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Effect of oral supplementation with different energy boosters in newborn piglets on pre-weaning mortality, growth and serological levels of IGF-I and IgG[1]

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ABSTRACT: Oral supplements are commonly used in commercial herds to improve energy status and passive immune acquisition of newborn piglets. However, there is little scientific evidence on the efficacy of oral supplements for piglets. The objective of this experiment was to study the effects of 2 oral supplementation products on piglet pre-weaning mortality and growth. A total of 62 litters (749 piglets) were distributed according to the sow's parity among 3 treatments: 1) CONTROL group, no oral supplementation to piglets; 2) EN group, light piglets (LP: birth BW ≤ 1.35 kg) received 2 doses of 1 mL Lianol Colostro; 3) COLO group, LP received 2 doses of 5 mL ColoBoost. Treatments were administered within 4 h after birth and repeated 8 h after the first dose. Piglets were weighed at d 0, 1, 10, and 21 after birth. Piglet rectal temperature was recorded shortly after birth and at 24 h. Cross-fostering was performed 24 h after birth. Blood samples were obtained from 39 LP at d 5 and 21 to determine IGF-I and IgG levels. Total mortality and LP mortality rate (percentage of LP in the litter that died) were recorded. At d 1, the EN group had a lower total mortality rate (2.1 vs. 7.1 ± 1.4%, P = 0.036) and LP mortality rate (4.5 vs. 11.1 ± 2.8%, P = 0.047) than the CONTROL group. At d 1, the COLO group tended to have a lower LP mortality rate than the CONTROL group (8.4 vs. 11.1 ± 3.0%, P = 0.058). After cross-fostering, the COLO group had a lower LP mortality rate at d 21 than the CONTROL group (6.3 vs. 18.3 ± 2.8%, P = 0.043). The total mortality rate and piglet body weight did not differ among groups at d 21. Piglets in the COLO group had a higher IgG level at d 5 than those in the EN group (24.9 vs. 16.3 ± 2.15 mg/mL, P = 0.034) and tended to be higher than those in the CONTROL group (24.9 vs. 17.7 ± 2.35 mg/mL, P = 0.072). Piglets in the EN group had a higher serum IGF-I concentration than those in the CONTROL group at d 21 (137.6 vs. 100.3 ± 11.15 ng/mL, P = 0.030). The results suggested that 2 doses of oral supplementation within 12 h after birth might be effective in increasing small piglet survival and improving their IGF-I or IgG levels during lactation without compromising litter growth.

Key words: colostrum, IGF-I, IgG, mortality, oral supplementation, piglet

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INTRODUCTION

Piglet losses during early lactation are a major economic and welfare concern in swine production. Although crushing, starvation and chilling are usually identified as the main causes of death, insufficient colostrum intake remains the main underlying cause for early postnatal mortality (Edwards, 2002; Muns et al., 2016). It is also well known that birth weight is the most important factor influencing future performance of piglets (Muns et al., 2013). Secondary to the increase in litter size, there has been an increase in the number of small and immature piglets at birth (Vasdal and Andersen,

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2012), resulting in more piglets at risk of reduced colostrum intake. Colostrum provides the newborn piglet with energy as well as with immunoglobulins, hormones and growth factors (Quesnel et al., 2012; Rooke and Bland, 2002; Wu et al., 2010). Several attempts to increase piglet survival through early management have been studied. Positive results have been observed by drying the piglets after birth (Christison et al., 1997), or drying and placing them close to the udder (Vasdal et al., 2011). While oral supplementation of newborn piglets with colostrum is commonly performed by farmers and the use of energy boosters is increasing in sow herds, there is a lack of studies on the effect of oral supplements on pre-weaning survival and growth of newborn piglets (De Vos et al., 2014; Muns and Tummaruk, 2016). The objective of this experiment was to study the benefits of oral supplementation using 2 commercial booster preparations (differing in their composition and their protein content) on piglet survival and growth, focusing on low birth weight piglets: 1) a booster preparation derived from glycerol and fermented potato protein (Lianol Colostro), and 2) a colostrum replacer containing bovine derived immunoglobulin (ColoBoost). We hypothesized that oral supplementation will increase early survival of piglets and that the use of a colostrum replacer containing bovine derived immunoglobulins will also enhance their serological levels of immunoglobulin.

