Agriculture and Natural Resources 51 (2017) 303–309

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Effects of altrenogest treatment in sows on the variation of piglet birth weight and pre-weaning piglet performance

Supatee Kitkha,[a, b, 1] Alongkot Boonsoongnern,[c] Nattavut Ratanavanichrojn,[c] Pichai Jirawattanapong,[c] Anuchai Pinyopummin[d, *]

[a] *Center for Agricultural Biotechnology, Kasetsart University Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand*
[b] *Center of Excellence on Agricultural Biotechnology: (AG-BIO/PERDO-CHE), Bangkok 10900, Thailand*
[c] *Department of Farm Resources and Production Medicine, Faculty of Veterinary Medicine, Kasetsart University Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand*
[d] *Department of Large Animal and Wildlife Clinical Sciences, Faculty of Veterinary Medicine, Kasetsart University Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand*

ARTICLE INFO

Article history:
Received 4 July 2016
Accepted 27 February 2017
Available online 16 October 2017

Keywords:
Altrenogest
Birth weight variation
Piglet
Pre-weaning
Sow

ABSTRACT

The effect of altrenogest (ALT) feeding combined with induced ovulation by human chorionic gonadotropin (hCG) in sows was evaluated on piglet birth weight (BW) variation and pre-weaning performance. Sows were divided into four groups: the control (no ALT; without hCG induction; artificial inseminated (AI) at 12 and 36 h after estrus; $n = 40$), ALT + hCG72 (ALT 20 mg/d, D-4–D2 (D0: weaning day); hCG 750 IU at 72 h post ALT; AI at 24 and 40 h after hCG; $n = 41$), ALT + hCG96 (ALT 20 mg/d, D-4–D2; hCG 750 IU at 96 h post ALT; AI at 24 and 40 h after hCG; $n = 41$) and ALT + no hCG (20 mg/d, D-4–D2; without hCG induction; AI at 12 and 36 h after estrus; $n = 41$). The results revealed that piglet BW was not different among the groups ($p > 0.05$). However, the standard deviation of piglet BW (SDBW) was lower in ALT + hCG72 (0.32 ± 0.02 kg; $p = 0.032$), compared to ALT + hCG96 (0.40 ± 0.02 kg) and ALT + no hCG (0.40 ± 0.02 kg), except for the control (0.39 ± 0.02 kg). In addition, the pre-weaning mortality rate (%PWM) due to underweight elimination at weaning (below 3.50 kg) was decreased in ALT + hCG72 (8.33%) compared to the control (32.50%; $p = 0.007$) but similar to ALT + hCG96 (10.71%) and ALT + no hCG (24.05%). Therefore, ALT + hCG72 treatment in sows could reduce piglet BW variation and the number of piglets eliminated at weaning.

Introduction

Increased litter size (LS) has some bearing on a reduction in mean piglet birth weight (BW); concomitantly, a greater proportion of low BW piglets (1 kg or less) results in higher variability of piglet BW within the litter. This problem decreases the viability of low BW piglets and their growth performance during lactation (Quiniou et al., 2002) because they have less ability to compete with their littermates to receive the required level of colostrum and milk intake (Le Dividich, 1999).

The difference in piglet BW initiates during early pregnancy (Patterson et al., 2008) including the pre-implantation and post-implantation periods. The causes of piglet BW variation are: heterogeneous oocyte maturation (6.5–10.0 mm) (Knox, 2005), variation in ovulation time (1–9 h) (Pope, 1994), the positioning of implantation (Perry and Rowell, 1969) and placental efficiency (Wilson et al., 1999). Thus, the improvement of follicular development and reducing the range in ovulation time may decrease the piglet BW variation that takes place during the pre-implantation period.

