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Summary

A total of 360 barrows (DNA Line 200 × 400; initially 13.6 ± 0.07 lb) were used in a 38-d study to evaluate the interactive effects of added dietary calcium carbonate and benzoic acid on nursery pig growth performance, fecal dry matter, and blood Ca and P concentration. Upon arrival to the nursery research facility, pigs were randomly assigned to pens (5 pigs per pen) and pens were allotted to 1 of 6 dietary treatments with 12 pens per treatment. Dietary treatments were formulated to provide 0.45, 0.90, or 1.35% calcium carbonate, with or without 0.5% benzoic acid (VevoVital, DSM Nutritional Products, Parsippany, NJ). Diets were fed in three phases with phase 1 treatment diets (0.66, 0.83, or 1.00% Ca) fed from weaning (d 0) to d 10; phase 2 treatment diets (0.54, 0.72, or 0.89% Ca) fed from d 10 to 24; and a common phase 3 diet from d 24 to 38 (0.68% Ca). Standardized total tract P concentrations were formulated to 0.58, 0.51, and 0.47 in phases 1, 2, and 3, respectively. There were no calcium carbonate × benzoic acid interactions observed for any response criteria ($P > 0.10$). From d 0 to 10 (phase 1), there was evidence for benzoic acid to marginally increase ($P = 0.092$) ADG and significantly increase ($P = 0.042$) ADFI. From d 10 to 24 (phase 2), F/G improved ($P = 0.022$) as the level of calcium carbonate decreased. For the overall experimental period (d 0 to 24), there was a tendency for benzoic acid to improve ($P = 0.056$) ADG and ($P = 0.071$) ADFI, as well as an improvement (linear, $P = 0.014$) in F/G as calcium carbonate in the diet decreased. During the common period (d 24 to 38), pigs previously fed benzoic acid had increased ($P = 0.045$) ADG and marginally increased ($P = 0.091$) ADFI. For the overall study, pigs fed benzoic acid had increased ($P = 0.011$) ADG and ($P = 0.030$) ADFI and marginally improved ($P = 0.096$) F/G. For fecal DM, there was no observed evidence ($P > 0.10$) for differences among treatments. For serum analysis, serum Ca decreased ($P < 0.001$) as the level of dietary calcium carbonate decreased. These data suggests that lower levels of calcium carbonate may improve feed efficiency in the early nursery period. Also, nursery pigs fed benzoic acid had increased ADG and ADFI, and tended to have improved F/G.

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Introduction

Calcium carbonate is the main form of Ca in pig diets and has cationic properties that would increase the pH in the pig's stomach. A low stomach pH (< 4) improves protein digestion and intestinal health, whereas a high gastric pH has been observed to result in negative gastrointestinal challenges, including increased intestinal microflora.² Organic acids can decrease gastric pH and improve protein digestion. Benzoic acid has been shown to decrease the gastric population of lactic acid bacteria and cecal bacteria while improving ileal digestibility and growth performance.³ Recent studies have shown that decreasing calcium carbonate levels for the first 21 days post-weaning improved growth performance.

Ingredients that are higher in buffering capacity, such as calcium carbonate, increase dietary acid binding capacity (ABC). One method to characterize ABC is the use of $ABC - 4$, which is the amount of acid in milliequivalents (mEq) required to lower the pH of 1 kg of feed to a pH of 4. It is hypothesized that decreasing the diet ABC by decreasing calcium carbonate levels or adding an organic acid to lower the diet ABC would improve growth performance of nursery pigs. Also, the Ca and P blood status in relation to dietary calcium and acid additions are not well documented. Therefore, the objective of this study was to investigate the effects of added calcium carbonate with or without benzoic acid on the growth performance, fecal dry matter, and blood Ca and P concentrations of nursery pigs.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan, KS. The facility has two identical barns that are completely enclosed, environmentally controlled, and mechanically ventilated. Each pen contains a 4-hole, dry self-feeder and a cup waterer to provide *ad libitum* access to feed and water. Pens (4×4 ft) had metal tri-bar floors and allowed approximately 2.7 ft²/pig.

