RESEARCH ARTICLE

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Marine derived Ca-Mg complex supplementation basal diet during four subsequent parities improved longevity and performance of sows and their litters

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No potential conflict of interest relevant to this article was reported.

Abstract

The aim of the present study was to evaluate the effects of dietary supplementation of Ca-Mg complex on the longevity and reproductive performance of sows. In total, seventy-two gilts ([Yorkshire × Landrace] × Duroc, average body weight 181 kg) were randomly allocated to 1 of 3 treatments during 4 successive parity in a 4 × 3 factorial arrangement. Treatments consisted of CON (basal diet), CM1 (basal diet -MgO - 0.3% limestone + 0.4% Ca-Mg complex), and CM2 (basal diet - MgO - 0.7% limestone + 0.4% Ca-Mg complex). A higher ($p < 0.05$) number of totals born and live piglets, and sows increased feed intake during gestation and lactation, increased backfat thickness, and increased estrus interval were observed ($p < 0.05$) during their third and fourth parity than during their first and second parity. Ca-Mg complex supplementation improved ($p < 0.05$) the number of total piglets during the first and second parity as well as live-born piglets during the first to third parity, reduction ($p < 0.05$) in backfat thickness during the third and fourth parity, a higher ($p < 0.05$) initial and final number of suckling piglets as well as higher weaning weight compared with sows fed CON diet during the first, second, and third parity. The average daily gain (ADG) was higher ($p < 0.05$) in piglets born to CM1 and CM2 sows regardless of parity. The treatment diets fed to sows lowered ($p < 0.05$) the duration of first to last piglet birth and placenta expulsion time compared with CON sows. A significant interactive effect ($p = 0.042$) between parities and treatment diets was observed for the first to last piglet birth. Thus, Ca-Mg complex supplementation by partially replacing limestone in the basal diet enhanced sow performance, specifically during their third and fourth parity, thereby improving sow longevity.

Keywords: Ca- Mg complex, Longevity, Parity, Sow and suckling piglet performance

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Availability of data and material
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Authors' contributions
Conceptualization: Upadhaya SD, van der Veen RH, Kim IH.
Data curation: Seok WJ, Suresh Kumar S.
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Ethics approval and consent to participate
The experimental protocol (DK-2-1927) for this study got the consent from Animal Care and Use Committee of Dankook University, Cheonan, Korea.

INTRODUCTION

Among a wide variety of factors, nutritional management plays an influential role in improving the longevity of breeding animals throughout their productive lives. Moreover, a critical driver of sow lifetime productivity is good management of the gilt [1]. Sows that remain in a breeding herd for a longer period can produce more offspring in their lifetime than those who remain in a breeding herd for a shorter period [2,3], consequently resulting in improved economic returns to the pork producers [4]. Thus, it becomes imperative to improve pork producers' profitability by improving the sow longevity and reducing the expenses that may incur for the replacement of gilts as well as other associated costs.

In general, the reproductive performance of a sow is supposed to increase with increasing parity, reaching the highest level from parity 3 to 5 [5,6]. Many sows, however, show an equal or lower litter size in the second parity than in the first parity [7,8], which negatively influences the reproductive efficiency of second parity sows and farm productivity [9]. Being physically immature at first farrowing and having limited body reserves, the first parity sows are prone to negative effects of body reserve losses during conception and lactation. In addition, first parity sows still need energy for growth and further development. Thus, it is necessary to develop a sound feeding program that focuses on a nutritional strategy that is beneficial to sows throughout the whole lifespan of the female.

Among several nutrients, minerals constitute a small percentage of swine diets, but their impact on the pig's growth, health, and productivity is significant. The adequacy of dietary mineral recommendations needs to be re-evaluated due to the improvements in sow productivity resulting from genetic improvements. It has been reported that low levels or a low utilization rate of Ca in the diet fed to gestating sows can reduce litter size, prolong delivery time, increase the number of stillbirths, and result in a higher occurrence of skeletal problems in piglets [10]. Sows that had completed the third parity have shown a decline in mineral (Ca, P, Mg, Na, Zn, and K) composition compared to first parity gilts [10]. Mahan and Newton [11], suggest that proper nutrition management is needed throughout the lifespan of the breeding herd. Therefore, for the enhanced performance of sows, it is necessary to improve the efficient utilization of Ca and other mineral elements. Macro-minerals such as Ca, P, and Mg are indigenous in most feed grains but are available at low concentrations in feedstuffs. Furthermore, the efficiency of mineral absorption is influenced by the concentration of these minerals in the diet, the mineral source and its bioavailability, mineral-to-mineral interactions in the diet, and the mineral status of the animal [12]. The demand for Ca and Mg during gestation and lactation is high therefore, the bioavailability of these minerals in the diet has a significant influence on improving sow longevity.

Previously, several studies indicated that commercial sows leave the breeding herd at approximately parity 4, predominantly due to reduced reproductive performance and an increase in the incidence of feet and leg problems [13,14]. Both Ca, and Mg have been shown to play a role in aiding farrowing ease by increasing the strength and frequency of myometrium contractions, improving milk production, minimizing type II stillbirths and weaning to estrus interval, and improving the number of piglets born alive and their weaning weights [15–18].

