Quantifiable and feasible estrus detection using the ultrasonic sensor array and digital infrared thermography

Ji Hwan Lee[1#], Dong Hoon Lee[2#], Won Yun[1], Han Jin Oh[1], Ji Seon An[1], Young Gwang Kim[1], Gok Mi Kim[3] and Jin Ho Cho[1*]

[1]Division of Food and Animal Science, Chungbuk National University, Cheongju 28644, Korea
[2]Department of Biosystems Engineering, Chungbuk National University, Cheongju 28644, Korea
[3]Department of Beauty Art, Yonam College, Cheonan 31005, Korea

Abstract

Detection of estrus is an essential factor as a method of successful breeding in the sow. As increasing the adaption of the information and communication technology (ICT) into swine industry, this study focuses on a possibility and quantification of standing time, vulva and body temperature as methods of estrus detection, comparing each time and temperature in estrus and non-estrus period, and analyzing each success rate of new and existing methods. Ultrasonic sensor array and digital infrared thermography were used to evaluate whether new methods such as standing time and number, and vulva and skin temperature can be replaced, or these methods can be quantifiable in estrus period. Ultrasonic sensor array was installed beside the stall and digital infrared thermography was placed in the rear of sow to collect the dates of sow in estrus and non-estrus period. This study showed total standing time, number and number over 10 minutes, and vulva temperature of the sow in estrus period were increased ($p < 0.05$) compared with those of sow in non-estrus period, respectively. Detection of estrus using standing time and vulva temperature tended ($p = 0.06$) to increase the success rate when artificial insemination (AI) was performed. In conclusion, standing time and vulva temperature increased when estrus happened. Success rate of AI of sow using these methods showed an increasing trend. Therefore, existing method using the naked eye can be replaced to new method such as vulvar temperature and standing time when detecting the estrus.

Keywords: Ultrasonic sensor array, Digital infrared thermography, Standing time, Vulvar temperature, Estrus

Background

Information and Communication Technology (ICT) is a valuable tool in decreasing management costs and early identification of problems at farms [1]. In the case of Korea, the introduction of ICT was increased on the pig industry in recent years. ICT technology of Korea was applied in the basic areas such as temperature and humidity change, and fire detection in the farm, the real-time monitoring system in the feed bin in the swine industry [2]. On the other hands, the development and application of ICT were far behind compared to other countries. Recently, the number of holding female pigs per farm continues to increase due to continuous scale-up, meat consumption, and specialization while a total of farms has decreased. Thus, precise detection of estrus is one of the

critical factors for the farm's economy, but it requires a lot of labor and time consuming of the production system [3,4]. There is various detecting method of estrus. First of all, detection using boar is widely investigated by many previous researchers [5–7]. Especially, Bressers et al. [5] and Korthals. [8] reported that 75%–96% estrus cases were classified. Secondly, the back-pressure test (BPT) is to investigate the standing response sow when the back was pressed [9]. Thirdly, physical activity, vulva swelling and redding is a visible sign of the upcoming estrus in sow [10,11]. These methods are the most widely used up to now, but the method spends a lot of money to maintain boars such as feed cost and space for the rearing compared with other methods. Also, detection using physical, physiological traits and BPT are not objective because people judge them subjectively, consequently the ordinary people cannot clearly distinguish the onset of estrus compared with technicians. Therefore, this study was conducted to investigate the feasibility and quantification of standing time, vulva and body temperature (BT) as methods of estrus detection using ICT technology.

Materials and Methods

The Animal Care and Use Committee of Chungbuk National University approved all the experimental protocols used in the current study.

Animals and housing
A total of eighty sows were used in an experimental period between March 2018 and February 2019 in Chungbuk National University research farm. Yorkshire × Landrace sows were of good health at the beginning of the experiment. They were housed in temperature and humidity controlled environment. Sows were individually fed two times and had ad libitum access to water.

Experiment 1
The estrus cycle of sows was synchronized using a progesterone-altrenogest solution (Regumate®; Roussel-Uclaf, París, France). They administered at a dosage of 5 mL to each sow daily for 18 days. Estrus synchronization\was performed in March 2018 and July 2018.