A total of 360 barrows (DNA Line 200 $\times$ 400; initially 13.6 ± 0.07 lb) were used in a 38-d study with 5 pigs per pen and 12 pens per treatment. Pigs were randomly assigned to pens and then pens were allotted to 1 of 6 dietary treatments. Treatment diets were fed from d 0 to 24 and a common phase 3 diet fed from d 24 to 38. Dietary treatments were formulated to provide 0.45, 0.90, or 1.35% calcium carbonate with or without 0.5% benzoic acid (VevoVital, DSM Nutritional Products, Parsippany, NJ) added at the expense of corn (Tables 1 and 2). A common phase 3 diet was formulated to contain 0.85% calcium carbonate. The calculated Ca levels were 0.66, 0.83, or 1.00% in phase 1, 0.54, 0.72, or 0.89% in phase 2, and 0.68% in phase 3. This corresponded with final calculated $ABC - 4$ values of 450, 508, and 566 mEq in phase 1, and 387, 445, and 502 mEq in phase 2, respectively, for the diets without benzoic acid. The addition of benzoic acid decreased $ABC - 4$ by approximately 30 mEq when added to each diet. A single base diet was manufactured at Hubbard Feeds in Beloit, KS, with calcium

² Ravindran, V. and E. T. Kornegay. 1993. Acidification of weaner pig diets: A review. J. Sci. Food. Agric. 62(4):313-322. doi: 10.1002/jsfa.2740620402.

³ Guggenbuhl, P., A. Séon, A. Piñón Quintana, C. Simões Nunes. 2007. Effects of dietary supplementation with benzoic acid (VevoVital®) on the zootechnical performance, the gastrointestinal microflora and ileal digestibility of the young pig. Livest. Sci. 108:218-221. doi:10.1016/j.livsci.2007.01.068.

carbonate, corn and benzoic acid additions mixed at the Kansas State University O.H. Kruse Feed Technology Innovation Center, Manhattan, KS. All diets were fed in meal form. Pig weight and feed disappearance were measured on d 0, 10, 24, and 38 of the experiment to determine ADG, ADFI, and F/G.

Complete diet samples of each treatment were taken with a grain probe from every other bag (phase 1) and every third bag (phase 2) upon completion of manufacturing. Phase 3 diet samples were taken with a grain probe from four random bags per ton of feed delivered. All diet samples were stored at -4°F. Three sub-samples of each treatment from each phase were ground with a food processor to create a homogeneous sample, and then submitted for analysis of Ca and P (K-State Research and Extension Soil Testing Laboratory, Manhattan, KS).

On d 7 of the experiment, feces were collected from 3 piglets per pen and dried at 130°F for 48 h to determine fecal dry matter. On d 21 of the experiment, blood was collected from 1 pig per pen, centrifuged at 40°F and $1800 \times g$ for 30 minutes, and serum was submitted for analysis of total Ca and P (Kansas State University Veterinary Diagnostics Lab).

Statistical analysis

Data were analyzed as a completely randomized design with pen serving as the experimental unit. Treatment was included in the statistical model as a fixed effect and barn was incorporated in the model as a random effect. Data were analyzed using R Studio (Version 3.5.2, R Core Team; Vienna, Austria). Contrasts were used to test for linear and quadratic responses to calcium carbonate and for the main effects of calcium carbonate, benzoic acid, and their interaction. Differences between treatments were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

Analyzed Ca values were greater than calculated levels in both phases 1 and 2, but they increased in a linear fashion as expected (Tables 1 and 2).

For all response criteria, there was no evidence for calcium carbonate $\times$ benzoic acid interactions observed ($P > 0.10$; Table 3). From d 0 to 10 (phase 1), there was a tendency for pigs fed benzoic acid to have increased ($P = 0.092$) ADG and significantly increased ($P = 0.042$) ADFI (Table 4). From d 10 to 24 (phase 2), pigs fed decreasing calcium carbonate had improved (linear, $P = 0.022$) F/G but ADG, ADFI, and d 24 BW were not influenced by dietary treatment.

For the overall experimental period (d 0 to 24), there was a tendency observed for benzoic acid to improve ($P = 0.056$) ADG and ($P = 0.071$) ADFI, and an improvement (linear, $P = 0.014$) was observed in F/G as calcium carbonate in the diet decreased. During the common period (d 24 to 38), pigs previously fed benzoic acid had increased ($P = 0.045$) ADG and marginally increased ($P = 0.091$) ADFI. For the overall study, pigs fed benzoic acid had increased ($P = 0.011$) ADG and ($P = 0.030$) ADFI and marginally improved ($P = 0.096$) F/G and ($P = 0.059$) final BW.

For fecal DM, there was no observed evidence ($P > 0.10$) for differences among treatments (Table 4). For serum analysis, serum Ca decreased (linear, $P < 0.001$) as the level of calcium carbonate in the diet decreased.

These data suggests that lower levels of calcium carbonate may improve growth performance in the early nursery period, which supports previous data. These data also suggest that including benzoic acid for the first 21 days post-weaning improves ADG and ADFI, and tends to improve F/G. More research is needed to determine if the improvements in growth performance are attributed to the dietary ABC – 4 concentration or a change in nutrient utilization from altered diet Ca and benzoic acid inclusion.