Marine-derived Ca and Mg complex is a marine multi-mineral food/feed raw material derived from the calcified skeletal remains of the red marine algae species Lithothamnion and has been reported to be highly bioavailable in Ca and Mg [19]. Lithothamnion is a naturally replenishing alga that grows in the Atlantic waters off the southwest of Ireland and the northwest coast of Iceland. Minerals from seawater are accumulated in the alga frond, which breaks off and falls to the ocean floor from where they are harvested. The mineralized fronds are separated from extraneous materials, sterilized, dried, and milled, making it available as a commercial marine-derived Ca-Mg complex [20] in a number of forms for the feed and food industries. In addition to Ca and Mg, this mineral complex comprises 72 trace minerals associated with bone health, including, strontium, manganese, selenium, copper, and zinc. Unlike the presence of calcite as the main component in calcium carbonate which is derived from limestone or rock, the marine-derived Ca-Mg complex is plant-based and has a porous honeycombed vegetative cell structure containing aragonite, vaterite, and calcite calcium salts. This structural and chemical makeup of marine-derived Ca-Mg complex offers several significant benefits in its chemical behaviour and absorption [21].

It was hypothesized that the application of this marine-derived Ca-Mg complex in the diet with higher solubility and bioavailability may increase the availability of these minerals to the animals which may eventually contribute to improving longevity, reproductive performance, and the bone health of the sows. Therefore, the present study aimed to evaluate the partial replacement of limestone (that serves mainly as a Ca source) in the basal diet with marine-derived Ca-Mg complex for four successive parities on the performance of sows and their litters.

MATERIALS AND METHODS

Animal care

The experimental protocol (DK-2-1927) for this study got the consent from Animal Care and Use Committee of Dankook University, Cheonan, Republic of Korea.

Ca-Mg complex

The Ca-Mg complex, which is a marine-derived mineral complex containing 27% Ca and 10% Mg is a product of Celtic Sea Minerals (Cork, Ireland). In addition to Ca and Mg, this mineral complex comprises 72 trace minerals that are associated with bone health, including strontium, manganese, selenium, copper, and zinc.

Experimental design, animals, housing, and diets

The experimental trial commenced in June 2019 and ended in March 2021 at Dankook University swine research facility, Cheonan, Republic of Korea. A total of 72 cross-bred gilts ([Yorkshire × Landrace] × Duroc, average body weight [BW] 181 kg) in their first pregnancy were randomly allocated to 1 of 3 treatments with 24 gilts per treatment diet. Each treatment group of 24 gilts was divided into three groups of 8 gilts. The gilts remained in their allocated treatments and groups for subsequent parities up to 4th parity. Thus, each treatment was replicated 24 times for four subsequent parities.

Treatments consisted of CON (basal diet), CM1 (basal diet - MgO - 0.3% limestone + 0.4% marine-derived Ca-Mg complex), and CM2 (basal diet - MgO - 0.7% limestone + 0.4% marine-derived Ca-Mg complex).

Experimental diets were fed from the day of conception to the end of lactation (total of 135 days) during each successive parity. At day 1 of gestation, all sows' individual BW and backfat thickness were recorded. Sows were moved in fully slatted individual farrowing crates, each with 2.10 × 1.80 m and equipped with a feed trough and water nipple, and were fed either CON or CM1, or CM2 gestation diets in two equal meals. During gestation gilts/sows were fed their respective diets twice a day with a standard concentrated gestation diet (2.5 kg of a diet with 3,200 kcal metabolizable energy and 13% crude protein, half of the allocated daily amount in the morning and the other half of the allocated daily amount 12 h later. The gestation (Table 1) and lactation (Table 2) basal diets of sows were formulated to meet or exceed the nutrient requirements of pigs as recommended by National Research Council [22]. The feed leftovers were recorded weekly to calculate the average

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Table 1. Ingredient composition of experimental gestation diets (%, as-fed basis)

Items	Gestation		
	CON[1)]	CM1	CM2
Ingredients			
Corn	49.02	48.93	49.33
Soybean meal (48%)	4.22	4.25	4.06
Soybean oil	2.06	2.10	1.89
Dehulled soybean meal	5.94	5.94	5.94
Palm kernel meal	2.00	1.94	2.30
Wheat	24.41	24.41	24.41
Wheat bran	3.30	3.30	3.33
Soybean hull	2.20	2.20	2.20
Molasses	3.25	3.25	3.25
Mono calcium phosphate	0.80	0.80	0.80
Limestone	1.39	1.09	0.69
Magnesium oxide	0.02	-	-
Salt	0.50	0.50	0.50
Methionine (99%)	0.01	0.01	0.01
Threonine (100%)	0.09	0.09	0.09
L-Lysine (78%)	0.23	0.23	0.24
Vitamin/mineral premix[2)]	0.40	0.40	0.40
Choline (25%)	0.15	0.15	0.15
Phytase	0.01	0.01	0.01
Ca-Mg complex	-	0.40	0.40
Calculated composition			
Metabolizable energy (kcal/kg)	3,200	3,200	3,200
Analyzed composition			
Dry matter	88.5	89.1	88.6
Gross energy	3,45	3,45	3,46
Crude protein	12.8	13.0	12.9
Fat	4.40	4.44	4.24
Calcium	0.78	0.77	0.62
Phosphorous	0.51	0.49	0.50
Magnesium	0.19	0.19	0.19
Lysine	0.71	0.72	0.70
Methionine	0.21	0.20	0.22

[1)]CON, basal diet; CM1, Basal diet – MgO - 0.3% limestone+ 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone +0.40% marine derived Ca-Mg complex.

