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Activated crystalline silicon dioxide mitigates weight loss in lactating sows

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ABSTRACT

This study investigated activated crystalline silicon dioxide (SIL) supplementation in late pregnancy and lactating sows on reproductive parameters as well as the performance of suckling piglets. Eighty sows were assigned to two groups: control (CON, $n=40$), and activated crystalline SIL ($n=40$). Both treatments received identical basal diets, without (CON), or with 0.3 kg of activated SIL/ton at day 111 of pregnancy up to day 21 of lactation. The sows were evaluated at day 110 of gestation and at day 21 of lactation for individual body weight (BW), backfat (BF), average daily feed intake (ADFI), percentage of BW and BF loss, and milk production. The litter was evaluated for size and BW at birth, and at 21 d old, likewise the preweaning survival percentage. At day 21 lactation, the SIL sows were 2.39% heavier than the CON group. The sows also had an increase of 5.05% in milk yield compared to the CON sows. In addition, SIL sows showed lower weight loss compared to CON sows. The weaned piglets from SIL sows had an increase of 4.43% in BW compared to CON sows. In conclusion, supplementation of 0.03% of activated crystalline SIL applied to late pregnancy, and to lactating sows reduced weight loss and marginally improved the milk yield and BW of piglets at weaning.

HIGHLIGHTS

- The activated crystalline silicon dioxide (SIL) in diets from late pregnancy to lactation reduced body weight loss of sows.
- Sows that received activated crystalline SIL in late pregnancy and lactating period tended to improve the milk yield in 5.05%.
- The piglets from sows fed activated crystalline SIL tended to enhance 4.43% in body weight at 21-d old.

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Introduction

Modern sows develop catabolism during lactation due to the high tissue mobilisation associated with an insufficient feed intake (Kim and Easter 2001; Langendijk et al. 2016). Catabolism harmful effects are impaired to reproductive lifetime, milk production and litter weight gain (Costermans et al. 2020). Thus, the strategies to optimise milk production and litter growth in modern sows have been studied, focussing on female body condition at gestation or feed intake during lactation (Schenkel et al. 2010; Eckhardt et al. 2013; Mallmann et al. 2018; Costermans et al. 2020).

Silicon dioxide (SIL) is a mineral found in several clays and diatomaceous earth, commonly used as a

feed additive due to the amorphous molecular structure that can absorb humidity and toxins (Zhu et al. 2016). The crystalline SIL can be activated through an electromagnetic treatment (Decaux 2017), then retain and transfer electromagnetic energy to an aqueous solution. This activated silica can increase the water electronegativity inside the gut and accelerate biochemical changes in the digestive tract, such as enzymatic digestion and nutrient transfer across cells (Decaux 2016; 2017).

The cation exchange and absorption properties of silica, such as increasing feed retention time and decreasing intestinal emptying rates, improve nutrient absorption and feed efficiency in poultry (Safaeikatouli et al. 2012; Faryadi and Sheikhhahmadi 2017), improve

Table 1. Ingredients of pre-partum and lactation diets (as-fed basis).

Item	Pre-partum	Lactation
Ingredients, %		
Corn ^a	62.64	45.27
Wheat bran	20.00	3.00
Soybean meal ^b	11.00	25.00
Meat and bone meal, 42%	3.50	4.00
Yeast	0.61	2.87
Sugar	–	5.00
Soybean oil	–	2.00
Biscuit bran	–	10.00
Salt	0.40	0.20
Limestone	0.40	0.35
Organic selenium, 2%	0.002	0.002
Organic zinc, 10%	0.015	0.015
Organic chromium, 0.4%	0.027	0.027
Copper sulphate, 25%	0.03	0.03
Coline, 60%	0.05	0.05
Vit D - Hy D 25	0.02	0.02
Phytase ^c	0.02	0.02
Protease ^d	0.015	0.015
Carbohydrase ^e	0.01	0.01
L-Lysine HCl, 78.4%	0.015	0.03
L-Threonine, 98.5%	0.24	0.185
DL-Methionine, 99%	0.025	0.165
L-Tryptophan, 99%	0.005	0.045
Yeast wall cell	0.50	1.00
Antioxidant	0.02	0.02
Adsorbent	0.25	0.25
Vitamin supplement ^f	0.07	0.07
Mineral supplement ^g	0.10	0.10
Biotin	0.04	0.04
Sodium bicarbonate	–	0.2
Flavour	–	0.01
Total	100	100
Analysed composition		
ME calculated, kcal/kg	3,100	3,450
Crude protein, %	15.164	19.584
Crude fibre, %	3.743	2.655
Fat, %	3.718	5.691
Ash, %	4.575	5.129
Calcium, %	0.843	0.948
Total phosphorus, %	0.660	0.599