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Table 1. Phase 1 diet composition (as-fed basis)¹

Benzoic acid²:		Without			With		
Ingredient, %	CaCO₃, %:	0.45	0.90	1.35	0.45	0.90	1.35
Corn		44.82	44.30	43.79	44.33	43.84	43.36
Soybean meal, 46.5% CP		17.47	17.55	17.60	17.47	17.50	17.54
Spray-dried whey		10.00	10.00	10.00	10.00	10.00	10.00
Whey permeate		10.00	10.00	10.00	10.00	10.00	10.00
Corn DDGS		5.00	5.00	5.00	5.00	5.00	5.00
ME Pro ³		4.00	4.00	4.00	4.00	4.00	4.00
Menhaden fish meal		2.50	2.50	2.50	2.50	2.50	2.50
Spray-dried bovine plasma		2.00	2.00	2.00	2.00	2.00	2.50
Choice white grease		1.00	1.00	1.00	1.00	1.00	1.00
Monocalcium P, 21.5% P		0.80	0.80	0.80	0.80	0.80	1.00
Calcium carbonate		0.45	0.90	1.35	0.45	0.90	1.35
Zinc oxide		0.40	0.40	0.40	0.40	0.40	0.40
Sodium chloride		0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix with phytase ⁴		0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix		0.15	0.15	0.15	0.15	0.15	0.15
L-Lys-HCl		0.40	0.40	0.40	0.40	0.40	0.40
DL-Met		0.19	0.19	0.19	0.19	0.19	0.19
L-Thr		0.17	0.17	0.17	0.17	0.17	0.17
L-Trp		0.02	0.02	0.02	0.02	0.02	0.02
L-Val		0.08	0.08	0.08	0.08	0.08	0.08
Benzoic acid		---	---	---	0.50	0.50	0.50
Total		100	100	100	100	100	100

continued

Table 1. Phase 1 diet composition (as-fed basis)¹

Benzoic acid²:		Without			With		
Ingredient, %	CaCO₃, %:	0.45	0.90	1.35	0.45	0.90	1.35
Calculated analysis							
SID amino acids, %							
Lys		1.35	1.35	1.35	1.35	1.35	1.35
Ile:Lys		57	57	57	57	57	57
Leu:Lys		120	120	119	120	119	119
Met:Lys		36	36	36	36	36	36
Met and Cys:Lys		59	59	59	59	59	59
Thr:Lys		64	64	64	64	64	64
Trp:Lys		19.2	19.2	19.2	19.2	19.2	19.2
Val:Lys		70	70	70	70	70	70
Total Lys, %		1.51	1.52	1.52	1.51	1.51	1.51
NE, kcal/lb		1,153	1,147	1,142	1,147	1,141	1,136
SID Lys:NE g/Mcal		5.87	5.91	5.94	5.90	5.93	5.96
CP, %		21.5	21.5	21.5	21.5	21.4	21.4
Ca, %		0.66	0.83	1.00	0.66	0.83	1.00
P, %		0.66	0.66	0.66	0.66	0.66	0.66
STTD P, %		0.58	0.58	0.58	0.58	0.58	0.58
Formulated analyzed Ca:P		0.99	1.26	1.52	1.00	1.26	1.53
ABC – 4 ⁵		450	508	566	420	477	535
Chemical analysis, % ⁶							
Ca		0.77	0.90	1.04	0.74	0.89	1.05
P		0.68	0.65	0.63	0.63	0.65	0.58

¹ Phase 1 experimental diets were fed for 10 days.² VevoVital, DSM Nutritional Products, Parsippany, NJ.³ Prairie Aquatech, Brookings, SD.⁴ Ronozyme 2700 (DSM Nutritional Products) provided a 0.13 release of STTD P % with 1250 FTU/kg inclusion in the premix.⁵ Acid binding capacity (ABC) was calculated based on published or estimated ingredient values.⁶ Three representative samples were collected from each treatment diet, ground with a food processor, and submitted for analysis to the K-State Research and Extension Soil Testing Laboratory, Manhattan, KS.

