increased more than that of the small farms. The LMFY means differed between the small and large farms ($P=0.044$) in some years (Fig. 2D). The POWM mean was lowest on the small farms throughout the study period, although no statistical differences were observed ($P>0.05$; Fig. 2F). Supplementary Table 2 provides these details.

DISCUSSION

The PBA, PWL, PWMFY, and MP improved markedly during the 6-year study period, mainly owing to the increased PBA. This improved the PWL and MP, which are located in the upper part of the PBA in the production tree. The mean PBA increased by 0.22 annually, from 11.3 in 2013 to 12.4 in 2018. A previous study conducted in Japan reported a PBA of 10.3 in 2003 [15]. Hence, the average annual increase was 0.1 from 2003 to 2013. The rate of increase in the PBA in this study doubled compared with that of the previous decade (2003–2013), although different study designs are difficult to compare. Sasaki *et al.* [26] found that the mean PBA increased by 0.20 annually from 11.1 in 2014 to 11.9 in 2018, which was similar to our results. The PBA was higher in the current study because our samples were taken from farms using consulting veterinarians and PigINFO benchmarking services, which attributed to the selection bias for the better performance. Similar studies in other countries found that the mean PBA increased by 0.24 annually from 2013 to 2018 in the UK [2] and by 0.27 from 2012 to 2018 in Catalonia, Spain [5], demonstrating a similar increasing trend as that in the present study. The rapid increase in PBA during the study period was likely due to the introduction of highly prolific sows from the EU, which began around 2008 [28]. Previous studies in Japan [10, 26] found that farms that introduced highly prolific sows from foreign companies had higher PBAs than did farms from domestic companies. A study from the Netherlands reported that the PWMFY increased by approximately 35% in the 20 years prior to 2009 owing to genetic selection and management techniques [11]. Similarly, in France, the average PBA increased by 0.2 annually from 1996 to 2007 using a strategy of hyperprolificacy [22]. These findings suggest that introducing sows that can produce more litters is essential for improving productivity on swine farms. The extensive introduction of highly prolific sows from EU countries was started by a highly motivated farmers' group [8]. After trial use of highly prolific sows demonstrated the advantages to productivity and management, highly prolific sows began to be mass produced on breeding farms in Japan. Thereafter, more farms began adopting these sows. As per the Animal Quarantine Service of the Ministry of Agriculture, Forestry and Fisheries (MAFF), 122 breeding sows were imported from Denmark from 2007–2012, and this number increased to 236 from 2013–2015 and to 591 from 2016–2018 [21]. Also, Japanese government conducted some policies supporting farmers economically to install advanced technology. Hence, the rapid spread of highly prolific sows during the study period resulted in an increased PBA in Japan.

The biggest reason for the differences between farm sizes in parameters such as PBA was that the large farms adopted highly prolific sows much earlier than did the medium and small farms. Large farms with abundant capital could more easily purchase highly prolific sows; thus, large farms adopted these sows first, and the small farms adopted them later. The same trends were observed in the United States and Poland, where larger farms tended to have more pigs per litter [6, 14]. This was attributed to larger farms having more capital investments, which were advantageous for introducing new technology and automated equipment and to farm owners being more motivated to make improvements.