^a7.86% crude protein.^b45% crude protein.^cPhytase = improved *E. coli* phytase with expected activity of 5,000 FTU/g.^dProtease = obtained from *Bacillus licheniformis* PWD-1 with minimum expected activity of 600,000 u/g.^eCarbohydrase = obtained from the fermentation of *Penicillium funiculosum* with expected activity of 12,500 VU/g of endo-β-1,4-xylanase, 8,600 VU/g endo-β-1,3(4)-glucanase; and 46,000 VU/g of arabinofuranosidases.^fVitamin supplement (own farm production, Leme, Brazil); composition: vitamin A 21,000 UI/kg; vitamin D 3850 UI/kg; vitamin E 175 UI/kg; vitamin K 56 mg/kg; folic acid 3.5 mg/kg; thiamine 4.2 mg/kg; riboflavin 10.5 mg/kg; pantothenic acid 42 mg/kg; pyridoxine 7 mg/kg; biotin 0.595 mg/kg; cobalamin 0.075 mg/kg; niacin 75 mg/kg.^gMineral supplement (own farm production, Leme, Brazil); composition: copper 20 mg/kg; iron 100 mg/kg; iodine 1.6 mg/kg; manganese 60 mg/kg; zinc 140 mg/kg; selenium 0.70 mg/kg.

average daily gain and feed conversion ratio in turkeys (Tran et al. 2015), increase egg weight in quails (Faryadi and Sheikhahmadi 2017), and improve growth performance in broilers (Maradon et al. 2017) and weaned piglets (Martel-Kennes et al. 2016). On the other hand, studies on activated SIL in broilers

(Anshory et al. 2017) and turkeys (Majewska et al. 2009) have shown no improvement in growth performance. In addition, the productive parameters and follicular characteristics did not improve in quails when provided isolated (Ratriyanto et al. 2021).

Most studies on activated crystalline SIL have been carried out in poultry, and little is known about the effects in pigs, especially in pregnant and lactating sows. Therefore, this project considered that sows fed with activated crystalline SIL could mitigate the weight loss during the lactation and wean heavier pigs. Thus, this study evaluated the effects on reproductive parameters, milk yield and suckling piglets' performance of sows fed diets with supplementation of activated crystalline SIL, from late gestation until the end of the lactation period.

Material and methods

The trial was carried out in a Commercial Swine Farm, in Leme, São Paulo, Brazil. The Ethics Committee of the Faculty of Animal Science and Food Engineering, in University of São Paulo, approved the experimental protocol on Animal Use.

Experimental design

Eighty commercial hybrid sows from third to sixth parity (C23, Agroceres PIC®, Rio Claro, Brazil) were grouped in two treatments. The control group (CON, $n=40$), sows fed basal diets, and SIL group, sows fed basal diets added 0.3 kg/ton of activated crystalline SIL ($n=40$, Silica+, Ceresco Nutrition, Montreal, Canada). The SIL was provided for sows via top-dressing, from day 111 of pregnancy to day 21 of lactation. Diets were formulated according to nutritional requirements (Rostagno et al. 2017).

Animal management

Two rooms were used for this experiment. The sows were allocated in individual pens, including 40 crates (2.20 × 1.68 m) with plastic floor, following sanitary procedures as commercial farms, with nipples and semi-automatic feeders. Approximately 3 d before farrowing, all pregnant sows were transferred to individual farrowing crates. The pattern for the litter size was established until the second day after farrowing, performed using sows of same treatment. Routine procedures (tail docking, ear notching and iron injection) were conducted two days after farrowing. At 5 d old,

Table 2. Reproductive performance of sows fed diets with or without activated crystalline silicon dioxide supplementation.

Item	Treatment			
	CON (n = 40)	SIL (n = 40)	SEM	p Value
Average daily feed intake, Kg/d	6.80	6.81	0.03	.883
Back fat, mm				
110 d pregnancy	18.48	18.45	0.12	.590
Weaning	18.34	18.40	0.10	.716
Back fat loss, %	-1.03	-0.53	0.89	.779
Body weight, kg				
110 d pregnancy	221.20	221.60	1.35	.893
Weaning	200.40	205.30	1.39	.078
Body weight loss, %	9.33	7.34	0.45	.026
Milk yield, kg	247.43	260.60	4.36	.085

CON: control diet; SIL: activated crystalline silicon dioxide diet.

the males were surgically castrated, and no creep feed was offered for piglets.