Ultrasonic sensor array
Ultrasonic sensor (GP2Y0A02YK0F, Sharp Inc, Japan) was connected to a micro-controller (NUCLEO F446, ST-LINK, Japan), so that the standing time of sow could be measured. Also, a small LCD module was built in the micro-controller to show the measurement content on the screen (Fig. 1A). Also, we used the C language to create the program in micro-controller. Ultrasonic sensor was installed on the front-end side according to height of the stall at 30 cm intervals (Fig. 1B). Standing time and number were measured into standing sensor in estrus synchronized sow, and collected 4 times in the experiment period. Data represented total standing time and total standing number of 24 hours and sanding number more than 10 minute in estrus and non-estrus period, respectively. Leg lesion of the sows were examined at the beginning and the ending experiment period. Leg lesion score were assigned when sows were in estrus and non-estrus period, resulting in a rating of 0 (no lesion), 1 (slight scratch) or 2 (erosion). The same individual recorded all scores.

Signal processing
Each ultrasonic sensor produces an analog voltage signal from 0.0 V from 3.3 V corresponding to distance from a sow. The voltage signal indicates distance from 0.2 to 1.5 m through calibration curve provided by manufacturer. The microprocessor's analog to digital conversion (ADC) function provides 12 bit of resolution and continuous measurement with 100 ns of conversion time in stable conversion, which could lead that the minimum distance resolution is 0.0003 m resulted from 1.3 m of physical property divided by 4,096 steps of signal decomposition. A fixed sampling frequency was determined 100 Hz (100 measurements in one second) to compare the periodic characteristics of sow's movement. Data logging software was developed by a native C language and an executable application was compiled by gcc (GNU, version 5.4.0) in Linux operating system. The converted signal was recorded in a
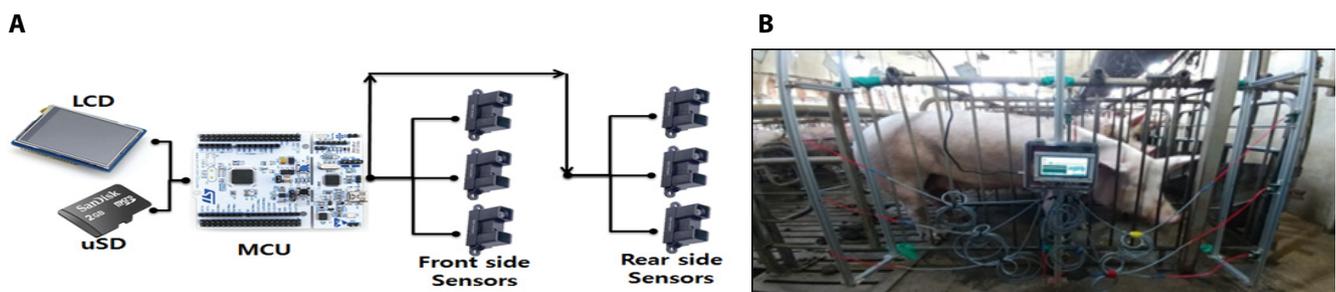