Several studies indicated that supplementation of ALT (orally-synthetic progesterone) to the sows during the pre- and post-weaning periods could enhance reproductive performance (van Leeuwen et al., 2011a) through improving the follicular growth, such as increasing the follicular size at the beginning of the follicular phase (van Leeuwen et al., 2011b) and generating a more homogeneous pool of pre-ovulatory follicles (Kitkha et al., 2014). hCG was used in a fixed-time artificial insemination (AI) protocol for a predictable time of ovulation (Brüssow et al., 1996; Hühn et al.,

* Corresponding author.
E-mail addresses: supatee_kitkha@hotmail.com (S. Kitkha), fvetacp@ku.ac.th (A. Pinyopummin).
[1] Co-first author.

https://doi.org/10.1016/j.anres.2017.02.006

1996; Brüssow and Wähner, 2011; Wongkaweewit et al., 2012). Ovulation in female pigs occurred within 42 h after hCG injection (Hunter, 1967; Roca et al., 2003; Tummaruk et al., 2011).

Therefore, the objective of this study was to evaluate the effect of ALT treatment in sows during the peri-weaning period, accompanied with ovulation induction by hCG after ALT withdrawal on piglet BW variation, PWM and pre-weaning piglet performance.

Materials and methods

Housing, animals and diets

Animal manipulations in this study were approved by the Animal Usage and Ethics Committee, Kasetsart University (ACKU 03555). The study was conducted on a commercial sow breeding farm in Chiang Mai, Thailand (18°47′25″ N, 98°59′04″ E), housing 5000 sows and using an evaporative cooling system during the rainy season (January–June 2014).

Gestating sows were kept in gestation crates and moved to a farrowing barn 1 wk before the expected day of parturition. The farrowing pen was composed of a farrowing crate on a slatted floor under the sow and a metal slatted floor under piglets. A heat lamp was placed inside the metal box, which was beside the sow, to provide heat for the piglets. The average temperature varied between 22.90 ± 0.50 °C to 26.50 ± 0.50 °C in the gestation barn, and 22.00 ± 0.20 °C to 23.70 ± 0.20 °C in the lactation barn.

Lactating crossbred sows (Landrace × Large White; $n = 163$), parity 3–6 and body condition score (BCS) 2.0–2.5 were used in the study. The sows' BCS was assessed according to the method used by Alexander and Muirhead (1997). The sows had parity, BCS at weaning, LS, nursing piglets (NP), piglets weaned per litter (PWL) and lactation length (LL) on average of 4.18 ± 0.10, 2.24 ± 0.02, 16.75 ± 0.30 piglets, 11.86 ± 0.17 piglets, 11.67 ± 0.21 piglets and 26.97 ± 0.09 d, respectively.

The sows and their piglets were fed a corn and soybean-based diet that provided higher nutrient requirements than the National Research Council (NRC, 2012) recommendation. Drinking water was provided *ad libitum*.

During lactation, all sows were fed the lactation diet *ad libitum*. The lactation diet contained 18.08% crude protein (CP), 3314.47 kcal/kg metabolizable energy (ME) and 1.16% lysine (Lys). After mating, the sows were fed with the gestation diet twice daily at 0700–0730 h and 1230–1330 h. The feeding level was controlled depending on the sow's BCS. Gestation diets were divided into two phases, during weeks 1–11 of gestation, the diet contained 15.51% CP, 3047.53 kcal/kg ME and 0.93% Lys (BCS < 3.0; 2.8 kg/d: BCS = 3.0; 2.4 kg/d: BCS > 3.0; 2.0 kg/d) and during the weeks 12–15 of gestation, the diet contained 16.41% CP, 3048.18 kcal/kg ME and 0.94% Lys (BCS ≥ 3.0; 2.8 kg/d: BCS < 3.0; 3.2 kg/d).

The piglets were individually weighed at birth and their birth characteristics were identified and recorded; for example mummified fetuses (MM), stillborn piglets (SB) and born alive piglets (BAL). At 24 h after birth, they were teeth-clipped, tail-docked and litter sizes were equalized by cross-fostering within the same group. All piglets received iron dextran at age 4 d. Males were castrated at age 5 d. At age 14 d, creep feed (20.65% CP, 3544.83 kcal/kg ME and 1.50% Lys) was provided to piglets at 0.01 kg/piglet/d on average. The piglets were weighted individually again at weaning.