Diets

The daily diet was based on corn and soybean meal (Table 1), regulated according to Body condition score (BCS). All sows received 1 kg of feed per day, from 90 d of pregnancy until farrowing. Moreover, 2.3 kg of lactation diet was provided once per sow on the farrowing day. On the first and second days after farrowing, 4.6 kg of the diet was provided once per sow. From the 3rd day to the 21st day (weaning), sows were fed *ad libitum* using the lactation diet. Water was provided *ad libitum* during gestation and lactation.

Sows' performance and milk production

At days 110 of gestation and 21 of lactation, the sows were individually weighed. Backfat (BF) was measured by ultrasound Scanning 100® (5-MHz transducers, Pie Medical, Philipsweg, Belgium) at P2 position for body weight (BW). Average daily feed intake (ADFI) was evaluated in the overall lactation period, and the percentage of BW loss was assessed from these data (Eckhardt et al. 2013). Milk yield was estimated considering the need of 4 kg of breast milk to every 1 kg of litter weight gain, according to Close and Cole (2001). Milk from 20 sows of each treatment was collected on the 10th day of lactation for protein, fat, lactose and solids-not-fat content analyses. The samples were analysed using an automatic milk analyser (Lactoscan MCC, Nova Zagora, Bulgaria).

Piglets' performance

The number of born alive and weaned piglets was evaluated in the treatments. The animals were

Table 3. Milk quality of sows fed diets with or without activated crystalline silicon dioxide supplementation.

Item	Treatment			
	CON (n = 20)	SIL (n = 20)	SEM	p Value
Fat, %	8.46	9.12	0.38	.441
Density, g/cm ³	1.08	1.07	0.06	.173
Solids non-fat, %	10.53	10.61	0.08	.618
Protein, %	3.88	3.91	0.03	.568
Lactose, %	5.79	5.84	0.04	.552

CON: control diet; SIL: activated crystalline silicon dioxide diet.

individually weighed using digital electronic scales at birth and at 21 d old (weaning). Furthermore, the pre-weaning survival percentage was calculated as described by the equation below:

$$\left[\frac{\text{(number piglets weaned}}{\text{number piglets born alive after transfer}} \times 100 \right]$$

Statistical analysis

According to a randomised design, data were analysed using the TTEST procedure of SAS software (2010) (Statistical Analysis System version 9.3, SAS Inc., Cary, NC). The sows from third to sixth parity were allotted to two treatments. Each group received a similar number of sows by parity and each animal was considered as one experimental unit. Outliers were identified as an absolute Studentized residual value of 3 or greater. The Wilcoxon–Mann–Whitney test was applied to compare the mean difference between the two treatments by using the NPAR1WAY procedure at the point the distribution for a t-test assumed non-normality. Effects were considered significant to $p < .05$, and as a trend when $p < .10$.

Results and discussion

In this study, the BF at day 110 of pregnancy and weaning, BF loss and the ADFI during the overall lactation period were similar between the CON and SIL sow groups (Table 2). At day 21 of lactation, SIL sows were 2.39% slightly heavier ($p = .078$), and presented reduced weight loss compared to the CON group (7.34 vs. 9.33%, respectively, $p < .05$, Table 2). In addition, sows fed SIL had a little increase of 5.05% in milk yield compared to the CON sow ($p = .085$, Table 2). The milk quality (fat, density, solids-not-fat, protein and lactose) was similar between the treatments (Table 3), as well as the number of piglets born alive, weaned piglets, BW at birth and preweaning survival percentage (Table 4). At weaning, the piglets

Table 4. Performance of pigs born from sows fed diets with or without activated crystalline silicon dioxide supplementation.

Item	Treatment			
	CON (n = 40)	SIL (n = 40)	SEM	p Value
Number of piglets born alive	11.82	11.95	0.09	.504
Number of weaned piglets	11.55	11.49	0.10	.763
Body weight, kg				
Birth	1.31	1.33	0.02	.660
Weaning	6.69	7.00	0.08	.060
Preweaning survival percentage, %	97.69	96.51	0.58	.188

CON: control diet; SIL: activated crystalline silicon dioxide diet.

from SIL sows had a minimal increase of 4.43% in BW compared to CON sows ($p=.060$, Table 4).