Fig. 1. (A) Standing sensor connecting diagram image. (B) Installed standing sensor image.
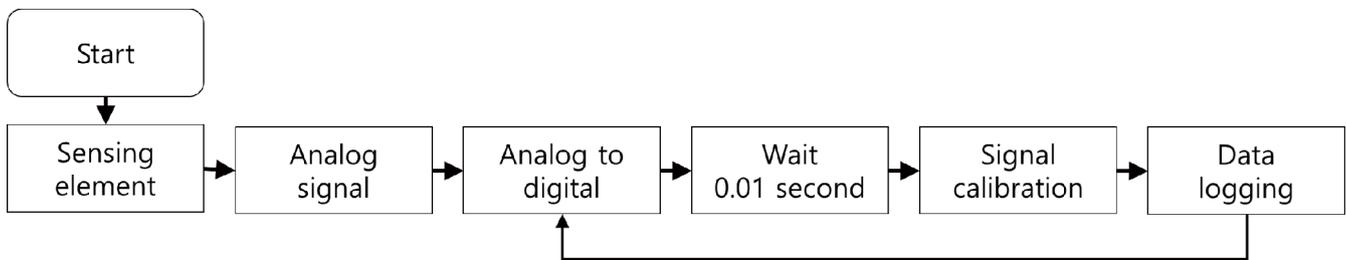
Fig. 2. Float chart of signal processing to log the distance between the sensors and sow's side surface in 100 Hz of measurement of frequency.
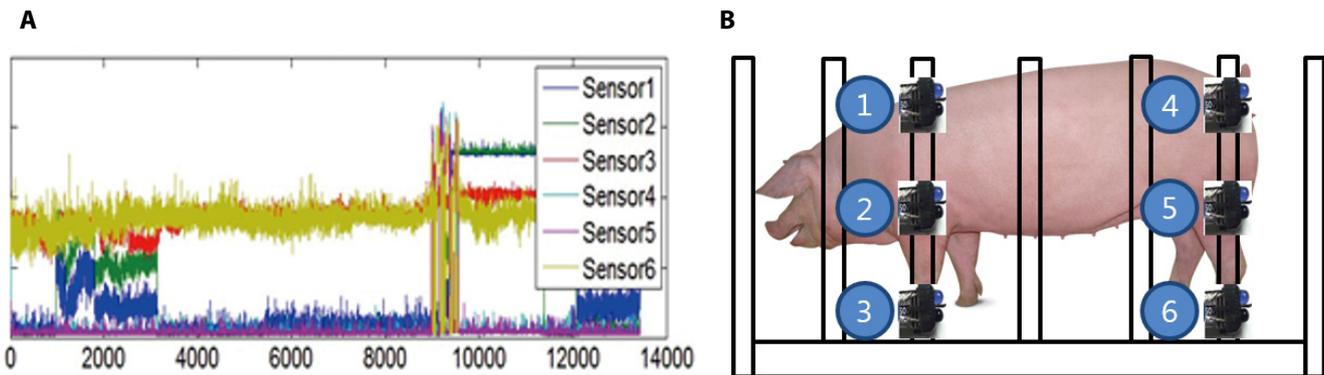

Fig. 3. (A) The horizontal axis shows the seconds of the day. (B) The position of sensor is as follows.

mass storage device with a common-separated values (CVS) format that measured date, time and distance values from sensor 1 to 6 in sequence. Total flow of signal processing is illustrated by Fig. 2.

Data analysis

Based on the assumption that 100 Hz of measurement frequency is accurately performed, the dimension of logged data forms 8 by n (multiplied by 100 to elapsed seconds during measurement) matrix. Each distance value per every 0.01 second recorded from third column in the matrix was post processed to denoise exceptional fluctuations due to systematic error by calculating the mean of adjacent values. The recorded data was post-processed and visualized using MatlabTM (Mathworks, CA, USA). Data visualization was performed using a built-in plot function in the software. The plot of individual distance data from each sensor's position was concurrently rendered for comparison between control groups in terms with variation and frequency in time domain with resolution of 0.01 second like Fig. 3A. The position of sensors is as illustrated by Fig. 3B. Thereafter, standing time, standing number and standing number over 10 minute were counted using this figure.
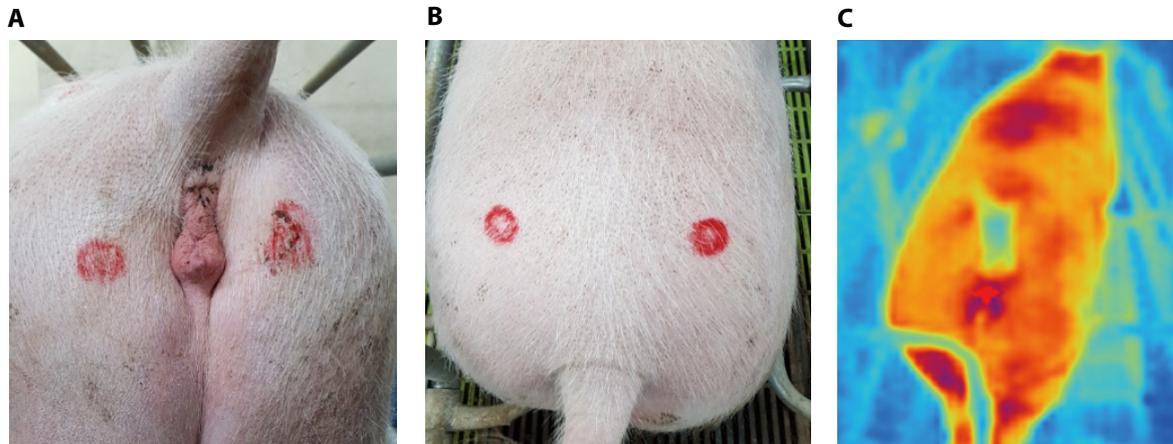
Digital infrared thermal thermography