MATERIALS AND METHODS

The experiment followed the guidelines documented in "The Ethical Principles and Guidelines for the Use of Animals for Scientific Purposes" edited by the National Research Council of Thailand, and was approved by the IACUC in accordance with the university regulations and policies governing the care and use of experimental animals. The experiment was conducted during May, 2015 on a commercial farm in Thailand with 3000-sow (Landrace × Yorkshire crossbred females produced in the farm) in a weekly batch system. The average ambient temperature during the experimental period was 30.7°C. The minimum and maximum temperature ranged from 25.8°C to 37.5°C. The average relative humidity was 71.0%.

Animals, Housing, and Management

Sows were kept in individual stalls (1.20 m^2) during gestation and fed a commercial gestation diet according to their requirements (NRC, 2012; Table 1). Feed was provided twice a day following a standardized feeding pattern, resulting in an average of 2.5 kg of feed per sow per d. The animals received water ad libitum in a continuous feed and water channel. On d 109 of gestation, sows were moved to the farrowing house. Both the gestation and farrowing facilities consisted in a conventional open-housing system provided with fans and individual water sprinklers to reduce the impact of high ambient temperature. Sows from the different treatments were evenly distributed within the house. Farrowing pens (3.28 m^2) were distributed in 2 rows with a central alley and 2 alleys on the sides. The pens were fully slatted with concrete at their center for the sows and with steel slats at both sides of the farrowing crate for the piglets. Each pen was provided with a creep area for the piglets (0.60 m^2) placed on the floor on 1 side and covered by a plastic plate without any heating source. The researcher had access to the sow from the front and the rear of the pen and had easy access to the creep area through the top of it. Following the usual feeding routine of the farm, lactating sows were fed twice a day with a dry corn-soybean meal diet (Table 1) that met or exceeded nutritional requirements (NRC, 2012). The amount of feed offered was increased daily until ad libitum feed was reached after 1 wk of lactation. Sows and piglets had ad libitum access to water via separated nipple drinkers. The parturition process was carefully supervised. The sows and piglets were interfered with as minimally as possible. The farm's routine intervention was limited to visual supervision of the farrowing and removing placenta, mummified piglets or dead piglets. No extra management was performed on the newborn piglets. Routine procedures performed on piglets included tail docking, tooth clipping and a 1 mL iron supplement administered

Table 1. Gestation and lactation diets composition

Item	Gestation diet	Lactation diet
Proximate analysis (%)		
Dry matter	93.8	94.1
Crude protein	19.7	23.7
Crude fat	5.8	6.6
Crude fiber	3.4	2.3
Metabolizable energy (MJ/kg)	14	16
Ingredients (g/kg)		
Soybean meal	180	220
Broken rice	430	400
Rice bran	280	120
Rice bran solvent meal	80	–
Steamed beans meal	–	100
L-Lysine HCl (99.0%)	0.5	0.7
DL-Methionine (99.0%)	0.05	0.2
L-Threonine (99.0%)	–	0.7
L-Valine (98.5%)	–	0.2
L-Tryptophan (99.0%)	–	0.2
Salt	4	3
Limestone	25	7
$CaHPO_4$	–	22
$Ca(H_2PO_4)_2$	4	–
Milk	–	150

intramuscularly (Gleptosil, Alstoe Ltd. Animal Health, Leicestershire, England) on the first day of life. Piglets were orally administered coccidiocide (Baycox, OLIC Ltd., Ayutthaya, Thailand) on the third day of age. No creep feed was offered to the piglets during lactation. Weaning took place at 23 ± 2 d of age. During the entire experiment the animals were checked daily for health or eating problems. During the experiment no pathologic symptoms were observed on the farm.