Altrenogest treatments

Sows were divided into four groups (Table 1). Control sows ($n = 40$) did not receive ALT (Altresyn®; Ceva Sante Animale; Libourne, France). Estrus monitoring detection and traditional artificial insemination (AI) in sows were carried out for 7 d after weaning at 0800–900 h and 1500–1600 h by trained farm technicians using fence-line boar contact. Estrus signs were indicated when the sows exhibited a standing heat reflex during a back pressure test in the presence of a boar. AI with pooled fresh semen was carried out at 12 and 36 h after estrus expression.

The sows in ALT + hCG72 ($n = 41$) were treated with ALT for 7 d, from 4 d before weaning (D-4; D0 = weaning day) to 2 d post weaning (D2) at 20 mg/d, as a top dressing over a small portion of feed prior to receiving their large meal at 1230–1330 h. After ALT withdrawal, estrus signs were detected and ovulation was induced using chorionic gonadotropin (hCG) 750 IU, i.m. (Chorulon®; Intervet/Schering Plough; Boxmeer, the Netherlands) (Wongkaweewit et al., 2012) at 72 h (1400–1500 h) post ALT withdrawal. Then, fixed times were implemented for AI at 24 and 40 h post hCG injection. The method of fixed-time AI was adapted from the protocols of Hühn et al. (1996) and Brüssow et al. (1996).

For ALT + hCG96 ($n = 41$), the sows were treated with ALT using the same regimen as the sows in ALT + hCG72, but ovulation was induced using hCG at 96 h (1400–1500 h) post ALT withdrawal. The fixed time AI of this group was at 24 and 40 h post hCG injection.

Lastly, the sows in ALT + no hCG ($n = 41$) were treated with ALT the same as the sows in ALT + hCG72 and ALT + hCG96 but there was no ovulation induction. Estrus detection started immediately after ALT withdrawal and continued for 7 d. The sows in ALT + no hCG were inseminated at 12 and 36 h post estrus expression (Table 1).

After insemination, the sows were reared under the general farm management system during gestation and lactation.

Data collection

Sows were detected for estrus for 7 d post weaning (control) or post ALT withdrawal (ALT + no hCG), whereas, the sows in ALT + hCG72 and ALT + hCG96 were detected for estrus post ALT withdrawal until hCG injection and fixed-time AI; these data were calculated as the percentage of estrus. The pregnancy rate (%) was determined at 30 d of pregnancy (PigLIVE version 3.0; Live Informatics Co., Ltd.; Nonthaburi, Thailand) and the farrowing rate was recorded at birth.

At birth, information was recorded on piglets and piglets' characteristics such as the number of mummified fetuses (MM), the percentage of MM (%MM), the number of stillborn piglets (SB), the percentage of SB (%SB) and the number of born alive piglets (BAL), piglet BW, the coefficient of variation of piglets' BW (%CVBW), SDBW and the percentage of small piglets (%Small) or piglets that weighed less than 1 kg. The piglets that died during lactation were indicated as the number of PWM piglets and %PWM. Additionally, the causes of piglet death were recorded: elimination after birth (BW < 0.70 kg), elimination at weaning (BW < 3.50 kg), crushing, weakness and others.

After weaning, data were recorded of the number of PWM piglets, %PWM, the number of piglets weaned per litter (PWL), weaning weight (WW), the coefficient of variation of piglets' weaning weight (%CVWW), the standard deviation of piglets' weaning weight (SDWW) and average daily litter weight gain (ADLWG).

Statistical analyses

Normality of co-factors was checked using the Shapiro-Wilk test. The difference of co-factors among the groups was tested by one-way analysis of variance (SPSS version 18; SPSS Inc., Chicago, IL, USA).

The data on percentage of estrus, pregnancy rate and farrowing rate were compared using the Fisher's exact test (Mcdonald, 2008) and a modification of the Bonferroni-corrected, pairwise technique (MacDonald and Gardner, 2000). The sows in the control and

Table 1
Protocol of altrenogest (ALT) treatments, ovulation induction by human chorionic gonadotropin (hCG) and fixed-time artificial insemination (AI) in sows.