[2)]Provided per kg of complete diet: 16,800 IU vitamin A; 2,400 IU vitamin D_3; 108 mg vitamin E; 7.2 mg vitamin K; 18 mg riboflavin; 80.4 mg niacin; 2.64 mg thiamine; 45.6 mg D-pantothenic; 0.06 mg cobalamine; 12 mg Cu (as $CuSO_4$); 60 mg Zn (as $ZnSO_4$); 24 mg Mn (as $MnSO_4$); 0.6 mg I (as Ca $(IO_3)_2$; 0.36 mg Se (as Na_2SeO_3).

daily feed intake (ADFI) during the gestation period. Water was freely available from a drinker within the feed trough. Sows were not offered the feed on the day of parturition. The temperature in the farrowing house was maintained at a minimum of 20℃. Supplemental heat was provided for piglets using heat lamps. After day 1 of farrowing, the lactation diet was offered, and the feed allowance was gradually increased through day 4, and then sows were allowed *ad libitum* intake until weaning (day 21).

Table 2. Ingredient composition of experimental lactation diets (as-fed basis, %)

Items	Lactation		
	CON[1)]	CM1	CM2
Ingredients			
Corn	41.08	40.94	41.19
Soybean meal (48%)	4.02	4.03	3.96
Soybean oil	3.21	3.26	3.08
Dehulled soybean meal	12.96	12.96	12.96
Wheat	23.00	23.00	23.00
Wheat bran	8.31	8.31	8.31
Rice bran	2.00	2.00	2.00
Molasses	2.00	2.00	2.40
Mono calcium phosphate	0.59	0.59	0.59
Limestone	1.43	1.13	0.73
Magnesium oxide	0.02	-	-
Salt	0.50	0.50	0.50
Threonine (100%)	0.05	0.05	0.05
L-Lysine (78%)	0.30	0.3	0.3
Vitamin / mineral premix[2)]	0.40	0.40	0.40
Choline (25%)	0.12	0.12	0.12
Phytase	0.01	0.01	0.01
Ca-Mg complex	-	0.40	0.40
Calculated composition			
Metabolizable energy (kcal/kg)	3,300	3,300	3,300
Analyzed composition			
DM	88.80	88.1	89.00
Dry matter	3,60	3,59	3,61
Gross energy	16.30	16.50	16.40
Crude protein	5.76	5.81	5.64
Calcium	0.74	0.75	0.60
Phosphorous	0.51	0.53	0.56
Magnesium	0.25	0.25	0.25
Lysine	0.92	0.90	0.89
Methionine	0.20	0.23	0.21

[1)]CON, basal diet; CM1, basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

[2)]Provided per kg of complete diet: 16,800 IU vitamin A; 2,400 IU vitamin D_3; 108 mg vitamin E; 7.2 mg vitamin K; 18 mg riboflavin; 80.4 mg niacin; 2.64 mg thiamine; 45.6 mg D-pantothenic; 0.06 mg cobalamine; 12 mg Cu (as $CuSO_4$); 60 mg Zn (as $ZnSO_4$); 24 mg Mn (as $MnSO_4$); 0.6 mg I (as Ca $(IO_3)_2$); 0.36 mg Se (as Na_2SeO_3).

Experimental procedures, sampling, and analysis

Performance of sows and their litter

Approximately 7–8 days before farrowing (day 107 of gestation), the BW and backfat thickness were recorded for all sows. One day after farrowing, BW, and backfat were recorded again. The backfat of sows was measured 6 cm off the midline at the 10th rib using a real-time ultrasound instrument (Piglot 105; SFK Technology, Herlev, Denmark) at different periods (initial, before, and after farrowing and at weaning).

Sows' ADFI was determined from the recording of orts on days 7, 14, and 21 during the lactation

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period. After farrowing, the numbers of total born piglets, piglets born alive, mummified fetuses, survival rate, and BW of piglets at birth and weaning were recorded. The average daily gain (ADG) of piglets was calculated at the end of weaning. Piglets were weighed collectively in their litters in a portable box scale. Additional heat to newborn piglets for 72 h after farrowing was provided using heat lamps. The morbidity of piglets was measured overall and calculated as a percentage of each pen occurrence for pneumonia, diarrhea, and hernia. Piglets were not offered creep feed; the only feed available during lactation was sow milk. The piglets born to sows from CON and treatment groups were weaned at day 21 of lactation, and sows were returned to their gestation housing systems. The periods to return to estrus were recorded after weaning. After weaning, the detection of estrus in sows was conducted twice per day, at 08:00 h and 16:00 h every day. When the sow exhibited a standing response induced by a back-pressure test when in the presence of a boar, it was considered that the sow was in estrus.

Fecal score

Fresh fecal samples from all sows (n = 24 per treatment) were collected by a rectal massage before and after farrowing. The incidence of constipation was determined by using a 5-grade score system [23], with grade 1 standing for hard, dry pellets in a small, hard mass, grade 2 indicating hard-formed stool that remains firm and soft, grade 3 for the soft-formed and moist stool that retains its shape, grade 4 for a soft unformed stool that assumes the shape of the container, and grade 5 for a watery liquid stool that can be poured.