Experimental Design

A total of 749 piglets from 62 multiparous sows, ranging from the second to sixth parity and involving 2 consecutive farrowing batches, were used in the experiment. On farrowing day, sows were allocated to 1 of 3 treatments according to their parity, back fat thickness (**BF**) and number of live born piglets: no oral supplementation (**CONTROL**); oral supplementation with 2 doses (2 × 1 mL) of Lianol Colostro (96.0% DM, 1.1% CP, 0.0% CF, 0.0% CFib and 0.3% CA; Huvepharma Ltd., Bangkok, Thailand), an energy booster composed of glycerol (898 g/kg), fermented potato protein (99 g/kg), and Vitamin E (3 g/kg; **EN**); and oral supplementation with 2 doses (2 × 5ml) of ColoBoost (96.0% DM, 27.0% CP, 7.3% CF, and 5.9% CA; Newborn animal care, Lamballe Cedex, France), a colostrum replacer prepared at 10% w/v from freeze dried skimmed bovine colostrum powder containing 30.7% of immunoglobulins (25.7% of IgG) according to the manufacturer (**COLO**). The analyzed energy content of Lianol Colostro was 1,602 kJ/100g and that of ColoBoost was 1665 kJ/100g. Oral supplementation was only given to light piglets with a birth weight of 1.35 kg or less (**LP**), leaving the heavy piglets born weighing more than 1.35 kg of BW (**HP**) without oral supplementation. According to Panzardi et al. (2013), piglets born with 1.30 kg or less approximately account for 55% of the deaths during the first 3 d of lactation. In the present study, LP were defined to include the piglets accounting for more than the half of the early deaths in the farm. Piglets were held with 1 hand and the supplement was carefully administered in their mouth to avoid regurgitation. The Lianol Colostro had its own dispenser and the ColoBoost was administered using a 10mL plastic syringe. After being supplemented, piglets were returned at the same place where they had been taken. The first dose of the treatments was administered within 4 h after the birth of each piglet, and the second dose was administered 8 h after the first. On d 1 (18 to 24 h after birth), all litters were standardized to 11 or 12 piglets ensuring that only 4 or 5 piglets of the litter were LP. Treatments were evenly distributed between batches. Cross-fostering was performed among sows of the same treatment and among sows that farrowed within a same 12 h period aiming to move piglets as minimally as possible from one sow to another. All the surplus piglets were excluded from the experiment and allocated to sows not included in the experiment. Back fat thickness from sows was measured on the P2 spot (last rib 65 mm down the dorsal middle line) on both sides of the body using a Renco Lean Meater ultrasound system (Renco Corporation, North Minneapolis, MN) 24 h after farrowing and on d 21 post-farrowing. To monitor sow's body energy mobilization during lactation, BF loss at d 21 was calculated. The number of piglets born alive and stillborn, and the number of mummified fetuses were recorded after the farrowing was completed.

Within 4 h after birth, piglet rectal temperature was recorded with a digital thermometer (MSR, Measure Technology Co. Ltd; Taipei, Taiwan, with a display resolution of 0.01°C and ± 0.1°C accuracy), and piglets were ear notched for individual identification. On d 1 (18 to 24 h after birth) piglet rectal temperature was recorded again. Piglets were weighed on d 0 (within 4 h after birth), 1, 10, and 21. Piglet body weight gain at d 1 was calculated as an indirect measure of piglets' colostrum intake within weightings. On d 1, cross-fostering was performed as described above. Litter pre-weaning mortality was recorded throughout the experiment differentiating between total piglet mortality rate in the litter and percentage of LP of the litter that died. After cross-fostering, 588 piglets from 52 multiparous sows remained in the experiment and were monitored until weaning. In addition, five extra sows whose litters were composed of only HP were also monitored from d 1 to 21 so that their information could be used when comparing piglet growth data (54 HP).

On d 5 post-farrowing, 2 mL blood samples were obtained from 39 female LP randomly selected from sows included in the experiment (CONTROL, n = 14; COLO, n = 13; and EN, n = 13). From the same piglets, a 2 mL blood sample was obtained again on d 21 post-farrowing. Samples were obtained by jugular venipuncture into 9 mL serum separated clot activator tubes (Vacuette, Greiner Bio-One GmbH, Kremsmünster, Austria) and centrifuged at 2000 × g for 10 min. The serum was stored frozen at -20°C until IgG and human IGF-I were determined. Immunoglobulin G was measured from serum samples using the Pig IgG ELISA Quantitation Set (Bethyl Laboratories, Inc., Montgomery, TX). Insulin-like growth factor I was measured from serum samples using the Mediagnost IGF-I ELISA E20 kit (Mediagnost Gesellschaft für Forschung und Herstellung von Diagnostika GmbH. Reutlingen, Germany).

