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Time of ovulation and reproductive performance over three parities after treatment of primiparous sows with PG600

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Abstract

Primiparous sows from a commercial pig farm in central Brazil were utilized to investigate the effect of post-weaning gonadotrophins (given during summer) on estrus, time of ovulation and reproductive performance over three parities. One group of sows (PG600) was treated with a combination of 400 IU equine chorionic gonadotrophin (eCG) + 200 IU human chorionic gonadotrophin (hCG) (PG600) 24 h after weaning ($n = 420$), whereas the control group received saline ($n = 408$). In a subset of sows ($n = 150$), estrus was detected and time of ovulation was determined by transcutaneous ultrasound. Treatment with PG600 increased the percentage of primiparous sows in estrus within 10 days after weaning (94.8% versus 79.7%) and reduced the first weaning-to-estrus interval (5.3 days versus 8.0 days) relative to control sows ($P < 0.05$). Although the duration of estrus was longer ($P < 0.05$) in sows given PG600 (65.7 h versus 61.0 h), the interval from estrus to ovulation was not different ($P > 0.05$) between PG600 and control sows (46.6 h versus 43.3 h). Treatment with PG600 did not affect ($P > 0.05$) rates of return-to-estrus and farrowing over three parities, but it increased the number of total piglets born ($P < 0.05$) in the second parity (11.2 versus 10.4), thereby minimizing the magnitude of second-litter syndrome. Culling rates from the first to the fourth parity were 26.7 and 24.5% ($P > 0.05$) for PG600 and control sows, respectively. In conclusion, PG600 given 24 h after the first weaning reduced the weaning-to-estrus interval and increased the size of the second litter.

Keywords: Gonadotrophins; PG600; Primiparous sows; Second-litter syndrome; Pigs

1. Introduction

Post-weaning anestrus is a major cause of reproductive failure. Several factors influence the ability of the female to return to estrus following weaning, including parity, season, genotype, lactation length, feed intake during lactation, litter size and boar exposure [1]. An extended weaning-to-estrus interval (WEI) in primiparous sows is also a common cause of increased non-productive days, which substantially increases costs [2]. The WEI is longer in primiparous sows and during summer and early fall [3,4]. Since primiparous sows have the highest risk of a prolonged WEI, they are good

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candidates to be treated with estrus-stimulating hormones, e.g. PG600 [5].

The duration and variability in the WEI are primary constraints to achieving breeding targets [6], leading to problems in the management of farrowing facilities. Gonadotrophins have been used to decrease the WEI and reduce the frequency of post-weaning anestrus [7], particularly in females predisposed to a longer WEI. Treatment with PG600, a combination of equine chorionic gonadotrophin (eCG) and human chorionic gonadotrophin (hCG), induced a fertile estrus in multiparous sows [8] or in primiparous sows, which are more susceptible to a prolonged WEI [2]. However, responsiveness to this combination can vary among herds and production systems [8]. Furthermore, there are limited studies regarding the duration of estrus, time of ovulation [9] and lifetime productivity in swine given PG600.

The reduction in the number of piglets in second litter compared to first litter, the second-litter syndrome, is another problem of primiparous sows [10]. The low second litter size is probably caused by a low ovulation rate or an increased embryonic mortality [5], which can be related to the high susceptibility of primiparous sows to weight loss during lactation [11]. There was a reduction of at least one piglet in the second litter size in 55 and 60% of sows in two herds from the central and south regions of Brazil, respectively [12,13].

The objective of this study was to investigate the effect of PG600 (given 24 h after weaning in primiparous sows) on WEI, duration of estrus and time of ovulation. Farrowing rate, litter size and culling rate were also evaluated (to Parity 4) to verify the effects of this treatment on lifetime productivity.

2. Materials and methods

2.1. Animals and facilities

This study was carried out in a commercial pig farm located in Mato Grosso State, in central Brazil. This farm had an inventory of 5800 Camborough 22® (Pig Improvement Company International Group, Fyfield, Oxon, England) females. The primiparous sows used in this study had an average lactation length of 18 days (range, 16–21 days) and a body condition score that ranged from 2 to 4 (scale of 1–5). Those with <7 piglets and with any apparently lesions were also excluded. The sows were kept in individual crates with a partly slatted floor until the last third of pregnancy when they were moved to collective pens with a space allowance of 2.0–2.5 m^2 per sow. Sows were transferred to farrowing rooms, approximately 1 week before the predicted farrowing date, where they were housed in individual farrowing crates.