Duration traits

The duration of farrowing was measured from the first birth piglet to the last birth piglet, and the duration of placenta expulsion from the birth of the last piglet was recorded via visual observation.

Health issues

The shoulder sore of all sows was measured before farrowing and after farrowing, according to the shoulder sore scoring system described by Meyer et al. [24] as follows: Score 0 indicated no sores caused by other factors such as fighting and physical injury, score 1 indicated sores in the top layer of the skin, score 2 for sores in the top layer of the skin, with crust formation and scar tissues, score 3 for sores in the deeper layer of the skin with crust formation and severe scar tissue, and score 4 for deep sores into the muscles, sometimes with visible shoulder bone.

Sows were monitored daily through visual observation for their condition legs to see if they stand normally or limp and other general health problems that may lead to the culling of sows.

Chemical analysis, sampling, and measurements

Feed and fecal samples

Feed samples were analyzed in duplicates for dry matter (DM; method 930.15), crude protein (N×6.25; method 988.05), crude fat (method 954.02), Ca (method 984.01), P (method 965.17), Mg (method 968.08) and amino acids (method 982.30E) following the procedure established by Association of Official Analytical Chemists [25]. Gross energy was determined by measuring the heat of combustion in the samples using a Parr 6100 oxygen bomb calorimeter (Parr Instrument, Moline, IL, USA).

Fresh fecal samples from all sows (n = 24) per treatment at the end of the trial (i.e., from sows in their 4th parity) were collected by rectal massage to determine the apparent total tract digestibility (ATTD) of DM, Ca, P, Mg, and nitrogen (N). Chromium oxide (Cr_2O_3, 0.2%) was added to the sows' diets as an indigestible marker for a period of 7 days before feces collection. All fecal samples were stored immediately at –20℃ until analysis. Fecal samples were dried at 72℃ for 72 h and finely ground to pass through a 1-mm screen and were analyzed for N (method 988.05), Ca (method 984.01), P (method 965.17), and Mg (method 968.08) following the procedures established by the Association of Official Analytical Chemists International [25]. A UV/VIS spectrophotometer (Optizen POP, Daejeon, Korea) was used to analyze chromium oxide. For calculating the ATTD, the following formula was applied:

$$\text{Digestibility} = 1 - [(Nf \times Cd) / (Nd \times Cf)] \times 100,$$

where Nf = nutrient content in feces (% DM), Nd = nutrient content in the diet, Cd = chromium content in the diet and Cf = of chromium content in the feces.

Statistical analyses

The data were analyzed as a 4 × 3 factorial arrangement using the MIXED procedure of Statistical Analysis Systems [26]. The model included the overall parity effect (4 successive parity) and dietary treatment effects (with/without supplemental marine-derived Ca-Mg complex) from gestation to lactation. Differences among the means for treatments were determined by using Duncan's multiple-range test. Fecal scores recorded before and after farrowing were analyzed using Chi-square test during four successive parities. Variability in the data was expressed as the standard error of means (SEM), and a probability level of $p < 0.05$ was considered significant and $p < 0.01$ or < 0.0001 highly significant.

RESULTS

Reproductive performance of sows

The effect of marine-derived Ca-Mg complex and parity on the performance of sows is presented in Table 3. A significant overall parity and treatment effects ($p < 0.0001$) on total born and live piglets were observed. The third and fourth parity sows had a higher ($p < 0.05$) number of total born and live piglets compared to sows from the first and second parity. The feed intake during gestation and lactation, estrus interval, BW, and the backfat thickness change before and after farrowing and at weaning were significantly affected by parity ($p < 0.0001$). Among the parity, the ADFI during gestation and lactation was higher ($p < 0.05$) during the third and fourth parity compared to the first and second parity. The backfat thickness before and after farrowing and at weaning were also higher ($p < 0.05$) for sows in the third and fourth parity compared to those on the first and second parity. The overall parity effect ($p < 0.0001$) in the decline of backfat thickness after farrowing to lactation was also observed. The estrus interval was the highest in the fourth parity followed by the third ($p < 0.05$) among the parities investigated. The supplementation of marine-derived Ca-Mg complex to the basal diet (CM1 and CM2) led to a significant improvement ($p < 0.05$) in total piglets born during the first and second parity as well as live born piglets during the first to third parity. A significant overall treatment effect was observed for the pre-weaning survival rate ($p = 0.013$) as well as a reduction ($p < 0.01$) in backfat thickness change in CM1 and CM2 sow groups compared to the CON sow group during the third and fourth parity. There were no interactive effects between parities and treatment diets on the reproductive performance parameters in sows.

Suckling piglet performance

The performance of suckling piglets born to sows fed gestation and lactation diets with marine-derived Ca-Mg complex in four successive parities is presented in Table 4. The initial and final

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Table 3. The effect of dietary supplementation of marine derived Ca-Mg complex on reproduction performance in gilts/sows in four successive parities[1)]