Statistical Analysis

All statistical analyses were performed using SAS 9.2 (SAS Inst. Inc., Cary, NC). All data was explored

to determine distribution using the UNIVARIATE procedure of SAS. All variables were analyzed using the litter as the experimental unit (to correct for clustering of piglets within litters and to correct for confounding factors at the sow level, the litter was introduced in all models as a random effect and was nested within the main treatment effect). The α level of significance was set at 0.05. All results are presented as mean values.

Piglet mortality variables did not follow normal distribution and were log transformed before being analyzed. Differences among groups for litter averages of piglet weight, litter weight variance and individual piglet weight during lactation were analyzed by repeated measures using the MIXED procedure of SAS. The model included oral supplementation treatment, day of weighing, as fixed effects, and the interaction between oral supplementation treatment and day of weighing was also included. Differences among treatments for litter averages of piglet birth weight, litter birth weight variance, total piglet mortality, LP mortality, sow BF loss during the experiment and piglet rectal temperature, body weight at d 0 and d 1 (before cross-fostering), body weight gain, and serological IgG and IGF-I concentrations were analyzed by general linear mixed models using the MIXED procedure of SAS. All models included the oral supplementation treatment as a fixed effects. Litter size was categorized into 3 groups (< 12, 12 – 14, > 14 live born piglets) and introduced as a fixed effect when significant ($P < 0.05$). In addition, farrowing batch and piglet sex (for piglet variables) were also introduced as a fixed effect when significant. For rectal temperature and body weight at d 1, body weight at d 0 was introduced as a covariate, and for rectal temperature at d 1, rectal temperature at d 0 was also introduced as a covariate. The relations between IGF-I and body weight at d 0, d 21 and body weight gain at d 21 were tested using Spearman correlation.

RESULTS

No treatment effect was observed on sows' parity, reproductive performance, litter average piglet body weight at d 0 or BF after farrowing ($P > 0.05$). The sows' parity averaged 4.3 ± 0.41. The number of piglets born alive, number of stillborn piglets and number of mummified fetuses per litter were 12.4 ± 0.77, 0.8 ± 0.22 (5.9%) and 0.3 ± 0.14 (2.2%), respectively. Litter average piglet body weight at d 0 was 1.52 ± 0.053 kg. Sows had an average BF of 15.8 ± 0.61 mm after farrowing. At d 1, after cross-fostering was performed, litters were fixed at 11.9 ± 0.19 piglets, with 5.0 ± 0.28 LP per litter.

Sow productive parameters for the different treatment groups during lactation (after cross-fostering) are presented in Table 2. Sows from the different groups had similar BF loss during lactation ($P = 0.329$). No

Table 2. Oral supplementation effect on litter average birth weight (BW) and litter birth weight variance[1]

Variable	CONTROL[2]	COLO[3]	EN[4]	SEM	*P*-value
n	*20*	*16*	*16*		
Backfat loss, mm	2.2	3.0	2.2	0.24	0.329
Litter size	12.1	11.7	11.8	0.19	0.433
Litter avg. piglet BW d 1, kg	1.53	1.57	1.55	0.051	0.642
Litter avg. piglet BW d 10, kg	3.23	3.25	3.36	0.109	0.179
Litter avg. piglet BW d 21, kg	5.65	5.56	5.90	0.199	0.268
Litter BW variance d 1	0.13	0.11	0.13	0.017	0.382
Litter BW variance d 10	0.66	0.50	0.64	0.091	0.676
Litter BW variance d 21	2.02	1.74	1.84	0.149	0.869

[1]Litter was considered the experimental unit for all data.

[2]CONTROL = no oral supplementation.

[3]COLO = oral supplementation of piglets born weighing 1.35 kg or less with two 5 mL doses of ColoBoost. First dose within 4 h after the birth, and the second dose 8 h after the first.

[4]EN = oral supplementation of piglets born weighing 1.35 kg or less with two 1 mL doses of Lianol Colostro. First dose within 4 h after the birth, and the second dose 8 h after the first.