Vulvar temperature (VT) and BT were measured in estrus synchronized sows using the infrared thermography camera in estrus and non-estrus period at experiment 1 period. Each sow was monitored from a fixed distance of 1.9 m. The monitoring focused

on the sow's vulvar region or body. The camera focused on the vulvar area and top area of tail in the sows (Fig. 4). A red spot was marked on each vulva area (Fig. 4A) and the top of tail (Fig. 4B) of the female with the aim of taking measurements at the same location during each imaging event. When their measuring area was excessively dirty by feces, it was wiped using the paper towel to prevent a minor temperature change. Estrus VT measurement continued until no longer showing signs of estrus, and non-estrus VT measurement performed at normal days. The infrared images were downloaded into a computer and visualized using the Smart View™ Version 2.0 software (Fluke Thermography, Plymouth, USA).

Experiment 2

A total of eighty (Landrace × Yorkshire) sows were consecutively used for this experiment in each treatment of twenty sows. They did not be synchronized. Estrus detection treatments were as follows: CON, visual evaluation; TRT1, standing time 110 or more minutes for 24 hours; TRT2, VT 31℃ or more; TRT3, BT 40℃ or more. The standards listed above were acquired from experiment 1. Sows were placed in an environmentally controlled farrowing facility. The temperature was maintained at a maximum of 22℃. Sows were placed in farrowing crates (2.2 × 0.7 m) with an area (2.2 × 0.7 m) on either side of the crate for the piglets. When estrus was detected using these methods, sows were inseminated three times by 12 hours intervals using semen from Duroc (Darby Genetics

Fig. 4. (A) Vulvar image. (B) Top area of tail image. Two red spots was used as guide. (C) Infrared thermal image. All digital images were taken using the SmartView™ Version 2.0 software (Fluke Thermography, Plymouth, USA).

Inc., Anseong, Korea). Artificial insemination (AI) was performed until the fertilization was finished. Mattress were put down for piglets to lie on before farrowing. The Lamp was dangled above the mattress to keep the temperature for newborn piglets constant at 35℃. After the birth, individual pig weight was recorded at birth to determine litter birth weight. Also, individual numbers of piglets alive and death per litter were recorded until weaning to determine total number born and number of born alive per litter, respectively.

Statistical analysis

In experiment 1, data were analyzed using the General Linear models procedure of the SAS software (SAS Institute, 2006). Difference among the treatments were separated by a t-test. Variability in the data is expressed as the standard error and probability level of $p < 0.05$ was considered to be statistically significant. In experiment 2, all data were analyzed by ANOVA using the General Linear models procedure of the SAS software (SAS Institute, 2006). Difference among all treatments were separated by Ducan's multiple range test. Variability in the data is expressed as the standard error and probability level of $p < 0.05$ was considered to be statistically significant.

Results

Recently, as interest in animal welfare has increased, pigs have been released from a variety of pain such as teeth clipping and tail docking, and have banned the usage of hormone. So far hormone associated with the growth was banned, but we think that usage of altrenogest also is banned in terms of animal welfare. Therefore, this study focused on finding new methods of estrus detection and whether quantified data are valuable.

Experiment 1

These results of experiment showed that sows in estrus period had greater ($p < 0.05$) total standing time, total standing number and standing number 10 minute or more than sows in non-estrus period (Table 1). However, there was no significant difference ($p > 0.05$) on leg lesion among the treatments. For the temperature, sows in estrus period had greater ($p < 0.05$) vulva temperature than sows in non-estrus period (Table 2). Vulva temperature of sow in estrus increased by 4℃. Also, BT of sows tended ($p = 0.06$) to increase when they reached in estrus.