Group†	N	Days after weaning (D0)													
		D-4	D-3	D-2	D-1	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9
Control	40						Heat detection (D1–D7)								
										AI-1 : 12 h					
										AI-2 : 36 h					
ALT + hCG72	41	ALT	ALT	ALT	ALT	ALT	ALT	ALT	Heat detection (D3–D7)						
											hCG 72 h	AI-1 24 h	AI-2 40 h		
ALT + hCG96	41	ALT	ALT	ALT	ALT	ALT	ALT	ALT	Heat detection (D3–D8)						
												hCG 96 h	AI-1 24 h	AI-2 40 h	
ALT + no hCG	41	ALT	ALT	ALT	ALT	ALT	ALT	ALT	Heat detection (D3–D9)						
												AI-1 : 12 h			
												AI-2 : 36 h			

ALT = altrenogest; hCG = human chorionic gonadotropin.

Note: †Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT+hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT+hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT+no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

ALT + no hCG were indicated as absent of estrus sign if they had not expressed estrus signs within 7 d post weaning or post ALT treatment respectively. The sows in ALT + hCG72 and ALT + hCG96 were also indicated as absent of estrus signs if they had not expressed estrus signs during the fixed-time AI protocol.

The information of sows and their piglets' characteristics were checked for normality using the Shapiro-Wilk test. Outlier values (total 14 sows; control = 3 sows, ALT + hCG72 = 2 sows, ALT + hCG96 = 5 sows, ALT + no hCG = 4 sows) were excluded from the analysis. The differences between the groups were analyzed using one-way analysis of variance and the Bonferroni multiple comparison test (SPSS version 18; SPSS Inc., Chicago, IL, USA). The relevant co-factors including previous LS (Pre-LS) (French et al., 1979), parity (Koketsu et al., 1999) and previous BCS at weaning (Pre-WBCS) (Schenkel et al., 2010) were adjusted before comparison of LS (Model 1), whereas, MM, %MM, SB, %SB, BAL, BW, %CVBW, SDBW, %Small piglets, PWM and %PWM were adjusted for parity (Koketsu et al., 1999), LS (Quiniou et al., 2002) and farrowing BCS (FBCS) (Clowes et al., 2003; Kim et al., 2015) before analysis (Model 2).

The PWL, WW, %CVWW, SDWW and ADLWG normality and significance were determined using one-way analysis of variance and the Bonferroni multiple comparison test (SPSS version 18; SPSS Inc., Chicago, IL, USA). Likewise, correction before analysis (Model 3) was applied for the relevant co-factors consisting of parity, the number of nursing piglets (NP) (Milligan et al., 2002a), LL (Koketsu et al., 1998; Milligan et al., 2002a) and BCS loss during lactation (BCS loss) (Clowes et al., 2003). The 33 sows (control = 13, ALT + hCG72 = 3, ALT + hCG96 = 9 and ALT + no hCG = 8 sows) that had to be nursed off during lactation because of sickness were excluded from the analysis.

A significant difference was identified when $p < 0.05$. Data were presented as mean ± SE.

Results

Comparisons of co-factors

The co-factors at birth such as Pre-LS, LS, parity, Pre-WBCS, FCS (Table 2) and co-factors at weaning such as parity, LL, BCS loss, NP were not significantly different between groups (Table 3).

Percentage of estrus, pregnancy rate and farrowing rates

The sows in ALT + hCG72 expressed a highly significantly ($p < 0.001$) lesser percentage of estrus than the sows in the control and ALT + no hCG. However, the percentage of estrus of ALT + hCG72 was not different from ALT + hCG96. After insemination, the sows in all the groups had the same pregnancy rate and farrowing rate (Table 4).

Piglet characteristics at birth, piglet birth weight and piglet birth weight variation

The LS, BAL, SB, %SB, MM, %MM, were not significantly different among the groups, as well as piglet BW. However, a difference in piglet BW variation was observed. The SDBW of ALT + hCG72 was lower than ALT + hCG96 and ALT + no hCG ($p < 0.032$) but it was the same as the control. In contrast, %CVBW and %Small did not differ significantly among the groups (Table 5).