Table 3. Oral supplementation effect on litter mortality during the first 24 h of life (before cross-fostering) and from Day 1 to 21 of lactation (after cross-fostering). Piglet mortality is represented by total piglet mortality rate in the litter and percentage of piglets of the litter born weighing 1.35 kg or less (LP) that died[1]

Variable	CONTROL[2]	COLO[3]	EN[4]	SEM	*P*-value
Number of litters	23	19	20		
Number of piglets evaluated	280	218	251		
LP mortality 24 h, %	11.1[b]	8.4[ab]	4.5[a]	3.21	0.071
Total piglet mortality 24 h, %	7.1[b]	5.8[ab]	2.1[a]	1.92	0.088
Number of litters	20	16	16		
Number of piglets evaluated	234	183	171		
LP mortality d 1–10, %	4.0	3.3	2.3	1.90	0.929
Total piglet mortality d 1–10, %	1.7	3.1	1.0	1.06	0.363
LP mortality d 1–21, %	18.3[b]	6.3[a]	11.5[ab]	2.43	0.094
Total piglet mortality d 1–21, %	9.1	7.0	8.4	0.99	0.634

[a,b]Values with different superscripts differ significantly ($P < 0.05$).

[1]Litter was considered the experimental unit for all data.

[2]CONTROL = no oral supplementation.

[3]COLO = oral supplementation of piglets born weighing 1.35 kg or less with two 5 mL doses of ColoBoost. First dose within 4 h after the birth, and the second dose 8 h after the first.

[4]EN = oral supplementation of piglets born weighing 1.35 kg or less with two 1 mL doses of Lianol Colostro. First dose within 4 h after the birth, and the second dose 8 h after the first.

Table 4. Oral supplementation effect on body weight and growth during lactation (before and after cross-fostering) of piglets born weighing 1.35 kg or less[1]

Variable	CONTROL[2]	COLO[3]	EN[4]	SEM	*P*-value
Number of litters	23	19	20		
Piglets born weighing < 1.35 kg	102/280[5]	84/218	88/251		
Body wt at d 0, kg	1.12	1.16	1.12	0.010	0.208
Body wt at d 1, kg	1.20	1.25	1.17	0.013	0.515
Body wt gain d 0–1, g	61.5	81.6	54.6	0.01	0.378
Number of litters	20	16	16		
Piglets born weighing < 1.35 kg	92/234[5]	75/183	80/171		
Body wt at d 1, kg	1.20	1.26	1.18	0.013	0.665
Body wt at d 10, kg	2.65	2.83	2.78	0.045	0.256
Body wt at d 21, kg	4.82	4.92	5.09	0.091	0.301
Body wt gain d 1–10, kg	1.43	1.55	1.59	0.038	0.321
Body wt gain d 1–21, kg	3.62	3.64	3.94	0.058	0.395

[1]Litter was considered the experimental unit for all data.

[2]CONTROL = no oral supplementation.

[3]COLO = oral supplementation of piglets born weighing 1.35 kg or less with two 5 mL doses of ColoBoost. First dose within 4 h after the birth, and the second dose 8 h after the first.

[4]EN = oral supplementation of piglets born weighing 1.35 kg or less with two 1 mL doses of Lianol Colostro. First dose within 4 h after the birth, and the second dose 8 h after the first.

[5]Number of piglets born weighing 1.35 kg or less/total number of piglets in the treatment group.

Table 5. Oral supplementation effect on body weight, and growth during lactation (before and after cross-fostering) of piglets born weighing more than 1.35 kg[1]

Variable	CONTROL[2]	COLO[3]	EN[4]	HP[5]	SEM	*P*-value
Number of litters	23	19	20	–		
Piglets born weighing > 1.35 kg	92/234[6]	75/183	80/171	–		
Body wt at d 0, kg	1.66	1.70	1.65	–	0.010	0.483
Body wt at d 1, kg	1.79	1.82	1.76	–	0.011	0.284
Body wt gain d 0–1, g	123.1	114.3	91.6	–	0.00	0.286
Number of litters	20	16	16	5	0.010	0.483
Piglets born weighing > 1.35 kg	142/234[6]	108/183	91/171	54/54		
Body wt at d 1, kg	1.76	1.79	1.80	1.91	0.011	0.603
Body wt at d 10, kg	3.63	3.53	3.77	3.86	0.036	0.510
Body wt at d 21, kg	6.20	5.99	6.44	6.71	0.069	0.627
Body wt gain d 1–10, kg	1.87	1.75	2.03	1.75	0.032	0.418
Body wt gain d 1–21, kg	4.43	4.21	4.71	4.80	0.068	0.596

[1]Litter was considered the experimental unit for all data.