Table 1. Analysis of behavior using standing sensor according to the estrus and non-estrus in sow (Exp 1)

Item[1]	ES	NES	SE	*p*-value
Total standing time (m)	129.15[a]	103.44[b]	4.07	0.03
Total standing number (n)	15.38[a]	11.62[b]	0.50	0.02
Sanding number 10 minute or more	6.75[a]	3.00[b]	0.48	0.03
Leg lesion[2]	0.75	0.63	0.16	0.41

[1]Total standing time and number, measurement of standing time and number for 24 hours according to the estrus and non-estrus; Sanding time more than 10 minute, measurement of sanding number more than 10 minute in each estrus and non-estrus.

[2]Leg lesion: score 0, no lesion; score 1, slight scratch; score 2, erosion.

[a,b]Means in the same row with different superscripts differ ($p < 0.05$).

ES, estrus; NES, non-estrus; SE, standard error.

Table 2. Change of vulva and body temperature according to the estrus and non-estrus in sow (Exp 1)

Item	ES	NES	SE	*p*-value
Temperature				
Vulva	34.95[a]	29.55[b]	1.65	0.03
Body	39.95	36.80	2.01	0.06

[a,b]Means in the same row with different superscripts differ ($p < 0.05$).

ES, estrus; NES, non-estrus; SE, standard error.

Table 3. Effect of using different estrus detection on number of AI and reproductive performance in sow (Exp 2)

Item[1]	CON	TRT1	TRT2	TRT3	SE	*p*-value
Number (n)						
AI	2.17	1.53	1.42	1.93	0.32	0.06
Performance						
Litter birth weight (kg)	16.13	16.83	16.53	16.67	0.39	0.24
Total number born per litter (n)	11.97	12.01	12.34	12.24	0.55	0.44
Number of born alive per litter (n)	11.47	11.42	11.58	11.47	0.24	0.38
Mortality rate	6.75	6.88	6.64	6.54	0.55	0.88

[1]AI, artificial insemination until fertilization was finished.

CON, visual evaluation; TRT1, standing time; TRT2, vulva temperature; TRT3, body temperature; standard error.

Experiment 2

Table 3 showed the effect different estrus detection on number of AI and reproductive performance in sow. In the results of AI, standing time and vulva temperature tended (p = 0.06) to improve number of AI until fertilization was finished. However, no differences (p > 0.05) were observed on reproductive performance among treatments in sow.

Discussion

Experiment 1

There were no researches on the relationship standing behavior and onset of estrus in sow. Some researchers reported that standing reflex was observed at some sows in estrus, but it is behavior in response to the presence of a boar [12,13]. We hypothesized that standing reflex was observed due to their excitement, and change of standing behavior may be increased by this excitement. In the present study, results showed that time and number related with stand increased (p < 0.05) about 25%, 32%, and 125% when sows reached in estrus (Table 1). Estrogen level usually peaked as sows reached in estrus phase [14]. Many researchers showed that estrogen elevated cortisol level [15–17]. Cortisol is a steroid hormone, and it is released in response to stress. Ziegler. [18] reported that stress increased sympathetic nerve activities such as increasing the heart, respiratory rate and blood pressure. As a result, increasing of standing behavior was considered by increasing the sympathetic stimulation into estrogen when sows reached in estrus.

In the livestock industry, infrared thermal imaging has been used for measurement of VT to identify the fertility or estrus [3,19–22]. Increasing usage of Infrared temperature measurements is considered because it reduce the risk of spreading infection, since touching the subject is unnecessary [23]. Also, the reason why many researchers focused on VT the pig's vulva is more noticeable than other livestock species and is not obstructed by the tail. In the present study, VT of sow in estrus increased (p < 0.05) about 20% compared with that of sow in non-estrus (Table 2). These results

agree with previous researches that vulva temperature were greater at estrus than at non-estrus [3,24,25]. When sow reached in estrus, blood flow to the vulva increases via the internal pudendal artery due to the influence of increased estradiol form the developing follicles [26]. This increase in blood flow causes surface area temperature in the vulva [25]. Also, VT degree in this study was different from the temperature obtained above listed studies. These difference were considered by environmental conditions, such as temperature and air flow and obstacle in skin because they can affect the accuracy of thermal images [27]. However, there was no significant difference (p > 0.05) on BT among the estrus presence. No difference on BT is considered because sows had thick backfat depth.