Pre-weaning piglet performance and pre-weaning mortality

After weaning, the variables PWL, PWM, %PWM, WW, SDWW, %CVWW and ADLWG were not significantly different between the groups (Table 6). However, %PWM due to underweight piglet elimination at weaning (below 3.50 kg) in ALT + hCG72 decreased prominently ($p = 0.007$) when compared to the control, but it was not dissimilar to ALT + hCG96 and ALT + no hCG. Other causes of PWM, %PWM were not significantly different among the groups (Table 7).

Discussion

Percentage of estrus, pregnancy rate and farrowing rate

The precise interval between ALT withdrawal and hCG injection was important for estrus expression in sows. The shortest interval (ALT + hCG72) resulted in a lower percentage of estrus. An insufficient interval might not allow follicular growth and the production of adequate amounts of estrogen and therefore not induce estrus (Driancourt et al., 1992). Additionally, improper timing of hCG injection had an ineffective effect on estrus due to the

Table 2
Comparisons of co-factors at birth between groups.

Co-factor	Group[a]	n	Mean ± SE	Significance[‡]
Previous litter size	Control	31	17.03 ± 0.51	NS
	ALT + hCG72	22	16.43 ± 0.70	
	ALT + hCG96	26	17.37 ± 0.69	
	ALT + no hCG	33	16.21 ± 0.60	
Litter size	Control	31	17.68 ± 0.48	NS
	ALT + hCG72	22	16.09 ± 0.65	
	ALT + hCG96	26	16.67 ± 0.74	
	ALT + no hCG	33	16.41 ± 0.54	
Parity	Control	31	4.19 ± 0.20	NS
	ALT + hCG72	22	4.04 ± 0.28	
	ALT + hCG96	26	4.26 ± 0.20	
	ALT + no hCG	33	4.21 ± 0.18	
Previous weaning body condition score	Control	31	2.17 ± 0.04	NS
	ALT + hCG72	22	2.26 ± 0.05	
	ALT + hCG96	26	2.26 ± 0.05	
	ALT + no hCG	33	2.26 ± 0.05	
Farrowing body condition score	Control	31	3.02 ± 0.04	NS
	ALT + hCG72	22	3.16 ± 0.05	
	ALT + hCG96	26	3.15 ± 0.05	
	ALT + no hCG	33	3.08 ± 0.04	

ALT = altrenogest; hCG = human chorionic gonadotropin.
Note.
[‡]NS = not significant ($p \geq 0.05$).
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

Table 3
Comparisons of co-factors at weaning between groups.

Co-factor	Group[a]	n	Mean ± SE	Significance[‡]
Parity	Control	18	3.90 ± 0.87	NS
	ALT + hCG72	19	4.09 ± 0.87	
	ALT + hCG96	17	4.24 ± 0.92	
	ALT + no hCG	25	4.17 ± 0.77	
Lactation length	Control	18	26.75 ± 5.98	NS
	ALT + hCG72	19	27.27 ± 5.81	
	ALT + hCG96	17	27.10 ± 5.91	
	ALT + no hCG	25	26.79 ± 4.98	
Body condition score loss	Control	18	0.85 ± 0.19	NS
	ALT + hCG72	19	0.89 ± 0.19	
	ALT + hCG96	17	0.90 ± 0.20	
	ALT + no hCG	25	0.79 ± 0.15	
Number of nursing piglets	Control	18	12.22 ± 2.88	NS
	ALT + hCG72	19	12.00 ± 2.75	
	ALT + hCG96	17	11.18 ± 2.71	
	ALT + no hCG	25	11.96 ± 2.39	

ALT = altrenogest; hCG = human chorionic gonadotropin.
Note.
[‡]NS = not significant ($p \geq 0.05$).
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

hormonal imbalance which resulted in a failure to observe pre-ovulatory luteinizing hormone (LH) surge. Earlier production of progesterone by luteinizing of follicles, consequently interfered with the ovulation process (Ziecik et al., 1987; Kaeoket, 2008). On the other hand, the 96 h interval could induce estrus expression at a greater percentage in sows.

Table 4
Difference in percentages of estrus, pregnancy rate and farrowing rates among groups.