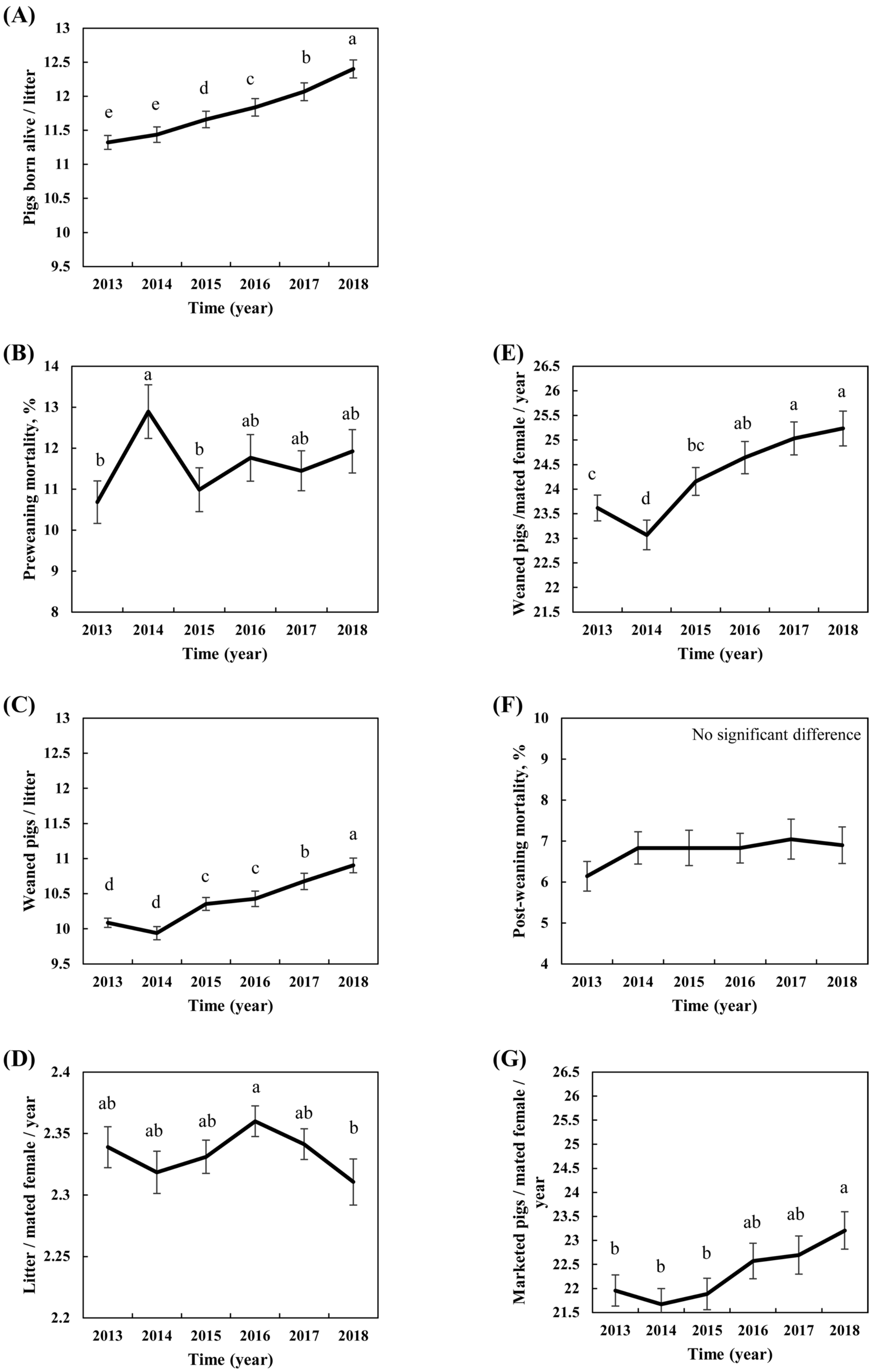

Fig. 1. Parameter trends. (**A**): Pigs born alive per litter, (**B**): Preweaning mortality, (**C**): Pigs weaned per litter, (**D**): Litters per mated female per year, (**E**): Pigs weaned per mated female per year, (**F**): Post-weaning mortality, (**G**): Marketed pigs per mated female per year. Each graph shows the overall means (standard error) with year. Data were provided by 70 farrow-to-finish farms in Japan via their consulting veterinarians; these data account for 7.68% of the sows in Japan. [a-e] Values with different superscript letters indicate significant differences (P<0.05) in each figure.