Temperature was measured (with a mercury-in-glass thermometer) at approximately 10:00 each day inside the building where sows were weaned and submitted to the treatments. Minimum and maximum temperatures were also recorded.

2.2. Treatments

On the day of weaning, primiparous sows were ranked according to their lactation length, number of piglets born in the first parity and body condition score, to be uniformly distributed between treatments. They were then randomly assigned to one of two treatments. One group (PG600) of sows ($n = 420$) was treated (5 mL given SC) with a combination of 400 IU eCG + 200 IU hCG (PG600®; Intervet, Boxmeer, The Netherlands), 24 h after weaning. Sows in the control group ($n = 408$) were treated with 5 mL of saline solution.

2.3. Estrus and time of ovulation

Sows were placed in individual crates after weaning and detection of estrus (back pressure test) was performed twice daily (12-h intervals) with the aid of a sexually mature boar. The WEI was calculated as the interval between weaning and the onset of estrus. Duration of estrus and time of ovulation were determined in 150 females (PG600 = 75; control = 75). In these females, estrus detection was performed thrice daily (8-h intervals). The onset of estrus was calculated as the moment at which the sow first showed a standing response to the back pressure test, minus half the interval to the previous assessment. The end of estrus was calculated as the moment at which the female no longer showed a standing response to the back pressure test, minus half the interval to the previous assessment. To determine the time of ovulation, starting at the onset of standing estrus, sows were examined (by a single operator) with real-time transcutaneous ultrasonography [14,15] with a 5-MHz Aloka (Aloka Co. Ltd., Mure, Mitaka-shi, Tokyo, Japan) convex linear transducer. Sows were standing (not restrained) and the probe was placed horizontally on the right inguinal region just dorsal to the last pair of teats, cranial to the hind leg. Ovaries were located using the bladder as a reference. Ovulation was defined as complete when large follicle numbers were noticeably reduced from the previous observation and ≤ 4 large follicles remained [16]. The time of ovulation was considered as the first time that

pre-ovulatory follicles could no longer be detected, minus 4 h. Ovulation was confirmed with an additional examination 8 h after initial diagnosis.

2.4. Artificial insemination (AI)

Primiparous sows were treated and inseminated with chilled semen extended in Beltsville Thawing Solution (BTS) with 3.0×10^9 sperm cells in 90 mL, during summer months in Brazil (January–March). Semen was stored for up to 36 h prior to insemination. The first insemination was performed 12 h after detection of estrus. Sows were subsequently inseminated at 12-h intervals as long as they exhibited standing estrus (for the three first inseminations and at 24-h intervals thereafter if estrus persisted).

2.5. Reproductive performance

To determine the return-to-estrus rate (RER), sows were subjected to daily estrus detection with a sexually mature boar from 18 to 30 days after insemination. The farrowing rate (FR) was calculated based on the number of females that farrowed as a proportion of those inseminated. Females culled for non-reproductive reasons were excluded from the calculation of the adjusted farrowing rate (AFR). Litter size (LS), including piglets born alive, stillborn piglets and mummified fetuses, was recorded at parturition. Culling rate included females that were removed from the herd for reproductive or non-reproductive reasons. Culling rates at each productive cycle and an overall culling rate, from the first to the fourth parity, were considered.

2.6. Statistical analysis

The WEI, duration of estrus, time of ovulation (relative to onset of estrus) and litter size were analyzed using the GLM procedure [17]. The lactation length was included as a covariate in the model used to analyze the WEI. Correlation of weaning-to-estrus interval with duration of estrus and time of ovulation was analyzed with the CORR procedure [17]. Correlation of second litter size with weaning-to-ovulation and estrus-to-ovulation intervals was also determined. Cumulative percentages of sows in estrus after weaning, return-to-estrus, farrowing and culling rates were submitted to Chi-square analysis. The mean number of piglets born in previous parturition was maintained as a covariate in the analysis of litter size. The litter size of second parity females was compared to the first litter size to evaluate the effect of treatment on the magnitude of the second-litter syndrome. Females with fewer piglets in the second parity relative to the first parity were considered as having the second-litter syndrome. Four groups were formed, taking into account the occurrence or absence of the second-litter syndrome in PG600 and control