Variable	Value	Group[a]				Significance[‡]
		Control	ALT + hCG72	ALT + hCG96	ALT + no hCG	
Estrus	%	90.00[a]	60.98[b]	80.49[ab]	95.12[a]	***
	n	36	25	33	39	
Pregnancy	%	97.22	100.00	100.00	100.00	NS
	n	35	25	33	39	
Farrowing	%	94.44	96.00	93.94	94.87	NS
	n	34	24	31	37	

ALT = altrenogest; hCG = human chorionic gonadotropin.
Note.
[‡]NS = not significant ($p \geq 0.05$); * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.
[a, b] = values within a row with different superscripts are significantly different at $p < 0.05$.
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

The different protocols of ovulation induction and fixed-time AI might have caused the dissimilar results that were observed in this study. Hühn et al. (1996) and Brüssow et al. (1996) recommended hCG injection at 72 h post equine chorionic gonadotropin (eCG) which was administered to the sows at 24 h post weaning without prior ALT treatment.

However, the number of ovulated follicles of the sows in ALT + hCG72 was sufficient for fertilization and development. Therefore, the sows in this group were able to have the same pregnancy rate, farrowing rate and LS as the sows in the other groups.

Piglet characteristics at birth, piglet birth weight and piglet birth weight variation

The ALT treatment during the peri-weaning period accompanied with the hCG induction in this study did not cause any differences in LS, BAL, SB and MM among the groups. This result was in agreement with van Leeuwen et al. (2011b) who supplemented ALT at 20 mg/d and 40 g/d to the multiparous sows during D-1–D6, D-3–D0 and D-3–D6. However, their results indicated that ALT could improve LS in primiparous sows with a compromised BCS after lactation, because the protocol of ALT treatment allowed a longer recovery period after weaning.

Quiniou et al. (2002) mentioned that increasing LS decreased the mean piglet BW but the similarity of LS among the groups in this study might lead to the same piglet BW between the groups. Decreasing BW variation by promoting follicular growth and reducing the ovulation time was effective only to some degree because BW variation was also determined by the post implantation process; for example, the positioning of implantation (Perry and Rowell, 1969) and placental efficiency (Wilson et al., 1999). Oocyte maturation and the ovulation time have been linked to the diversity of embryos within litter (Pope et al., 1990; Pope, 1994) and ALT supplementation in sows at 20 mg/d for 7 d (D-4–D2) could produce a homogeneous pool of follicles on day 4 of the follicular phase (Kitkha et al., 2014). The optimum ovulation time was essential for the cluster of ovulated follicles. The 72 h interval of ALT + hCG72 could reduce the SDBW. Nevertheless, it did not differ from the control, while a longer time interval (96 h) of ALT + hCG96 might allow the ovulation of large follicles before ovulation

Table 5
Piglet characteristics at birth, piglet birth weight and piglet birth weight variation.

Variable	Group[a]				Significance[‡]					
	Control	ALT + hCG72	ALT + hCG96	ALT + no hCG	Co-factor					Group
	$n = 31$	$n = 22$	$n = 26$	$n = 33$	Pre-LS	LS	Parity	Pre-WBCS	FBCS	
Litter size	17.86 ± 0.50	16.09 ± 0.65	16.67 ± 0.74	16.61 ± 0.57	***	–	NS	NS	–	NS
Number of mummified fetuses	0.71 ± 0.21	0.32 ± 0.12	0.81 ± 0.25	0.70 ± 0.21	–	**	NS	–	NS	NS
Percentage of mummified fetuses	3.87 ± 1.12	1.72 ± 0.64	4.55 ± 1.35	4.10 ± 1.17	–	NS	NS	–	NS	NS
Number of stillborn piglets	1.97 ± 0.35	1.64 ± 0.31	1.85 ± 0.33	1.94 ± 0.32	–	***	NS	–	NS	NS
Percentage of stillborn piglets	10.69 ± 1.85	9.95 ± 1.89	10.82 ± 1.91	11.17 ± 1.62	–	*	NS	–	NS	NS
Number of born alive piglets	15.00 ± 0.45	14.27 ± 0.61	14.12 ± 0.74	13.85 ± 0.45	–	***	NS	–	NS	NS
Birth weight (kg)	1.58 ± 0.03	1.51 ± 0.06	1.54 ± 0.04	1.58 ± 0.04	–	***	NS	–	*	NS
Standard deviation of piglet birth weight (kg)	0.39 ± 0.02[ab]	0.32 ± 0.02[a]	0.40 ± 0.02[b]	0.40 ± 0.02[b]	–	NS	NS	–	NS	*
Coefficient of variation of piglet birth weight	24.87 ± 1.16	22.04 ± 1.36	26.46 ± 1.45	25.60 ± 1.44	–	***	NS	–	NS	NS
Percentage of small piglets	7.75 ± 1.20	8.80 ± 2.11	8.35 ± 1.53	8.26 ± 1.32	–	***	NS	–	NS	NS