According to the previous analysis, no researches have been published about the use of SIL in pregnant and lactating sows or the effects on progeny. The supplementation of 0.02% of SIL for pigs increases the feed intake, and growth rate and BW in weaned piglets (Martel-Kennes et al. 2016).

Most studies have been carried out on poultry. Supplementation of 0.02% of SIL in turkey diets improves the average daily gain and feed conversion ratio, reduces pH and decreases ammonium conversion to ammonia (Tran et al. 2015). Furthermore, the nutrient absorption, feed efficiency and egg weight is enhanced in quails (Faryadi and Sheikhahmadi 2017) and broilers. Likewise, growth performance is improved (Maradon et al. 2017) and nutrient availability and fat retention are increased, without negative effect on growth performance (Anshory et al. 2017). Further, a recent study on tilapia shows the increase in growth performance and the utilisation of SIL in feed (Bashar et al. 2021).

At the end of the lactation period, the SIL sows had reduced weight loss and tended to increase milk yield despite not changing feed intake. The piglet weaning weight was higher, suggesting the nutrients have been better absorbed by the sow. Though the digestibility assay has not been measured in this study, some other studies have reported that activated silica increases the digestibility and absorption of nutrients, including proteins and lipids (Bashar et al. 2021). The water inside the gut, essential for homeostasis, has the molecules activated in the presence of activated SIL. Then, these activated molecules as nucleophiles can act on the peptide carbonyl group of the ingested protein, break down into small peptides and free amino acids. Activated water molecules may also regenerate the enzymes, enabling them to work again within the shortest possible time (Berg et al. 2002). Furthermore, the activated silica can temporarily connect to nutrients reducing the gastrointestinal passage

rate allowing the nutrients to be exposed to digestion for more extended (Safaeikatouli et al. 2012).

The impairment in current lactation and subsequent reproductive performance (Thaker and Bilkei 2005; Koketsu et al. 2017), and litter weight gain can be observed (Costermans et al. 2020) when weight loss exceeds 10% during the lactation. Some researches have been developed to mitigate lactational catabolism from strategies related to body condition and feed intake (Mallmann et al. 2018; Costermans et al. 2020), but with no consistent effectiveness. The activated SIL can mitigate the harmful effects as mentioned before, but using other nutritional strategies during this period is not very common.

The milk yield increased 5.05%, and probably collaborated on the raise in piglet weight at weaning, despite the SIL sow had no difference in milk quality. More studies are still required. The weight at weaning is essential in commercial swine farm and can influence the market weight (Wolter and Ellis 2002 Cabrera et al. 2010; Middelkoop et al. 2019; Martins et al. 2020). The factors include sow body condition, parity, feed intake during pregnancy, and the influence of milk yield (Eckhardt et al. 2013; Martins et al. 2020).

Feeding strategies for sows in late gestation or during lactation are essential and interfere in the BCS and milk yield, improving BW litter at birth and weaning. Besides, this management can also mitigate the effects on the subsequent reproductive performance. Activated SIL has been shown to improve performance, feed efficiency, increase nutrient digestibility and absorption, and egg quality in birds. However, further studies are needed to clarify the mechanisms by which these effects occur.

Conclusion

In conclusion, supplementation of 0.03% of activated crystalline SIL in late gestation and lactation sows reduced weight loss and marginally improved the milk yield and BW of piglets at weaning. However, further research is required to better define the position of activated crystalline SIL regarding the molecular and physiological prospects.

Ethical approval

The experimental protocol was approved by the Ethics Committee on Animal Use of the Faculty of Animal Science and Food Engineering, University of Sao Paulo.

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Author contributions

L. A. Vitagliano: Conceptualisation and investigation; Y. Sartore and C. A. Granghelli: Investigation and writing- original draft; R. S. B. Carvalho, M. L. P. Tse and S. M. M. K. Martins: formal analysis, and writing – review and editing; C. Decaux and F. T. Jansen: Conceptualisation, funding acquisition, writing – review and editing; L.F. Araújo and CSS. Araújo: Conceptualisation, funding acquisition, project administration, writing – review, and editing.

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Data availability statement

Data availability statement The data that support the findings of this study are available from the corresponding author, [LFA], upon reasonable request.

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