Experiment 2

Estrus detection using standing time and vulva temperature tended (p = 0.06) to improve number of AI until fertilization was finished while these detection did not affect reproductive performance in sow (Table 3). Visual evaluation was performed using redding and swelling vulva and back pressure test. During experimental period, we detected some sows in silent estrus. Soede et al. [28] showed that 18% of sows had an estrus duration of less than 24 h when estrus was detected by the back pressure test without a boar. Also, less intensive estrus detection caused the increasing incidence of silent estrus [29]. In experiment 2, boar and estrus synchronization were not used in terms of economic and welfare. Thus, new estrus detection using standing sensor and infrared Thermography can presumably be used for early detection with particular interest in animals with silent estrus in these conditions. Standing behaviors and vulva temperature increased by 25%, 32%, 125%, and 20% when sows reached in estrus, respectively. Therefore, new estrus detection are quantifiable when about standing behaviors and vulva temperature increased by 20% compared with non-estrus phase. Also, estrus detection using standing time and VT tended to improve number of AI until fertilization was finished. In conclusion, existing method be replaced to new method such as VT and

standing time when detecting the estrus.

Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions

Conceptualization: Lee JH, Lee DH, Cho JH.
Data curation: Lee JH, Lee DH.
Formal analysis: Lee JH, Lee DH.
Investigation: Yun W, Oh HJ, An JS, Kim YG, Kim GM.
Writing - original draft: Lee JH, Lee DH .
Writing - review & editing: Lee JH, Lee DH, Yun W, Oh HJ, An JS, Kim YG, Kim GM, Cho JH.

Ethics approval and consent to participate

The Animal Care and Use Committee of Chungbuk National University approved all the experimental protocols used in the current study.

ORCID

Ji Hwan Lee   https://orcid.org/0000-0001-8161-4853
Dong Hoon Lee   https://orcid.org/0000-0002-0582-1890
Won Yun   https://orcid.org/0000-0002-1835-2640
Han Jin Oh   https://orcid.org/0000-0002-3396-483X
Ji Seon An   https://orcid.org/0000-0002-9205-8095
Young Gwang Kim   https://orcid.org/0000-0003-2093-695X
Gok Mi Kim   https://orcid.org/0000-0003-1053-4535
Jin Ho Cho   https://orcid.org/0000-0001-7151-0778

References

1. Van Buiten A, Dekkers WA, Hengeveld A, Holster HC. Use and development of ICT in the Dutch agricultural sector. 4th European Federation for Information Technology in Agriculture, Food and the Environment (EFITA 2003); Debrecen, Hungary. 2003.

2. Lee JW. Example of oversea smart agriculture. World Agriculture. 2016;185:3-26.

3. Scolari SC, Clark SG, Knox RV, Tamassia MA. Vulvar skin temperature changes significantly during estrus in swine as determined by digital infrared thermography. J Swine Health Prod. 2011;19:151-5.

4. Rasmussen JDLK, Duus LK. Erfaringer med tidsforbrug i drægtighedsstalde. Landsudvalget for svin/Danske Slagterier. 2003.

5. Bressers HPM, Te Brake JHA, Noordhuizen JPTM. Automated oestrus detection in group-housed sows by recording visits to the boar. Livest Prod Sci. 1995;41:183-91.

6. Bure RG, Houwers HWJ. Automation in group housing of sows. Proceedings of the 11th International Congress on Agricultural Engineering, Dublin, Ireland. 1989. p. 827-30.

7. Houwers HWJ. Locality registration as a way of heat detection in an integrated grouphousing system for sows. International Congress of Applied Ethology in Farm Animals, Skara, Sweden. 1988. p. 44-50.

8. Korthals RL, The effectiveness of using electronic identification for the identification of estrus in swine. 1999 ASAE/CSAE-SCGR Annual International Meeting, Toronto, ON. 1999.

9. Willemse AH, Boender J. A quantitative and qualitative analysis of oestrus in gilts. Tijdschr Diergeneeskd. 1966;91:349-63.