[2]CONTROL = no oral supplementation.

[3]COLO = oral supplementation of piglets born weighing 1.35 kg or less with two 5 mL doses of ColoBoost. First dose within 4 h after the birth, and the second dose 8 h after the first.

[4]EN = oral supplementation of piglets born weighing 1.35 kg or less with two 3 mL doses of Lianol Colostro. First dose within 4 h after the birth, and the second dose 8 h after the first.

[5]HP = litters composed only of piglets born weighing more than 1.35 kg.

[6]Number of piglets born weighing more than 1.35 kg/total number of piglets in the treatment group.

difference among groups for average litter weight or for litter weight variance was observed during the lactation period ($P > 0.05$). Piglet pre-weaning mortality data from sows before and after cross-fostering are presented in Table 3. The mortality results included total mortality rate in the litter and LP mortality rate (percentage of LP in the litter that died). During the first 24 h after farrowing (before cross-fostering), the EN group had a lower total mortality rate ($P = 0.036$) and a lower LP mortality rate ($P = 0.047$) than the CONTROL group. The COLO group showed a tendency for reduced LP mortality rate compared to the CONTROL group ($P = 0.058$). After cross-fostering, the COLO group had a lower LP mortality rate than the CONTROL group ($P = 0.043$) from d 1 to 21 after farrowing, but total mortality rate in the litter did not differ among groups.

Body weight and body weight gain of LP and HP during the first day of life (before cross-fostering) are presented in Table 4 and 5. At d 0, LP birth weight did not differ among groups ($P > 0.05$), and no differences for LP body weight at d 1 were observed either ($P > 0.05$). Moreover, body weight of HP did not differ among groups at birth ($P > 0.05$) or at d 1 ($P > 0.05$). Body weight gain at d 1 did not differ among groups for neither LP nor HP ($P > 0.05$). No main treatment effect was observed for piglet rectal temperature at d 1 (LP 38.2 ± 0.05°C, $P = 0.777$; HP 38.5 ± 0.04°C, $P = 0.125$; data not shown).

Body weight and body weight gain results for LP and HP during lactation (after cross-fostering) are presented in Tables 4 and 5, respectively. Light piglet body weight and growth at d 10 and 21 of lactation did not differ among groups ($P > 0.05$). Similarly, HP's body weight and growth at d 10 and 21 of lactation did not differ among groups ($P > 0.05$). In addition, the body weight and growth of piglets from litters composed of only HP did not differ from HP in the oral supplementation groups ($P > 0.05$).

Oral supplementation treatment tended to influence IgG levels of LP at d 5 ($P = 0.073$). Light piglets in the COLO group had a higher serum IgG level than LP in the EN group (24.9 vs. 16.3 ± 2.15 mg/mL, $P = 0.034$) and tended to have a higher serum IgG level than LP in the CONTROL group (24.9 vs. 17.7 ± 2.35 mg/mL, $P = 0.072$). At d 21, oral supplementation treatment had no effect on LP's serum IgG level (3.7 ± 0.30 mg/mL, $P = 0.855$). Oral supplementation treatment had no effect on LP's serum IGF-I concentration at d 5 (71.8 ± 6.03 ng/mL, $P = 0.628$) but tended to influence LP's serum IGF-I concentration at d 21 ($P = 0.086$). At d 21

of lactation, LP from the EN group had a higher serum IGF-I concentration than those in the CONTROL group (137.6 vs. 100.3 ± 11.15 ng/mL, $P = 0.030$) but did not differ from those in the COLO group (137.6 vs. 114.9 ± 9.41 ng/mL, $P = 0.188$). Sampled piglets did not differ ($P > 0.05$) in birth weight (average value 1.17 ± 0.020 kg), body weight at d 21 (average value 4.87 ± 0.135 kg) or body weight gain at d 21 (average value 3.69 ± 0.132 kg) among treatments. The serum concentration of IGF-I at d 5 and 21 were not correlated with piglet body weight at d 0 ($r = 0.01$ and $r = -0.04$, respectively; $P > 0.05$) but showed a positive correlation with both body weight at d 21 ($r = 0.67$ and $r = 0.52$, respectively; $P < 0.001$) and body weight gain at d 21 ($r = 0.73$ and $r = 0.56$, respectively; $P < 0.001$).