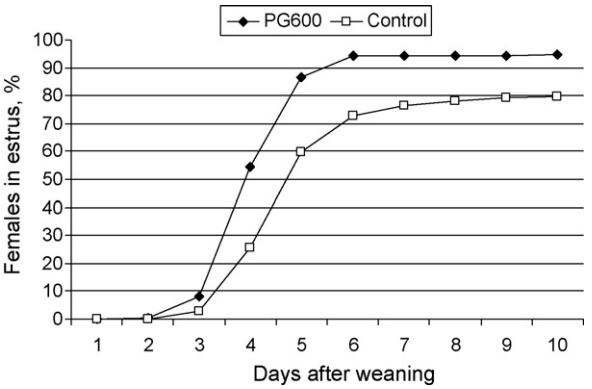

Fig. 1. Cumulative percentage of primiparous sows showing estrus in response to PG600 or no treatment (control) 24 h after weaning. Cumulative percentages of females showing estrus were different between the groups ($P < 0.05$), from 3 to 10 days after weaning.

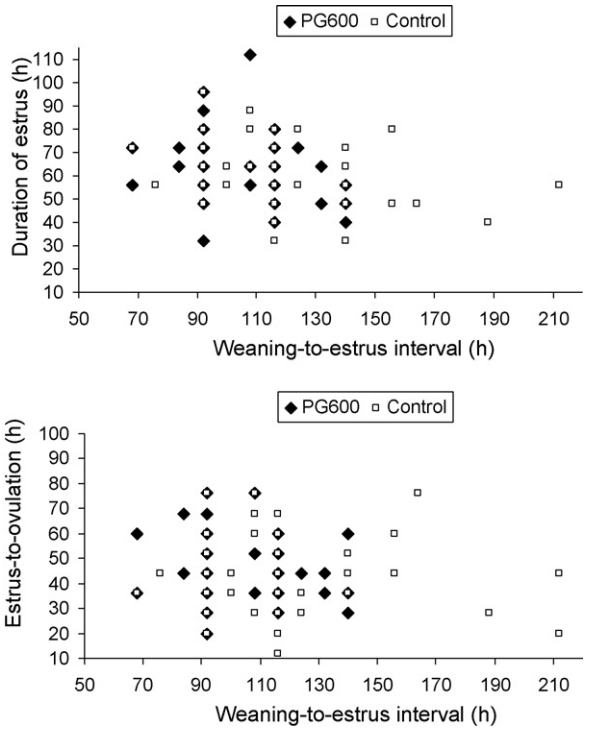

Fig. 2. Association of weaning-to-estrus interval with duration of estrus ($r = -0.222$, $P = 0.055$, and $r = -0.261$, $P = 0.024$) and time of ovulation ($r = -0.256$, $P = 0.027$, and $r = -0.106$, $P = 0.363$) in PG600 ($n = 75$) and control ($n = 75$) primiparous sows.

groups. Litter size, WEI, duration of estrus and time of ovulation were compared among these groups.

3. Results

Treatment with PG600 increased the percentage of primiparous sows in estrus within 10 days after weaning (94.8% versus 79.7%; Fig. 1). Duration of estrus was longer ($P < 0.05$) in PG600 sows (65.7 ± 13.3 h versus 61.0 ± 13.5 h) but time of ovulation (relative to start of estrus) was not different ($P > 0.05$) between PG600 (46.6 ± 12.9 h) and control (43.3 ± 13.8 h) sows. The duration of estrus was negatively correlated with WEI in both groups. There was a significant negative correlation between the time of ovulation and WEI in PG600 females, but not in those of control group (Fig. 2).

For first parity females, the WEI of those given PG600 was shorter ($P < 0.05$) than that of control females (Table 1). The WEI of second, third and four parity females was not affected by PG600 treatment ($P > 0.05$). Return-to-estrus and farrowing rates were not influenced ($P > 0.05$) by treatment with PG600 (Table 1).