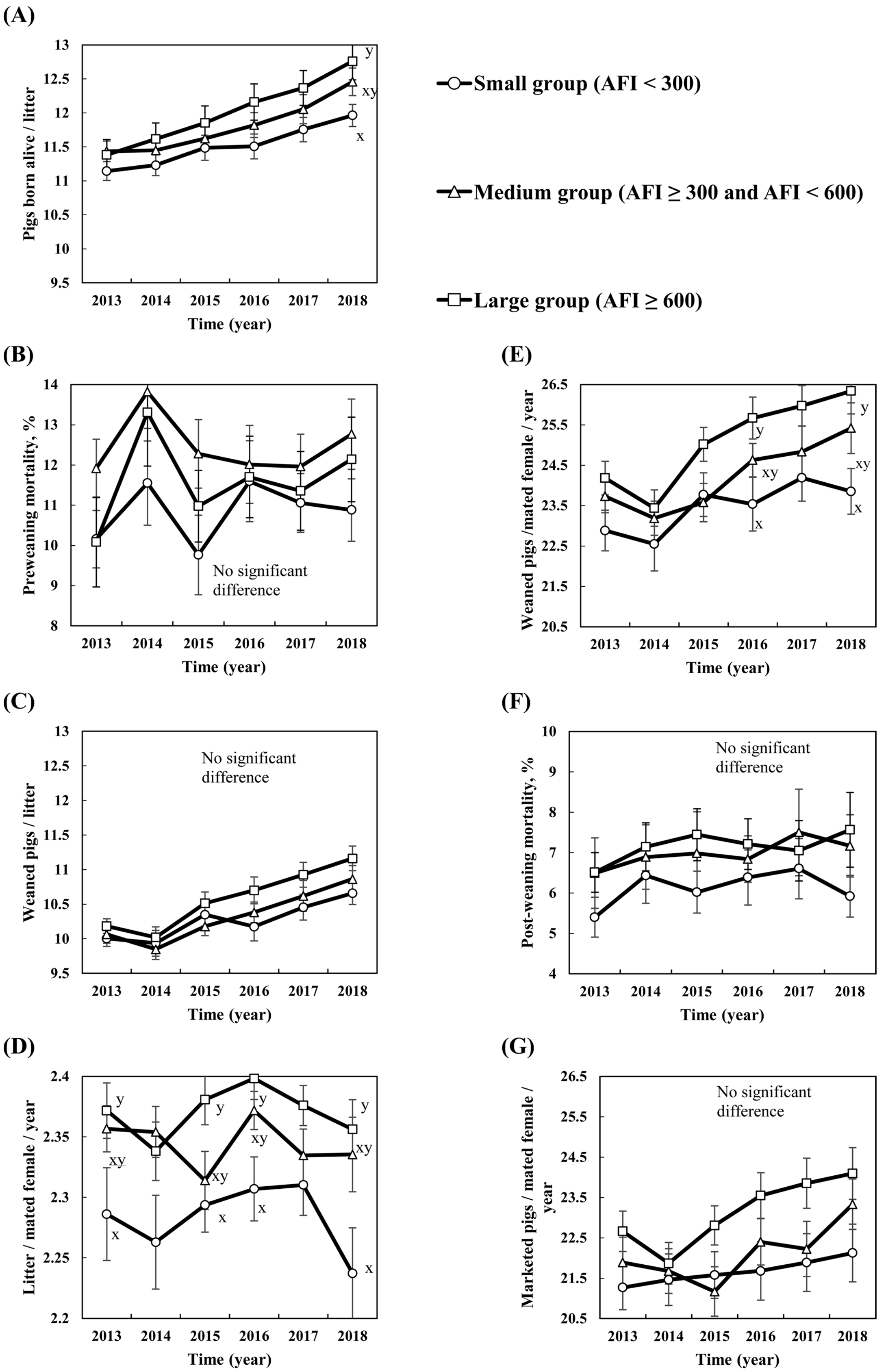

Fig. 2. Farm-size classification trends. (**A**): Pigs born alive per litter, (**B**): Preweaning mortality, (**C**): Pigs weaned per litter, (**D**): Litters per mated female per year, (**E**): Pigs weaned per mated female per year, (**F**): Post-weaning mortality, (**G**): Marketed pigs per mated female per year, each graph shows the means of the small, medium and large farms (standard error) with the year. Data were from 23 large, 22 medium and 25 small farms. $^{x-y}$ Values with different superscript letters indicate significant differences (P<0.05) within a group in each figure. AFI=average female inventory.