ALT = altrenogest; hCG = human chorionic gonadotropin; LS = litter size; Pre-WBCS = previous body condition score at weaning (Pre-WBCS); FBCS = farrowing body condition score.
Note.
[‡]NS = not significant ($p \geq 0.05$); * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.
[a, b] = values (mean ± SE) within a row with different superscripts are significantly different at $p < 0.05$.
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

Table 6
Pre-weaning piglet performance.

Variable	Group[a]				Significance[‡]				
	Control	ALT + hCG72	ALT + hCG96	ALT + no hCG	Co-factor				Group
	$n = 18$	$n = 19$	$n = 17$	$n = 25$	Parity	LL	BCS loss	NP	
The number of piglet weaned/litter (PWL)	12.33 ± 0.42	12.21 ± 0.36	9.94 ± 0.39	11.96 ± 0.31	NS	NS	NS	***	NS
The number of pre-weaning mortality piglets (PWM)	2.28 ± 0.52	2.11 ± 0.79	4.12 ± 1.28	1.60 ± 0.59	NS	NS	NS	***	NS
The percentage of pre-weaning mortality piglets (%PWM)	14.53 ± 3.59	11.15 ± 5.10	18.10 ± 10.71	8.95 ± 4.26	NS	NS	NS	***	NS
Weaning weight (WW, kg)	7.03 ± 0.22	6.85 ± 0.24	7.42 ± 0.20	6.94 ± 0.17	NS	NS	NS	NS	NS
Standard deviation of weaning weight (SDWW, kg)	1.24 ± 0.09	1.45 ± 0.08	1.26 ± 0.10	1.29 ± 0.08	NS	NS	NS	NS	NS
Coefficient of variation of piglet weaning weight (%CVWW)	17.93 ± 1.47	21.36 ± 1.06	17.22 ± 1.39	18.66 ± 0.98	NS	NS	NS	NS	NS
Average daily litter weight gain (kg/litter/d)	2.53 ± 0.13	2.35 ± 0.11	2.15 ± 0.12	2.41 ± 0.09	NS	NS	NS	***	NS

ALT = altrenogest; hCG = human chorionic gonadotropin; LL = lactation length; BCS loss = body condition score loss during lactation; NP = number of nursing piglets.
Note.
[‡]NS = not significant ($p \geq 0.05$); * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.
[a, b] = values (mean ± SE) within a row with different superscripts are significantly different at $p < 0.05$.
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

Table 7
Causes of pre-weaning mortality.

Causes of pre-weaning mortality	Group[a]								Significance
	Control		ALT + hCG72		ALT + hCG96		ALT + no hCG		
	n	%	n	%	n	%	n	%	
Elimination at birth (below 0.70 kg)	0	0.00	4	8.33	2	3.57	5	6.33	NS
Elimination at weaning (below 3.50 kg)	13	32.50[a]	4	8.33[b]	6	10.71[ab]	19	24.05[ab]	**
Crushing	8	20.00	16	33.33	24	42.86	26	32.91	NS
Weakness	15	37.50	20	41.67	22	39.29	27	34.18	NS
Others	4	10.00	4	8.33	2	3.57	2	2.53	NS