Treatment with PG600 increased the number of piglets born ($P < 0.05$) in the farrowing subsequent to treatment, but the litter size of parities three and four were not affected (Table 1). The mean number of piglets was lower ($P < 0.05$) in second than in first parity in both PG600 (11.9 versus 11.2) and control (11.7 versus 10.4) sows. In both groups, there was no significant correlation between the weaning-to-ovulation interval and second litter size ($r = 0.023$, $P = 0.849$ for PG600, and $r = -0.102$, $P = 0.400$ for control group). Furthermore, the second litter size was not significantly correlated with the estrus-to-ovulation interval ($r = -0.013$, $P = 0.918$ for PG600, and $r = 0.160$, $P = 0.185$ for the control group).

Control females tended ($P = 0.08$) to have a higher rate (57.3%; 209/365) of second-litter syndrome than PG600 females (50.9%; 190/373). In both PG600 and control groups, females with the second-litter syndrome were those with a larger first litter (Table 2). Within the

Table 1
Weaning-to-estrus interval (WEI), return-to-estrus rate (RER), farrowing rate (FR), adjusted farrowing rate (AFR) and litter size over three parities following PG600 administration in primiparous sows

	Control	PG600	*P* level
Parity 1			
Litter size[a]	11.7 ± 2.3	11.9 ± 2.3	0.155
WEI (days)	8.0 ± 7.1	5.3 ± 4.1	<0.0001
No. of females inseminated	408	420	–
RER (%)	32 (7.8)	29 (6.9)	0.605
FR (%)	365 (89.5)	373 (88.8)	0.763
AFR (%)	365/398 (91.7)	373/405 (92.1)	0.839
Parity 2			
Litter size	10.4 ± 3.2	11.2 ± 3.3	0.001
WEI (days)	5.7 ± 4.6	5.7 ± 4.3	0.983
No. of females inseminated	369	381	–
RER (%)	31 (8.4)	36 (9.4)	0.615
FR (%)	329 (89.2)	333 (87.4)	0.454
AFR (%)	329/360 (91.4)	333/368 (90.5)	0.672
Parity 3			
Litter size	11.5 ± 2.9	11.4 ± 3.1	0.663
WEI (days)	5.8 ± 4.9	5.9 ± 5.5	0.718
No. of females inseminated	328	334	–
RER (%)	22 (6.7)	13 (3.9)	0.106
FR (%)	290 (88.4)	298 (89.2)	0.742
AFR (%)	290/313 (92.6)	298/313 (95.2)	0.181
Parity 4			
Litter size	11.2 ± 3.3	11.3 ± 3.0	0.897
WEI (days)	5.2 ± 4.1	5.5 ± 4.2	0.445
Culling rate from parity 1 to 4 (%)	100/408 (24.5)	112/420 (26.7)	0.477

Litter size and WEI are LS means ± S.D. Females removed for non-reproductive reasons were excluded from the calculation of AFR.
[a] The first litter size was determined before submitting sows to PG600 treatment.

Table 2
Litter size, weaning-to-estrus interval (WEI), duration of estrus and time of ovulation in PG600 and control females, according to the presence or absence of the second-litter syndrome

End point	Control		PG600	
	Yes	No	Yes	No
No. of females	209	156	190	183
WEI (days)	7.6 ± 6.4^{a}	8.2 ± 8.1^{a}	5.6 ± 4.8^{b}	4.9 ± 3.5^{b}
First litter size	12.5 ± 2.3^{a}	10.6 ± 1.9^{b}	12.7 ± 2.1^{a}	11.1 ± 2.2^{b}
Second litter size	8.7 ± 2.8^{a}	12.6 ± 2.3^{b}	9.2 ± 2.6^{a}	13.4 ± 2.5^{c}
No. of females	43	27	39	31
Duration of estrus (h)	61.9 ± 12.8	60.1 ± 14.1	65.6 ± 13.1	64.5 ± 11.0
Time of ovulation (h)	44.7 ± 15.2	43.1 ± 11.4	46.7 ± 11.2	45.5 ± 14.4

Within a row, means without a common superscript (a–c) differ ($P < 0.05$). Values correspond to LS means ± S.D.

PG600 or control groups, females with and without the syndrome had no differences ($P > 0.05$) in WEI, duration of estrus and time of ovulation.