Items	Parity 1			Parity 2			Parity 3			Parity 4			SEM	*p*-value		
	CON[2)]	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2		Parity	Treatment	P × T
Litter size																
Total birth piglet (head)	14.2^{bB}	15.1^{a}	14.9^{a}	14.4^{bB}	15.2^{a}	15.1^{a}	15.2^{A}	15.8	15.5	15.4^{A}	15.8	15.7	0.212	***	***	NS
Live piglet (head)	13.7^{bB}	14.8^{a}	14.6^{a}	13.8^{bB}	14.8^{a}	14.7^{a}	14.7^{bA}	15.4^{a}	14.9^{a}	14.8^{A}	15.3	15.3	0.242	***	***	NS
Stillbirth (head)	0.5	0.3	0.3	0.4	0.3	0.3	0.5	0.4	0.6	0.5	0.4	0.4	0.099	NS	NS	NS
Mummification (head)	0.04	0.00	0.00	0.04	0	0	0	0	0	0.04	0	0	0.021	NS	NS	NS
Dead after 3 days of birth (head)	0.04	0.00	0.08	0.1	0.1	0.1	0	0	0	0.1	0	0	0.050	NS	NS	NS
Disorder (head)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Survival rate (%)	96.1	98.4	97.7	96.0	97.5	97.1	96.7	97.6	96.1	95.9	97.1	97.0	0.702	NS	**	NS
Sow body weight (kg)																
Initial	181.4^{C}	181.6	181.3	182.9^{C}	179.8	181.2	198.8^{B}	198.3	199.6	218^{A}	219	219.6	1.28	***	NS	NS
Before farrowing	222.2^{D}	220.7	221.3	238.3^{C}	237.7	239.5	257.9^{B}	258.9	259.8	278.2^{A}	280.6	280.7	1.401	***	NS	NS
After farrowing	196.7^{D}	194.1	194.7	213.20^{C}	211.30	212.60	231.70^{B}	232.3	233.4	252.1^{A}	254.4	254.1	1.429	***	NS	NS
Weaning	182.9^{D}	179.8	181.2	198.8^{C}	198.3	199.6	218^{B}	219	219.6	237.6^{A}	240.9	240.6	1.468	***	NS	NS
Back fat thickness (mm)																
Initial	15.37^{C}	15.41	15.37	15.41^{bC}	16.12^{a}	15.75^{a}	16.33^{B}	16.95	16.95	18.62^{bA}	19.25^{a}	19.70^{a}	0.242	***	**	NS
Before farrowing	17.95^{D}	18.16	18.0	18.5^{C}	18.66	18.83	21.04^{B}	21.37	21.54	22.70^{bA}	23.45^{a}	23.50^{a}	0.23	***	*	NS
After farrowing	17.41^{D}	17.75	17.41	17.95^{C}	18.29	18.41	20.25^{B}	20.45	20.87	21.83^{bA}	22.66^{a}	22.62^{a}	0.219	***	**	NS
Weaning	15.41^{bD}	16.12^{a}	15.79^{ab}	16.33^{C}	16.95	16.95	18.62^{bB}	19.25^{ab}	19.70^{a}	19.95^{bA}	21.08^{a}	21.20^{a}	0.236	***	***	NS
Backfat thickness difference 1[3)]	2.58^{C}	2.75	2.62	3.08^{C}	2.54	3.08	4.70^{A}	4.41	4.58	4.08^{B}	4.20	3.79	0.204	***	NS	NS
Backfat thickness difference 2	0.54	0.41	0.58	0.54	0.37	0.41	0.79	0.91	0.66	0.87	0.79	0.87	0.112	***	NS	NS
Backfat thickness difference 3	2.05	1.62	1.62	1.62	1.33	1.45	1.62^{a}	1.20^{b}	1.16^{b}	1.87^{a}	1.58^{ab}	1.41^{b}	0.130	***	***	NS
Average daily feed intake (kg)																
Gestation	2.02^{C}	2.02	2.02	2.06^{B}	2.07	2.06	2.16^{A}	2.17	2.16	2.16^{A}	2.17	2.16	0.005	***	NS	NS
Lactation	6.14^{B}	6.17	6.18	6.12^{B}	6.15	6.15	6.38^{A}	6.40	6.40	6.38^{A}	6.41	6.40	0.024	***	NS	NS
Estrus interval (day)	3.8^{C}	3.4	3.3	3.6^{BC}	3.3	3.3	4.3^{AB}	3.9	4.3	4.6^{A}	4.5	4.5	0.226	***	NS	NS

[1)] Values represent the means of 24 sows per treatment.

[2)] CON, basal diet; CM1, basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

[3)] Backfat thickness difference: 1, initial to before farrowing; 2, before farrowing to after farrowing; 3, after farrowing to weaning.

[a,b] Different superscripts within a row indicate a significant difference ($p < 0.05$) in response to treatment diets CM1 and CM2.

[A–D] Different superscripts within a row indicate a significant difference ($p < 0.05$) among parity.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$.

P × T, interactive effects between parity and dietary treatments; NS, non-significant.

number of suckling piglets was higher ($p < 0.05$) for the third and fourth parity sows compared to the first and second parity sows. The overall parity effect ($p < 0.0001$) was observed for the survival rate of suckling piglets, although no significant effects were seen among the parity for the survival rate of the suckling piglets. The supplementation of CM1 and CM2 to the basal diet of the sows resulted in a higher ($p < 0.05$) initial and final number of suckling piglets as well as higher weaning weight compared to the piglets born to sows fed CON diet during the first, second and third parity. The ADG was higher in piglets born to sow receiving CM1 and CM2 diets ($p < 0.05$) regardless of parity. However, there were no significant overall parity effects on the weaning weight and ADG of piglets. No morbidity due to pneumonia, hernia, and scouring was observed in piglets born to the sows fed with either CON or CM1, or CM2 diets through four parities (data not shown).