ALT = altrenogest; hCG = human chorionic gonadotropin.
Note.
[‡]NS = not significant ($p \geq 0.05$); * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.
[a, b] = values within a row with different superscripts are significantly different at $p < 0.05$.
[a] Control: no ALT treatment without ovulation induction, AI at 12 and 36 h after estrus; ALT + hCG72: ALT treatment at 20 mg/d for 7 d (D-4–D2; D0 = weaning day), ovulation induction by hCG 750 IU, i.m. at 72 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + hCG96: ALT treatment at 20 mg/d for 7 d (D-4–D2), ovulation induction by hCG 750 IU, i.m. at 96 h after ALT withdrawal, fixed-time AI at 24 h (AI-1) and 40 h (AI-2) post hCG injection; ALT + no hCG: ALT treatment at 20 mg/d for 7 d (D-4–D2) without ovulation induction, AI at 12 h (AI-1) and 36 h (AI-2) after estrus.

induction by hCG. Therefore, the ovulated follicles of the sows in ALT + hCG96 might occur over a wide period. This was the reason why the SDBW of the sows in ALT + hCG96 remained higher than the SDBW of the sows in ALT + hCG72. In addition, the SDBW of ALT + hCG96 was not different from the sows without ovulation induction such as the sows in the control and ALT + no hCG.

Pre-weaning piglet performance and pre-weaning mortality

The distinction of WW, WW variation and ADLWG among the groups was not noticeable in this study. In general, the differences in BW were maintained or increased throughout lactation because of the indirect competition or the ability of piglets with a larger BW to stimulate and drain their teats more effectively and to receive a larger fraction of the hormone and nutrients provided by the milk (Fraser et al., 1979; Thompson and Fraser, 1986; Algers et al., 1991; Milligan et al., 2002b). However, the normal sow herd management of the pig farm in this study might have reduced the indirect competition effect because the underweight piglets (below 1.20 kg BW) at birth were supplemented with a milk replacer at 7 d after birth. Moreover, cross-fostering of low BW piglets at 24 h after birth into the litter with similar size littermates and within the same group, possibly improved survival and weight gain (Marcatti Neto, 1986). In addition, a lot of nurse off sows due to sickness reduced the sample size in each group. Therefore, the power to find a significant difference of pre-weaning performance and pre-weaning mortality among groups was decreased (Lachin, 1981).

The reduction of piglet BW variation such as diminishing of the SDBW could not cope with the overall causes of PWM; for example crushing by the sow, starvation, scours, and respiratory problem (Shankar et al., 2009). Thus, the total PWM and %PWM were not different among the groups. However, %PWM from underweight piglet elimination at weaning (below 3.50 kg) of ALT + hCG72 was lower than in the control. During lactation, direct competition within a litter with the exclusion of light littermate access to functional and productive teats caused a lower survival of low BW piglets (English et al., 1977; English and Morrison, 1984). Although, the low BW piglets remained alive at weaning in this study due to milk replacer supplementation and cross-fostering, a larger elimination of underweight piglets (below 3.50 kg) at weaning was evident in the groups that had a higher SDBW.

In conclusion, the improvement of follicular development and the reduction of ovulation time during the pre-implantation period by supplementation with ALT (D-4–D2) at 20 mg/d and ovulation induction by hCG 750 IU, i.m. at 72 h post ALT withdrawal concomitantly with fixed-time AI at 24 and 40 h after hCG injection in sows could improve piglet BW variation to some degree. Other factors during post-implantation period also reflected piglet BW and BW variation. Nevertheless, the advantage of improving piglet BW variation during the pre-implantation period led to a lower elimination of underweight piglets (below 3.50 kg) at weaning. Furthermore, fine-tuning of the timing of hCG injection was necessary to enhance the percentage of estrus and thus obtain a satisfactory result.

Conflict of interest

The authors warrant that there are no conflicts of interests among the authors, and between the authors and other people, institutions or organizations.

Acknowledgements

The authors gratefully thank the Center for Agricultural Biotechnology, Kasetsart University, Bangkok Thailand and the Center of Excellence on Agricultural Biotechnology: (AG-BIO/PERDO-CHE), Thailand for their financial support, Ceva Animal Health, Thailand for financial support and supplying Altresyn®, the V.P.F. Group and its employees for their assistance in this study and the Faculty of Veterinary Medicine, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand for the use of their facilities.

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