10. Altmann M. Interrelations of the sex cycle and the behavior of the sow. J comp Psychol. 1941;31:481-98.

11. Worwood D. Swine artificial insemination for begginers: heat detection. Utah State University. 2007. http://extension.usu.edu/files/publications/publication/AG_Swine_2007-02.pdf. Accessed 23 Apr 2012.

12. Knauer MT, Cassady JP, Newcom DW, See MT. Phenotypic and genetic correlations between gilt estrus, puberty, growth, composition, and structural conformation traits with first-litter reproductive measures. J Anim Sci. 2011;89:935-42.

13. Patterson JL, Beltranena E, Foxcroft GR. The effect of gilt age at first estrus and breeding on third estrus on sow body weight changes and long-term reproductive performance. J Anim Sci. 2010;88:2500-13.

14. Henricks DM, Guthrie HD, Handlin DL. Plasma estrogen, progesterone and luteinizing hormone levels during the estrous cycle in pigs. Biol Reprod. 1972;6:210-8.

15. Qureshi AC, Bahri A, Breen LA, Barnes SC, Powrie JK, Thomas SM, et al. The influence of the route of oestrogen administration on serum levels of cortisol-binding globulin and total cortisol. Clin Endocrinol (Oxf). 2007;66:632-5.

16. Shifren JL, Desindes S, Mcllwain M, Doros G, Mazer NA. A

randomized, open-label, crossover study comparing the effects of oral versus transdermal estrogen therapy on serum androgens, thyroid hormones, and adrenal hormones in naturally menopausal women. Menopause. 2007;14:985-94.

17. Vamvakopoulos NC, Chrousos GP. Evidence of direct estrogenic regulation of human corticotropin-releasing hormone gene expression. Potential implications for the sexual dimophism of the stress response and immune/inflammatory reaction. J Clin Invest. 1993;92:1896-902.

18. Ziegler MG. Psychological stress and the autonomic nervous system. In: Robertson D, Low PA, Polinsky RJ, editors. Primer on the autonomic nervous system. Oxford: Academic; 2012. p. 291-93.

19. Kastelic JP, Coulter GH, Cook RB. Scrotal surface, subcutaneous, intratesticular, and intraepididymal temperatures in bulls. Theriogenology. 1995;44:147-52.

20. Kastelic JP, Cook RB, Coulter GH, Saacke RG. Ejaculation increases scrotal surface temperature in bulls with intact epididymides. Theriogenology. 1996;46:889-92.

21. Lunstra DD, Coulter GH. Relationship between scrotal infrared temperature patterns and natural-mating fertility in beef bulls. J Anim Sci. 1997;75:767-74.

22. Purohit RC, Hudson RS, Riddell MG, Carson RL, Wolfe DF, Walker DF. Thermography of the bovine scrotum. Am J Vet Res. 1985;46:2388-92.

23. Soerensen DD, Pedersen LJ. Infrared skin temperature measurements for monitoring health in pigs: a review. Acta Vet Scand. 2015;57:5.

24. Simoes VJG. Variations in the vulvar temperature of sows as determined by infrared thermography and its relation to ovulation [Ph.D. dissertation]. Lisboa, Portugal: Faculdade de Medicina Veterinaria, Universidade Tecnica de Lisboa; 2012.

25. Sykes DJ, Couvillion JS, Cromiak A, Bowers S, Schenck E, Crenshaw M, et al. The use of digital infrared thermal imaging to detect estrus in gilts. Theriogenology. 2012;78:147-52.

26. Frandson RD, Wilke WL, Fails AD. Anatomy of the female reproductive system. In: Troy D, editor. Anatomy and physiology of farm animals. John Wiley & Sons, 2003. p. 394.

27. Cravello B, Ferri A. Relationships between skin properties and environmental parameters. Skin Res Technol. 2008;14:180-6.

28. Kemp B, Soede NM, Langendijk P. Effects of boar contact and housing conditions on estrus expression in sows. Theriogenology. 2005;63:643-56.

29. Soede NM, Wetzels CCH, Kemp B. Oestrus (standing response for boar and man) and ovulation in sows. Reprod Domest Anim. 1996;31:293-4.