Incidence of constipation and shoulder sores in sows

The effect of marine-derived Ca-Mg complex and parity on the incidence of constipation based on fecal scores before and after farrowing is presented in Table 5. There were no significant dietary treatment, time and parity effects on fecal scores. The shoulder sores (data not shown) were also not affected ($p > 0.05$) by treatment and parity.

Duration traits

The effect of marine-derived Ca-Mg complex and parity on the duration of parturition from the first to last piglet birth and the duration of placenta expulsion after the last piglet birth is presented in Table 6. A trend ($p = 0.080$) in the overall parity effect and a significant treatment effect ($p < 0.0001$) in the duration of the first to last piglet birth were observed. The treatment diets (CM1 and CM2) fed to the sows lowered ($p < 0.05$) the duration of the first to last piglet birth compared to those from sows fed the CON diet. Significant interactive effects ($p = 0.042$) between parities and treatment diets were observed for the duration of the first to last piglet birth. A significant overall parity effect ($p = 0.01$) and treatment effect ($p < 0.0001$) were observed for the reduction in the duration of placenta expulsion, and a significant overall treatment effect ($p < 0.0001$) on the duration between the first and last piglet birth were observed although there were no significant differences among the parity for the placental expulsion duration. The sows fed treatment diets exhibited a reduction ($p < 0.05$) in placenta expulsion time compared with sows fed CON diet regardless of parities and a significant reduction ($p < 0.05$) in duration between the first and last piglet birth from sows receiving CM1 and CM2 versus CON diets was observed during parity 1 and 2.

Apparent total tract digestibility

The ATTD of N, Ca, P and Mg measured at the end of the experimental trial were unaffected ($p > 0.05$) by the partial replacement of limestone with Ca-Mg complex (Table 7).

DISCUSSION

Sows longevity is a complex trait wherein multiple factors are involved in contributing to a long and productive life in a commercial breeding herd. The predominant reason for sows being removed from the breeding herd due to reproductive failure [27–29]. In modern swine production, sows with lean genotype and improved breed led to high prolificacy of sows, thereby leading to the improvement in their productivity levels, maximization of the number of piglets/litters, lactation yield, optimization of piglet birth weight, and longevity [30]. All these improvements with a sow and her litter warrant proper nutritional support that is bioavailable for animals. The nutritional

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Table 4. **The effect of dietary marine derived Ca-Mg complex supplementation to gestating and lactating sows in four successive parities on the performance of their litters**

Items	Parity 1			Parity 2			Parity 3			Parity 4			SEM	*p*-value		
	CON[1)]	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2		Parity	Treatment	P × T
Initial number	13.66^{bB}	14.83^{a}	14.58^{a}	13.79^{bB}	14.80^{a}	14.66^{a}	14.70^{bA}	15.40^{a}	14.90^{ab}	14.79^{A}	15.30	15.25	0.242	***	***	NS
Final number	13.40^{bB}	14.83^{a}	14.58^{a}	13.50^{bB}	14.60^{a}	14.54^{a}	14.30^{A}	15	14.58	14.41^{A}	15.08	15.04	0.258	**	***	NS
Survival rate (%)	98.20^{b}	100^{a}	100^{a}	97.90	98.50	99.04	97.20	97.30	97.78	97.47	98.30	98.65	0.614	**	*	NS
Birth weight (kg)	1.69	1.67	1.69	1.68	1.70	1.70	1.73	1.70	1.69	1.71	1.67	1.70	0.02	NS	NS	NS
Weaning weight (kg)	6.40^{b}	6.75^{a}	6.67^{a}	6.45^{b}	6.82^{a}	6.80^{a}	6.40^{b}	6.80^{a}	6.70^{a}	6.46	6.74	6.72	0.05	NS	***	NS
Average daily gain (g)	225^{b}	242^{a}	237^{a}	227^{b}	244^{a}	241^{a}	225^{b}	243^{a}	240^{a}	227^{b}	241^{a}	240^{a}	2.12	NS	***	NS

[1)]CON, basal diet; CM1, basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

[a,b]Different superscripts within a row indicate a significant difference ($p < 0.05$) in response to treatment diets CM1 and CM2.

[A,B]Different superscripts within a row indicate a significant difference ($p < 0.05$) among parity.

*$p < 0.05$; **$p < 0.01$, ***$p < 0.0001$.

P × T, interactive effects between parity and dietary treatments; NS, non-significant.

Table 5. **The effect of dietary marine derived Ca-Mg complex supplementation to gestating and lactating sows in four successive parities on fecal score before and after farrowing[1)]**

Items	Parity 1			Parity 2			Parity 3			Parity 4			SEM	*p*-value		
	CON[2)]	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2		Parity	Treatment	P × T
Before farrowing	2.27	2.25	2.25	2.27	2.24	2.25	2.24	2.25	2.24	2.21	2.21	2.24	0.020	NS	NS	NS
After farrowing	2.31	2.29	2.29	2.32	2.29	2.29	2.28	2.31	2.30	2.28	2.30	2.30	0.021	NS	NS	NS

[1)]Values represent the means of 24 sows per treatment.

Fecal score data before and after farrowing were also analyzed using chi-square test. The fecal score before and after farrowing were found to be non-significant during all four subsequent parities.