DISCUSSION

In the present study, oral supplementation tended to reduce total piglet mortality during the first day of life due to its beneficial impact on LP survival. This effect was significant in the EN group, and a tendency in the COLO group when compared to the CONTROL group. On the other hand, only LP in the COLO group had a lower mortality rate at d 21 compared to the CONTROL group. Using similar designs and supplementing LP with 15 mL of sow colostrum obtained from the same farm instead of a using a commercial product, Muns et al. (2014, 2015) did not observe any effect of oral supplementation on piglet survival at d 1 nor at the end of lactation. Muns et al. (2015) only observed an increase in LP body weight at d 1 in primiparous sows, while Muns et al. (2014) only observed an increase in LP body weight at d 19. Muns et al. (2014) found that an effect from oral supplementation with sow colostrum was observed in non-homogenized litters after cross-fostering but not in homogenized litters. Despite the supplements used in the present experiment are not the same as in Muns et al. (2014, 2015), their similar characteristics might suggest that the use of 2 doses of oral supplementation in the present experiment compared to the use of a single dose of colostrum in Muns et al. (2014, 2015) could explain the higher effect of oral supplementation on LP survival observed in the present experiment.

If we consider the energy content of sow colostrum to be approximately 260 kJ/100g (Theil et al., 2014), the energy provided in 1 mL of Lianol Colostro is equal to 6.2 g of colostrum while 5 mL of ColoBoost at 10% w/v is equal to 3.2 g of colostrum. Therefore, the different effect on LP mortality observed in COLO and EN groups is probably related to the commercial boosters' differences in energy content and composition. Besides having more energy content, Lianol Colostro is mainly composed of glycerol (a sugar alcohol with 3-carbon and three hydroxyl groups) which has a very high digestibility (> 99%) and is easily metabolized (Kerr et al., 2009; Oliveira et al., 2014). Presumably, LP in EN would benefit from a faster and more efficient energy boost than LP in COLO group, which could explain the reduced LP mortality at d 1 in EN group compared to CONTROL in contraposition to the tendency observed in COLO group compared to CONTROL. On the other hand, higher levels of IgG result in piglets immunologically more competent and protected (Declerck et al., 2016b). Moreover, IgG acquisition during the first day of life is positively related to piglet's growth and survival (Decaluwé et al., 2014; Ferrari et al., 2014). Therefore, the higher serum IgG levels observed in LP from COLO group would explain the lower LP mortality at d 21. Further studies including the information on the cause of death of the piglets would be of great value to better understand the benefits of the different oral supplementation options and to study whether different composition protects against different causes of death.

It has been well demonstrated that oral supplementation combined with other management strategies is effective in increasing newborn piglet survival and performance (Dewey et al., 2008; Holyoake et al., 1995; White et al., 1996). In a recent study, daily supplementation of piglets with bovine colostrum during the first 3 d after birth extended life in piglets that died during the first 10 d of lactation, but had no effect on the performance of surviving piglets (Viehmann et al., 2015). In the same study, Viehmann et al. (2015) also failed to observe beneficial effects of bovine colostrum supplementation on piglet survival or growth when tested as a single dose on d 1 of life. However, such results are mentioned but not presented in their publication. Similarly, Declerck et al. (2016a) also observed a reduction of mortality in low birth weight piglets after the administration of 2 doses of energy supplementation. In agreement with Viehmann et al. (2015) and Declerck et al. (2016a), our results suggest a cumulative effect of oral supplementation in LP irrespective of the supplemental product. In addition, the positive effect of oral supplementation on LP weaning survival observed in the present study and Declerck et al. (2016a), but not in Viehmann et al. (2015), suggests the need to perform oral supplementation during the first 12 h after birth, while the sow's colostrum is available. Due to their physical and physiological characteristics, piglets are very vulnerable at birth, and hypothermia and suboptimal energy intake might further increase their risk of mortality. Therefore, energy intake is crucial for newborn piglets. The average body weight gain during the first day of life for LP in the present experiment was not influenced by oral supplementation treatment. Since colostrum is the only energy source for newborn piglets, it can be assumed that LP had similar colostrum intake.