In this study, between 2013 and 2015, the mean PBA increased continuously, but the mean PWL, PWMFY, and MP did not. This was because the increased PRWM in 2014 resulted in poor PWL performance. The PRWM increased sharply in 2014, likely because of the PED outbreaks in Japan between 2013 and 2014 [29]. During the PED outbreaks, many suckling pigs died, resulting in an increased PRWM [24]. Additionally, the increased PRWM in 2014 was higher on large farms (Fig. 2B) than on medium and small farms. Previous studies reported similar results, in which farms with more sows had a higher risk of PED outbreaks [25]. Cross-infection by shipping trucks from slaughterhouses was suspected in the US [18]. Therefore, PED infections in Japan may have occurred more frequently on larger farms because of the higher frequencies of vehicles entering and leaving farms and shipments to slaughterhouses. However, the mean PRWM decreased after 2015 after PED outbreaks were adequately controlled. Consequently, improved PWL was first accomplished after 2015 owing to the reduced PRWM because the PBA improved continuously during study period. A previous report using the same data collection system demonstrated a positive correlation between PBA and PRWM, indicating that increased PBA due to the introduction of highly prolific sows may not contribute to a higher PWL [28]. In other word, high proportion of piglets borne from these sows were not weaned properly. Thus, even if highly prolific sow introductions increased the PBA, they also increased the mortality rates among suckling pigs owing to poor rearing techniques. This same trend was also reported in other countries [4]. Muns *et al*. [23] found that piglets, sows and the environment can each affect the PRWM. In Japan, producers have become actively engaged in learning breeding techniques during the suckling phase and have adopted them more widely. Consequently, PRWM has been moderately maintained, while the PBA increased.

The mean LMFY remained constant throughout the study period. This contributed to the positive correlation between PWL and PWMFY (Fig. 1C and 1E). Previous studies [15, 27] reported that the average LMFY in Japan was 2.20 in 2003 and 2.33 in 2010, then stayed constant after 2010. Large farms had significantly higher LMFY than small farms (Fig. 2D). Previous studies [6] also reported that farm size was positively associated with LMFY. This could be another reason that higher PWMFY and MP were observed on larger farms. One reason for the difference in LMFYs between farm sizes may be that larger farms could adopt more systematic reproductive management than could smaller farms. In other words, scaling up businesses and investments in system expansions likely improved the work efficiency, including using techniques such as synchronized ovulation and estrus, farrowing, and feeding management during lactation [17].

The mean POWM remained nearly constant during the study period (Fig. 1F). Thus, the mean PWMFY and MP were positively correlated. A previous study reported that the POWM in Japan was 6.38% in 2007 [16], thus denoting that the POWM was controlled at the same level as in this study. However, the POWM increased in 2014, likely owing to the PED outbreaks. PED generally increased the mortality of suckling pigs and negatively affected post-weaning piglets [3]. The veterinarians who collaborated on this study also confirmed piglet deaths in the post-weaning stage due to PED. Smaller farms had lower POWM in this study. Regarding the relationship between farm size and infections, pathogens may be better able to enter farms with larger herds, leading to a greater risk of infection transmission among herds on larger farms [7]. Thus, farm size may affect the POWM. Smaller farms have fewer piglets as their sow capacity is limited; hence, they may be better able to raise pigs more carefully with considerate clinical observation and treatment. Conversely, large farms are more prone to infections; thus, they may have to slaughter sick animals to maximize farm efficiency. Another possibility is that small-scale farmers may have more time to observe the clinical conditions of growing pigs and be better able to detect sick animals, resulting in prompt treatment. Employees of large farms can devote less time to individual observation and treatment of fattening pigs [13]. Thus, detection of sick pigs may be delayed, leading to an increased POWM.