Fecal score: 1, hard, dry pellet in a small, hard mass; 2, hard, formed stool that remains firm and soft; 3, soft, formed, and moist stool that retains its shape; 4, soft, unformed stool that assumes shape of the container; 5, watery, liquid stool that can be poured.

[2)]CON, basal diet; CM1, Basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

P × T, interactive effects between parity and dietary treatments; NS, non-significant.

Table 6. **The effect of dietary marine derived Ca-Mg complex supplementation to gestating and lactating sows in four successive parities on farrowing and placenta expulsion time duration[1)]**

Items (min)	Parity 1			Parity 2			Parity 3			Parity 4			SEM	*p*-value		
	CON[2)]	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2	CON	CM1	CM2		Parity	Treatment	P × T
Duration between first to last piglet birth	245^{a}	215^{b}	217^{b}	236^{a}	217^{b}	216^{b}	230	221	238	245.6	223.6	231	5.442	NS	***	*
Placenta expulsion time after last piglet birth	83^{a}	62^{b}	61^{b}	84^{a}	72^{b}	70^{b}	85^{a}	75^{b}	72^{b}	85.3^{a}	74.1^{b}	68.3^{b}	3.372	**	***	NS

[1)]Values represent the means of 24 sows per treatment.

[2)]CON, basal diet; CM1, basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

[a,b]Different superscripts within a row indicate a significant difference ($p < 0.05$) in response to treatment diets CM1 and CM2.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.0001$.

P × T, interactive effects between parity and dietary treatments; NS, non-significant.

Table 7. The effect of dietary marine derived Ca-Mg complex supplementation on apparent total tract digestibility of P, Ca, Mg, and N at the end of trial[1)]

Items (%)	CON[2)]	CM1	CM2	SEM	*p*-value
Phosphorus	32.00	36.08	34.35	1.63	0.2183
Calcium	33.77	36.77	35.88	1.60	0.4024
Magnesium	23.98	25.68	25.05	0.65	0.1839
Nitrogen	66.52	68.21	69.35	1.03	0.1614

[1)]Values represent the means of 24 sows per treatment.

[2)]CON, basal diet; CM1, basal diet – MgO - 0.3% limestone + 0.40% marine derived Ca-Mg complex; CM2, basal diet - MgO - 0.7% limestone + 0.40% marine derived Ca-Mg complex.

status of a sow at an earlier stage of the reproductive cycle will affect productivity during subsequent stages. Thus, an integrated feeding intervention, starting with the gilt and continuing throughout each successive parity may maintain productivity and prolong the reproductive life of the sow. Among several nutrients, minerals equally play an important role in the reproductive life of sows. Therefore, the present study was undertaken to assess the parity effects (four successive parities) as well as treatment effects by supplementing the basal diet with marine-derived Ca-Mg complex with better bioavailability as a partial replacement to limestone during four successive parities on the longevity and reproductive performance of sows.

Marine-derived Ca-Mg complex effects

The predominant reasons for the culling of sows having three parities or less are due to reproductive failure and leg and foot problems [31–33]. Results from the present study demonstrated that during the four successive parities, sows were not culled since there were no problems in the overall health of sows including lameness, shoulder sores, or incidence of constipation regardless of the diets offered to sows, and their parities.

The inclusion of Ca-Mg complex in the basal diet or the partial replacement of limestone in the basal diet of sows with marine-derived Ca-Mg complex significantly improved total and live born piglets, piglet survival rate, number of piglets pre-weaning, number of weaned piglets, and weaning weight. However, there was no effect observed on the piglet birth weight and weaning to oestrus interval compared with the sow-fed CON diet regardless of parity although first and second-parity sows had better results. Different inclusion levels of Ca in the diet of sows did not significantly affect the number of born alive, birth weight, weaning weight, and ADG of piglets [34]. Earlier studies revealed that Mg supplementation to the diet of gilts had no influence on the number of total and live piglets at birth [16,35]. In contrast, the supplementation of 0.015 and 0.03% Mg to parity 3 sows significantly increased the total number of piglets born, live-born piglets, and weaned reduced the weaning to oestrus interval in gilts as well [16] which agreed with the findings of Gaal et al. [36] who indicated that Mg supplementation improved litter size and reduced wean to estrus interval. The disparities in the findings among different studies might be due to the bioavailability of mineral supplements as well as the dose and feeding duration of these minerals from gestation to lactation.

To increase sow longevity, it is important for breeding and farrowing managers to focus on the maintenance of sow body tissue reserves throughout their lifetime. Improper nutrition may cause direct or indirect adverse effects resulting in premature culling. To maximize the lifetime number of live piglet birth, some minimum level of backfat is needed [14]. Females that are too lean may experience low litter weaning weights, smaller subsequent litter size, physical weakness, and poor return to estrus [37]. An earlier study reported that in Duroc females at an off-test weight of 96.2 kg, the optimum backfat thickness is 16 mm [38]. A study by Challinor [39], reported that gilts at an average weight of 150 kg that had 18 to 22 mm of backfat had an average of 7.2 more piglets