The number of inseminations was not different ($P > 0.05$) between PG600 (3.5 ± 0.6) and control (3.4 ± 0.6) primiparous sows. The culling rate at each production cycle, was similar for PG600 and control sows ($P > 0.05$). The overall culling rate, from first up to fourth parity, was not affected ($P > 0.05$) by treatment (Table 1). The ambient temperature averaged 34 °C (range, 24–39 °C).

4. Discussion

The present study confirmed that the combination of eCG and hCG mimicked or supplemented endogenous gonadotrophin hormones necessary for folliculogenesis and ovulation, with increased expression of post-weaning estrus [9]. Reproductive performance is enhanced when sows are inseminated within 5–7 days after weaning; these sows are likely to have a higher conception rate, good fertility and bigger litter size [18] compared to those inseminated in the second week post-weaning. In the present study, more primiparous sows given PG600 were detected in estrus within 7 days after weaning (94.5% versus 76.5%). The reduction in WEI was consistent with other studies that used PG600 [7,8]. At weaning, suckling stimuli are removed, opioid release is inhibited and pulsatile secretion of LH increases [19]. In females with good body condition, gonadotrophin secretion is increased, follicular growth, estradiol production and pre-ovulatory LH peak occur, culminating in estrus and ovulation within 7 days after weaning. Perhaps the lower percentage of control sows in estrus within 10 days after weaning was due to suppressed gonadotrophin secretion and follicular growth. In that regard, a longer WEI is common in first parity sows [20,21], prompting a greater use of hormones such as PG600 in these animals [21].

For PG600 and control groups, the association between weaning-to-estrus interval and duration of estrus was weaker than reported previously [9,22]; perhaps this apparent discrepancy was due to the variation in duration of estrus and in its relationship with WEI among farms [23] or even within an individual farm over time [24]. Although ovulation occurs, on average, at the beginning of the last third of standing estrus, the extreme range in the time of ovulation in the present study (16–112 h) confirmed the great variability of this event in swine [15,22]. Time of ovulation was not affected by PG600, consistent with previous results [9].

Although weak, the negative association between WEI and time of ovulation, observed only in PG600 females, reinforced the notion that females with a shorter WEI have a longer estrus-to-ovulation interval; that could justify an adjusted protocol for the insemination of females given PG600 [16]. Nevertheless, second litter size was not correlated with estrus-to-ovulation or with weaning-to-ovulation interval, suggesting that the weak association between WEI and time of ovulation did not affect the litter size of females given PG600 and inseminated at 12-h intervals.

Return-to-estrus and farrowing rates were not affected by treatment, in agreement with primiparous sows treated with the same hormonal combination [6]. However, in another study [7], sows treated with PG600 had a lower farrowing rate than the controls in two of eight herds. In one of these two herds, sows displayed clinical signs of leptospirosis (that could have accounted for their reduced fertility despite PG600 treatment). In another study [8], the percentage of inseminated sows that farrowed tended to be higher for control versus PG600-treated sows. Differences in results were not unexpected and may have been due to

differences among studies in seasons, parity, genetics, housing and management [9].

Litter size is determined by rates of ovulation, fertilization and prenatal survival; it is difficult to determine which of these factors has the largest influence. Ovulation rate and litter size are positively correlated before 35 days of pregnancy, and the number of embryos increases linearly with an increase in number of corpora lutea [25]. In gilts, litter size increases linearly up to approximately 18 ovulations; beyond that, additional ovulations resulted in little or no increase in litter size [26]. In a review of 13 trials [27], eCG (500–1500 IU) stimulated an average of 4.8 additional ovulations, but only 1.0 additional embryos survived until 30 days of pregnancy. In the present study, litter size was increased by 0.8 piglets in swine given PG600 compared to the controls. Reports of litter size increased by 2.1 piglets [28] were in contrast with a reduction of 0.7 piglets [6] in primiparous sows treated with PG600. Multiparous sows have a greater feed intake, which probably stimulates an increase in gonadotrophin secretion earlier than in primiparous sows [19]. Since ovulation in primiparous sows occurs in association with a lactation-induced negative energy balance [29], a reduction in ovulatory rate could be overcome by exogenous gonadotrophin administration. Furthermore, feed intake during lactation is lower in summer, which may predispose sows to endocrine dysfunction [30].