In summary, productivity in the Japanese swine industry has improved significantly in recent years owing to high prolific sow utilization with appropriate breeding techniques. One suggestion for improvement is for low-performance farms to adopt highly prolific sows to increase the production efficiency per sow. However, implementation of suitable breeding techniques will be challenging on these farms. This will require more aggressive cross-country communication among producers, technicians, and researchers. Additionally, feed conversion ratio (FCR) improvement will become more important after productivity. Future works should cover the transition of FCR and the potential challenges.

Lastly, the authors acknowledge that the dataset did not represent all farmers in Japan. The sample used in this study was the population working with specialized consultants, which may deviate from other Japanese populations. Additionally, differences in farm management systems and calculation methods make it difficult to make accurate comparisons between countries. However, the trends revealed in this study will help those in the swine industry see how the industry has improved and where potential opportunities exist for enhancement.

CONFLICT OF INTEREST. Declarations of interest: none

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REFERENCES

1. Agriculture and Horticulture Development Board (AHDB). Pig cost of production in selected countries. https://ahdb.org.uk/cost-of-production-in-selected-countries [accessed on May 1, 2021].
2. AHDB Pork: cost of production and performance. https://ahdb.org.uk/pork-costings-and-herd-performance-2 [accessed on May 1, 2021].
3. Alvarez, J., Sarradell, J., Morrison, R. and Perez, A. 2015. Impact of porcine epidemic diarrhea on performance of growing pigs. *PLoS One* **10**:

e0120532. [Medline] [CrossRef]
4. Boulot, S., Quesnel, H. and Quiniou, N. 2008. Management of high prolificacy in French herds: can we alleviate side effects on piglet survival. *Proc. Adv. Pork Prod. Canada* **19**: 213–220.
5. d'Agricultura, D. Ramaderia, Pesca i Alimentació, 2018. Informe anual porcí. any 2018 (Swine Annual Report 2018). http://agricultura.gencat.cat/ca/departament/estadistiques/ramaderia/sectors-ramaders/porci/informes/anuals [accessed on May 1, 2021].
6. Dors, A., Czyzewska, E., Pomorska-Mól, M., Kolacz, R. and Pejsak, Z. 2013. Effect of various husbandry conditions on the production parameters of swine herds in Poland. *Pol. J. Vet. Sci.* **16**: 707–713. [Medline] [CrossRef]
7. Gardner, I. A., Willeberg, P. and Mousing, J. 2002. Empirical and theoretical evidence for herd size as a risk factor for swine diseases. *Anim. Health Res. Rev.* **3**: 43–55. [Medline] [CrossRef]
8. Japan Swine Farm Business Cooperation. 2013. Japan swine farm business cooperation started full-scale supply of high fertility sow to members. *Pig J.* **13**: 54–57.
9. Kanda, Y. 2013. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. *Bone Marrow Transplant.* **48**: 452–458. [Medline] [CrossRef]
10. Kazuno, Y., Watanabe, Y., Ishikawa, H. and Ishizeki, S. 2017. Trends in productivity performance of farms with high fertility sows based on benchmarking. *J. Japanese Assoc. Swine Vet.* **19**: 44–46.
11. Kemp, B., Soede, N. M. and den Hartog, L. A. 2011. Pig production in the Netherlands: analyses and trends. *Proc. Manitoba Swine Semin, Canada* 161–167.
12. Knauer, M. T. and Hostetler, C. E. 2013. US swine industry productivity analysis, 2005 to 2010. *J. Swine Health Prod.* **21**: 248–252.
13. Knox, R. V., Rodriguez Zas, S. L., Sloter, N. L., McNamara, K. A., Gall, T. J., Levis, D. G., Safranski, T. J. and Singleton, W. L. 2013. An analysis of survey data by size of the breeding herd for the reproductive management practices of North American sow farms. *J. Anim. Sci.* **91**: 433–445. [Medline] [CrossRef]
14. Knox, R. V. 2014. Impact of swine reproductive technologies on pig and global food production. pp. 131–160. In: Current and Future Reproductive Technologies and World Food Production (Lamb, G. Cliff and Nicolas, D. L. eds.), Springer New York, New York.
15. Koketsu, Y. 2007. Technical note: High-performing swine herds improved their reproductive performance differently from ordinary herds for five years. *J. Anim. Sci.* **85**: 3110–3115. [Medline] [CrossRef]
16. Koketsu, Y., Sasaki, Y., Ichikawa, H. and Kaneko, M. 2010. Benchmarking in animal agriculture : concepts and applications. *J. Vet. Epidemiol.* **14**: 105–117. [CrossRef]
17. Kraeling, R. R. and Webel, S. K. 2015. Current strategies for reproductive management of gilts and sows in North America. *J. Anim. Sci. Biotechnol.* **6**: 3. [Medline] [CrossRef]
18. Lowe, J., Gauger, P., Harmon, K., Zhang, J., Connor, J., Yeske, P., Loula, T., Levis, I., Dufresne, L. and Main, R. 2014. Role of transportation in spread of porcine epidemic diarrhea virus infection, United States. *Emerg. Infect. Dis.* **20**: 872–874. [Medline] [CrossRef]
19. MAFF. 2019. Livestock statistics survey 2018. https://www.e-stat.go.jp/dbview?sid=0003274496 [accessed on May 1, 2021].
20. MAFF. 2020. Food balance sheet 2018. https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00500300&tstat=000001017950&cycle=8&year=20181&month=0&tclass1=000001032890&tclass2=000001138503 [accessed on May 1, 2021].
21. MAFF. 2020. Animal quarantine annual report. https://www.maff.go.jp/aqs/tokei/toukeinen.html [accessed on May 1, 2021].
22. Martineau, G.P. and Badouard, B. 2009. Managing highly prolific sows. *Proc. London Swine Conf*, *Canada* 14–30.
23. Muns, R., Nuntapaitoon, M. and Tummaruk, P. 2016. Non-infectious causes of pre-weaning mortality in piglets. *Livest. Sci.* **184**: 46–57. [CrossRef]
24. OIE-World Organisation for Animal Health. 2014. OIE technical factsheet on infection with porcine epidemic diarrhoea virus. 1–4.
25. Sasaki, Y., Alvarez, J., Sekiguchi, S., Sueyoshi, M., Otake, S. and Perez, A. 2016. Epidemiological factors associated to spread of porcine epidemic diarrhea in Japan. *Prev. Vet. Med.* **123**: 161–167. [Medline] [CrossRef]
26. Sasaki, Y., Kawabata, T., Nakatake, S., Kohigashi, T., Toya, R., Uemura, R. and Sueyoshi, M. 2020. Assessment of reproductive and growth performance of pigs on commercial swine farms in southern Kyushu, Japan. *Anim. Sci. J.* **91**: e13492. [Medline] [CrossRef]
27. Yamane, I., Ishizeki, S. and Yamazaki, H. 2013. A survey on profitability and productivity variables and their component analysis in farrow-to-finish swine farms in Japan. *J. Vet. Epidemiol.* **17**: 44–51. [CrossRef]
28. Yamane, I., Ishizeki, S. and Yamazaki, H. 2014. Parameters contributing to improved reproductive performance at farrow-to-finish swine farms in Japan. *Nippon Juishikai Zasshi* **67**: 177–182.
29. Yamane, I., Yamazaki, H., Ishizeki, S., Watanabe, Y., Okumura, H., Okubo, M., Kure, K., Hayakawa, Y., Furukawa, M., Ooi, M., Mizukami, Y. and Ito, M. 2016. Impact of a porcine epidemic diarrhea outbreak on swine productivity in Japan: a retrospective cohort study. *J. Vet. Med. Sci.* **78**: 1385–1389. [Medline] [CrossRef]