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over five parities than the gilts having a backfat thickness of 14 to 16 mm. In agreement with this, Tummaruk et al. [40] noted that gilts with higher backfat adjusted to 100 kg had a higher number of live-born piglets in their second parity than the gilts with low backfat. In the present study, the backfat thickness of sows (before and after farrowing as well as at weaning) was improved by supplementing the diet with marine-derived Ca-Mg complex but gestation and lactation feed intake and the ATTD of Ca, Mg, P, and N were not affected by the inclusion of marine-derived Ca-Mg complex in the sow basal gestation and lactation diets. The improvement in sow backfat thickness in treatment groups might have resulted in an increased number of piglets born alive and weaned piglets in this study which affirms the report of Čechová and Tvrdoň [41] which suggested that the number of live born and weaned piglet is correlated with backfat thickness. The reduction in backfat thickness loss in sows receiving treatment diets during lactation may suggest that this marine-derived Ca-Mg complex had a positive effect in meeting the energy needs of the body. A recent study by Gao et al. [42] noted that ADFI and backfat thickness on day 85 of gestation was not affected by feeding extra Ca during different feeding time. The probable reason for the improvement in the reproductive performance in the present study could be due to the higher bioavailability of these minerals especially Mg because it is an important co-factor of different enzymes that are involved in energy and protein metabolism as well as other biochemical processes [36]. Calcium was found to play a role in lipogenesis and lipolysis, where a high Ca level in the plasma suppresses calcitriol. When combined with an energy-dense diet, this effect of Ca on calcitriol aided to prevent excessive fat accumulation and helped to maintain weight and fat content [43,44]. Likewise, increased availability of Ca reduced the sows reliance on bone deposits to satisfy lactational demands thus preserving bone stores and consequently improving bone health and sow longevity [13,21].

The risk of stillbirth has been reported to increase significantly when the birth interval is more than 90 min, whereas the duration of farrowing increased the risk cumulatively with every 2 h that elapsed [45]. Thus, the duration of birth from the first to the last piglet of a litter and the duration of placenta expulsion play an important role in determining the number of stillbirths. These duration traits seem to be partially affected by the availability of minerals such as Ca. In a recent study by Gao et al. [42], it has been reported that feeding an extra 9 g of Ca to sows led to a reduction in the number of stillbirths, the duration of farrowing, and placenta expulsion, and increased the ADG of piglets compared to the sows fed extra 4.5 g of Ca. In the present study, the supplementation of marine-derived Ca-Mg complex showed a decline in the duration of birth of piglets from the first to the last. A reduction in the duration of placenta expulsion from the time after the birth of the last piglet was also observed. The reduction in the duration of placenta expulsion and farrowing may be associated with the role of Ca ion in enhancing the contraction ability of smooth muscle in the uterine system [15,46].

Parity effects

Parity order is linked with the development of the reproductive system of animals. Pluym et al. [32] showed that it is economically viable to keep sows at least until parity 5. An important foundation of production is to lengthen the production life of sows because the economic returns to the producer begin from the third parity [47].

Therefore, in the present study, we evaluated the performance of gilt/sows during four successive parities and observed that the first parity gilts and second parity sows had significantly lesser numbers of litter and live born piglets, lower sow BW and backfat thickness size, lower lactation feed intake compared to third and fourth parity sows, but the birth weight, weaning weight, and ADG of piglets were not affected by parity. However, the results are inconsistent. For instance, Takai and Koketsu [48] observed that a higher number of piglets were born only in the first and second parity, but not in subsequent ones whereas Hoving et al. [49] reported that sows exhibited the best reproductive parameters between parity 3 and 5. Previous studies reported a lower birth weight for pigs born to primiparous sows versus multiparous sows [50,51], indicating that this difference could be due to fetal growth retardation and fewer skeletal muscle fibers [52], even though no differences in BW were detected at birth [53]. The possible reason for the increase in BW and backfat thickness of sows at the third and fourth parity as compared with the first parity gilts could be due to the higher maintenance requirement and feed intake. Sows with a 17 to 21 mm backfat thickness have been reported to be more efficient than those with a backfat thickness beyond this interval [54] suggesting the sow in first to third parity had a backfat thickness of reasonable range. The decline in backfat thickness after farrowing to weaning was slightly higher for the first parity sows compared with the other parities suggesting that with the increase in parity, sows were able to meet the energy demands via feed. The mechanisms behind these parity effects of young and old sows are different. In the case of primiparous sows, their reproductive cycle and hormonal system are naive and show lower feed intake capacity and lower fat and protein stores [55] despite their higher nutrient requirement for reproduction and muscle development as compared with multiparous sows which have well-established reproductive cycle [56] consequently, affecting the performance of sows. Interestingly, the duration of placenta expulsion after the birth of the last piglet was higher in the third and fourth parity sows compared with the first parity gilts and the second parity sows which could possibly be due to lower oxytocin levels in older sows [57,58]. Interactive effects were observed between treatment diets and parity in the duration of the first to last piglet birth indicating the synergistic effects of both parity and marine-derived Ca-Mg Complex treatment on the given parameter.

CONCLUSIONS

The supplementation of marine-derived Ca-Mg complex exerted positive effects on the reproductive performance of sows regardless of parities. The number of weaned piglets, weaning weight, and the ADG of suckling piglets born to sows in treatment groups were higher compared to those born from control group sows, indicating that marine-derived Ca-Mg complex supplementation is effective in improving the longevity and performance of sows and their litters. Among the parties, the third and fourth parity sows had better performance ability than the first and second parity sows. Thus, the findings of this study indicate that partial replacement of limestone with marine-derived Ca-Mg complex to the basal diets of sows is beneficial for improving sows' reproductive performance and longevity.

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