In the present study, primparous sows treated during summer were not compared to sows treated during winter. Nevertheless, it is known that exposure to high environmental temperatures can alter follicular growth of weaned sows. Indeed, heat-stressed sows had delayed follicular growth expressed by smaller follicular populations on the day of weaning compared to sows exposed to thermoneutral conditions during lactation [31]. Furthermore, LH pulse frequency was lower in primiparous sows weaned at 30 °C compared to sows maintained at 22 °C [30]. The content of GnRH in the hypothalamus and concentrations of LH in the pituitary and serum were lower after weaning in summer than winter [30]. Perhaps exposure to elevated ambient temperatures suppresses the responsiveness of the hypothalamic–pituitary–adrenal axis, disrupts function of the hypothalamic–pituitary axis [32], or changes its sensitivity to the feedback of estradiol [30]. In that regard, exposure to high ambient temperatures may have provoked endocrine disturbances [30,31] in primiparous sows in this study. Nevertheless, feed intake is reduced by high ambient temperatures; the effect of thermal stress on reproductive performance is, at least in part, mediated by reduced gonadotrophin secretion due to undernutrition [4].

Reduction in the second litter size can be a consequence of limited follicular development and incomplete recovery of the reproductive axis at weaning, that can also be affected by the metabolic state during lactation [33]. In the present study, the occurrence of the second-litter syndrome was most common among females having larger first litters, in both control and PG600 groups, confirming previous reports [10,12]. Whether the occurrence of the second-litter syndrome was due to an isolated or a combined effect of catabolism and of high environmental temperature during lactation is unknown. Nevertheless, the lower incidence of the second-litter syndrome in PG600 females contributed to a lesser mean reduction from the first to the second litter size compared to control sows (0.7 versus 1.3 fewer piglets/litter).

In conclusion, the combination of eCG and hCG was effective in reducing the weaning-to-estrus interval and in increasing the second litter size of sows treated 24 h after weaning. This hormonal treatment could be strategically used to minimize the impact of second-litter syndrome.

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References

[1] Dial GD, Marsh WE, Polson DD, Vaillancourt JP. Reproductive failure: differential diagnosis. In: Leman AD, Straw BE, Mengeling WL, D'Allaire S, Taylor DJ, editors. Diseases of swine. 7th ed., London: Wolfe; 1992. p. 88–137.

[2] Terreni M, Foccoli E. Effect of PMSG and hCG at weaning on weaning to oestrus interval of primiparous sows. In: 16th international pig veterinary society congress, casual productions. 2000. p. 417.

[3] Britt JH, Szarek VE, Levis DG. Characterization of summer infertility of sows in large confinement units. Theriogenology 1983;20:133–40.

[4] Prunier A, Quesnel H, Messias de Bragança M, Kermabon AY. Environmental and seasonal influences on the return-to-estrus after weaning in primiparous sows: a review. Livest Prod Sci 1996;45:103–10.

[5] Kemp B, Soede NM. Reproductive problems in primiparous sows. In: 18th congress of international pig veterinary society; 2004.p. 843–8.

[6] Kirkwood RN, Aherne FX, Foxcroft GR. Effect of gonadotropin at weaning on reproductive performance of primiparous sows. Swine Health Prod 1998;6:51–5.