Similarly, Declerck et al. (2016a) found no treatment effect on piglet colostrum intake. The increased survival and the lack of difference in weight gain at d 1 suggested that oral supplementation increased the number of LP achieving an optimum growth during the first day of life, thus increasing survival at d 1. Furthermore, the lack of treatment effect on body weight and body weight gain during lactation is in agreement with the lack of difference in weight gain at d 1, and suggests that the number of piglets with reduced growth capacity was not increased with the increase in survival. However, colostrum intake has been positively related to piglet pre-weaning daily body weight gain (Decaluwé et al., 2014; Devillers et al., 2004). The amount of oral supplementation administered in the EN and COLO treatments represents a small portion of the expected colostrum intake for LP. However, as suggested by Declerck et al. (2016a), providing direct energy to LP may assist them in reaching the minimum colostrum intake needed to survive.

In recent studies, Lianol Colostro supplementation within 12 h after birth increased serum IGF-I levels at d 7 and 25 (Poolperm et al., 2012), increased serum IgG levels at d 4 (Smulder and Kanora, 2012) and reduced mortality at 24h (Kummer et al., 2015; Scollo et al., 2014) in low birth weight piglets. Similarly, in the present study, LP in the EN group had an increased IGF-I serum concentration compared to the CONTROL group at d 21, but they did not have an increased serum concentration of IgG. In the study by Smulder and Kanora (2012), the authors attributed the increase in serum IgG to the positive effect of Lianol Colostro on colostrum intake. However, Poolperm et al. (2012) attributed the increase in serum IGF-I to the pro-metabolic effect of Lianol Colostro. Glycerol (the main component of Lianol Colostro) supplementation has increased IGF-I mRNA expression in other species (Silva et al., 2013). However, there are few studies about the effect of glycerol on the development of the gastrointestinal tract, metabolic status or the immune response of pigs (Oliveira et al., 2014). Studies on sows, nursery or growing-finishing pigs did not observe any effect on plasma IGF-I after supplementing diets with glycerol (Madrid et al., 2013; Oliveira et al., 2014; Schieck et al., 2010) although glycerol supplementation did improve growth and feed intake of nursery pigs (Shields et al., 2011). Insulin-like growth factor I is a growth factor present in colostrum and milk secretions but also synthesized by the organism. It stimulates gastro-intestinal tissue growth and functional maturation in newborn animals, and in pigs it is absorbed independently of gut closure (Xu et al., 2000). In the present study IGF-I levels showed a positive relationship with body weight at d 21 and body weight gain at d 21. Accordingly, Saleri et al. (2001)also observed a positive relationship between piglet growth and plasma IGF-I levels. A positive influence on IGF-I levels could be beneficial for piglet growth after weaning. The lack of treatment effect on weight gain at d 1 suggesting no influence on colostrum intake could explain the lack of EN effect on serum IgG and could suggest an indirect effect of Lianol Colostro on IGF-I levels. Nonetheless, more research is needed to further investigate the influence of Lianol Colostro supplementation on IGF-I levels. It would be interesting to confirm the positive effect on IGF-I levels observed in the present study and in Poolperm et al. (2012) and to investigate if it is due to a positive effect on colostrum intake, which would explain the increase in IGF-I levels, due to an indirect effect on gut maturation that would enhance further absorption of IGF-I, or due to an indirect effect on the metabolic status. On the other hand, in the present study, despite the lack of an oral supplementation effect on weight gain at d 1, LP in the COLO group had a higher serum IgG concentration at Day 5. The high protein content in ColoBoost (27.0%) and the low of protein content in Lianol Colostro (1.1%) would explain the differences in serum IgG concentration. Similarly, Muns et al. (2014) observed that one dose of sow colostrum (15 mL) was enough to increase the IgG concentration of LP at d 4. Therefore, supplementing piglets with colostrum replacement, rich in protein and immunoglobulin content, is also useful to ensure a proper serum IgG level.

To conclude, around 30% of the piglets on farms are born weighing less than 1.35 kg, and they account for more than half of the early deaths observed in the farm. Those piglets could benefit from oral supplementation during the first 12 h after birth (2 doses). In addition, our results suggest that the combination of the 2 treatments, 1 dose of an energy dense product able to increase IGF-I serological levels and 1 dose of a product rich in protein and immunoglobulin content, might be a promising strategy to implement in commercial herds to reduce piglet pre-weaning mortality and enhance piglet IGF-I and IgG plasma levels.

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