[7] Bates RO, Day BN, Britt JH, Clark LK, Brauer MA. Reproductive performance of sows treated with a combination of pregnant mare's serum gonadotropin and human chorionic gonadotropin at weaning in the summer. J Anim Sci 1991;69:894–8.
[8] Estienne MJ, Hartsock TG. Effect of exogenous gonadotropins on the weaning-to-estrus interval in sows. Theriogenology 1998;49:823–8.
[9] Knox RV, Rodriguez-Zas SL, Miller GM, Willenburg KL, Robb JA. Administration of P.G. 600 to sows at weaning and the time of ovulation as determined by transrectal ultrasound. J Anim Sci 2001;79:796–802.
[10] Morrow WEM, Leman AD, Williamson NB, Morrison RB, Robinson RA. An epidemiological investigation of reduced second-litter size in swine. Prev Vet Med 1992;12:15–26.
[11] Whittemore CT. Nutrition reproduction interactions in primiparous sows. Livest Prod Sci 1996;46:65–83.
[12] Schenkel AC, Kummer R, Schmidt ACT, Fries HCC, Bernardi ML, Bortolozzo FP, et al. Caracterização da síndrome do segundo parto em suínos. In: XII Congresso Brasileiro de Veterinários Especialistas em Suínos; 2005.p. 252–3.
[13] Furtado CSD, Kummer R, Mellagi APG, Koller FL, Bortolozzo FP, Wentz I, et al. Redução do número médio de leitões nascidos no segundo parto de acordo com a idade, o peso e a espessura de toucinho na primeira cobertura. In: XII Congresso Brasileiro de Veterinários Especialistas em Suínos; 2005.p. 222–3.
[14] Kauffold J, Rautenberg T, Gutjahr S, Richter A, Sobiraj A. Ultrasonographic characterization of the ovaries in non-pregnant first served sows and gilts. Theriogenology 2004;61:1407–17.
[15] Weitze KF, Wagner-Rietschel H, Wabersky D, Richter L, Krieter J. The onset of the heat after weaning, heat duration and ovulation as major factor in AI timing in sows. Reprod Dom Anim 1994;79:433–43.
[16] Breen SM, Rodriguez-Zas SL, Knox RV. Effect of PG600 and adjusted mating times on reproductive performance in weaned sows. Anim Reprod Sci 2006;93:157–64.
[17] SAS. SAS user's guide: statistical analysis system, release 8, 12th ed., Cary, NC: SAS Institute Inc.; 2000.
[18] Muirhead MR, Alexander TJL. Managing pig health and the treatment of disease. A reference for the farm Sheffield: 5M Enterprises; 1997. p. 133–226.
[19] Britt JH. Biology and management of the early weaned sow. In: 27th annual meeting of American association of swine practitioners; 1996.p. 417–26.
[20] Koketsu Y, Dial GD. Factors influencing the postweaning reproductive performance of sows on commercial farms. Theriogenology 1997;47:1445–61.
[21] Vesseur PC. Causes and consequences of variation in weaning to oestrus interval. Ph.D. thesis. Wageningen University; 1997. 165 pp.
[22] Kemp B, Soede NM. Relationship of weaning-to-estrus interval to timing of ovulation and fertilization in sows. J Anim Sci 1996;74:944–9.
[23] Steverink DWB, Soede NM, Groenland GJR, Van Schie FW, Noordhuizen JPTM, Kemp B. Duration of estrus in relation to reproduction results in pigs on commercial farms. J Anim Sci 1999;77:801–9.
[24] Belstra BA, Flowers WL, See MT. Factors affecting temporal relationships between estrus and ovulation in commercial sow farms. Anim Reprod Sci 2004;84:377–94.
[25] Van Der Lende T, Schoenmaker GJW. The relationship between ovulation rate and litter size before and after day 35 of pregnancy in gilts and sows: an analysis of published data. Livest Prod Sci 1990;26:217–29.
[26] Wu MC, Hentzel MD, Dziuk PJ. Relationships between uterine length and number of fetuses and prenatal mortality in pigs. J Anim Sci 1987;65:762–70.
[27] Anderson LL, Melampy RM. Factors affecting ovulation rate in the pig. In: Cole DJ, editor. Pig reproduction. London: Butterworths; 1972. p. 329–66.
[28] Hughes AME, Allcock JG, Richardson JS. Strategic use of gonadotrophins in first litter sows after weaning. Vet Rec 2000;146:164–5.
[29] Cox NM. Control of follicular development and ovulation rate in pigs. J Reprod Fertil 1997;(Suppl. 52):31–46.
[30] Armstrong JD, Britt JH, Cox NM. Seasonal differences in function of the hypothalamic–hypophysial–ovarian axis in weaned primiparous sows. J Reprod Fertil 1986;78:11–20.
[31] Lucy MC, Liu J, Boyd CK, Bracken CJ. Ovarian follicular growth in sows. Reproduction 2001;(Suppl. 58):31–45.
[32] Barb CR, Estienne MJ, Kraeling RR, Marple DN, Rampacek GB, Rahe CH, et al. Endocrine changes in sows exposed to elevated ambient temperature during lactation. Dom Anim Endocr 1991;8:117–27.
[33] Willis HJ, Zak LJ, Foxcroft GR. Duration of lactation, endocrine and metabolic state, and fertility of primiparous sows. J Anim Sci 2003;81:2088–102.