Table 2. Phase 2 and 3 diet composition (as-fed basis)¹

Ingredient, %	Benzoic acid²:	Without			With			Phase 3³
	CaCO₃, %:	0.45	0.90	1.35	0.45	0.90	1.35	
Corn		50.16	49.67	49.19	49.62	49.13	48.65	64.71
Soybean meal, 46.5% CP		23.75	23.79	23.82	23.79	23.83	23.86	31.30
Whey permeate		10.00	10.00	10.00	10.00	10.00	10.00	---
Corn DDGS		7.50	7.50	7.50	7.50	7.50	7.50	---
ME Pro ⁴		3.85	3.85	3.85	3.85	3.85	3.85	---
Choice white grease		1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium P, 21.5% P		1.00	1.00	1.00	1.00	1.00	1.00	1.00
Calcium carbonate		0.45	0.90	1.35	0.45	0.90	1.35	0.85
Zinc oxide		0.25	0.25	0.25	0.25	0.25	0.25	---
Sodium chloride		0.50	0.50	0.50	0.50	0.50	0.50	0.60
Vitamin premix with phytase ⁵		0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix		0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys-HCL		0.55	0.55	0.55	0.55	0.55	0.55	0.52
DL-Met		0.22	0.22	0.22	0.22	0.22	0.22	0.23
L-Thr		0.22	0.22	0.22	0.22	0.22	0.22	0.22
L-Trp		0.04	0.04	0.04	0.04	0.04	0.04	---
L-Val		0.12	0.12	0.12	0.12	0.12	0.12	0.06
Benzoic acid		---	---	---	0.50	0.50	0.50	---
Total		100	100	100	100	100	100	100

continued

Table 2. Phase 2 and 3 diet composition (as-fed basis)¹

Benzoic acid ² :		Without			With			Phase
Ingredient, %	CaCO ₃ , %:	0.45	0.90	1.35	0.45	0.90	1.35	3 ³
Calculated analysis								
SID amino acids, %								
Lys		1.35	1.35	1.35	1.35	1.35	1.35	1.35
Ile:Lys		57	56	56	56	56	56	55
Leu:Lys		118	118	118	118	118	118	114
Met:Lys		37	37	37	37	37	37	37
Met and Cys:Lys		58	58	58	58	58	58	58
Thr:Lys		63	63	63	63	63	63	63
Trp:Lys		19.3	19.3	19.3	19.3	19.3	19.3	20.3
Val:Lys		70	70	70	70	70	70	69
Total Lys, %		1.51	1.51	1.51	1.51	1.51	1.51	1.49
NE, kcal/lb		1,135	1,129	1,123	1,128	1,123	1,117	1,099
SID Lys:NE, g/Mcal		6.14	6.17	6.20	6.17	6.21	6.24	5.67
CP, %		21.5	21.4	21.4	21.4	21.4	21.4	21.2
Ca, %		0.54	0.72	0.89	0.54	0.72	0.89	0.68
P, %		0.61	0.61	0.61	0.61	0.61	0.60	0.61
STTD P, %		0.51	0.51	0.51	0.51	0.51	0.51	0.47
Formulated analyzed Ca:P		0.89	1.18	1.47	0.89	1.18	1.47	1.13
ABC – 4 ⁶		387	445	502	357	415	473	412
Chemical analysis, % ⁷								
Ca		0.58	0.74	1.04	0.61	0.79	1.07	0.68
P		0.52	0.51	0.53	0.58	0.59	0.54	0.54

¹ Phase 2 experimental diets were fed from d 10 to 24.² VevoVital, DSM Nutritional Products, Parsippany, NJ.³ Phase 3 common diet was fed from d 24 to 38.⁴ Prairie Aquatech, Brookings, SD.⁵ Ronozyme 2700 (DSM Nutritional Products) provided a 0.13 release of STTD P % with 1250 FTU/kg inclusion in the premix.⁶ Acid binding capacity (ABC) was calculated based on published or estimated ingredient values.⁷ Three representative samples were collected from each treatment diet, ground with a food processor, and submitted for analysis to the K-State Research and Extension Soil Testing Laboratory, Manhattan, KS.

Table 3. Effects of calcium carbonate with or without benzoic acid on nursery pig growth performance, fecal dry matter, and blood calcium and phosphorus concentration¹

Benzoic acid ² :									<i>P</i> =	
									Without	
Item	CaCO ₃ %:	0.45	0.90	1.35	0.45	0.90	1.35	SEM	Linear	Quadratic
BW, lb										
d 0		13.7	13.6	13.7	13.6	13.6	13.6	0.07	0.948	0.636
d 10		16.5	16.2	16.5	16.5	16.7	16.8	0.27	0.451	0.534
d 24		29.2	28.8	28.5	29.4	29.1	29.4	0.68	0.535	0.784
d 38		46.2	45.9	45.9	47.4	47.0	47.4	1.02	0.847	0.871
Phase 1 period (d 0 to 10)										
ADG, lb		0.29	0.26	0.28	0.29	0.31	0.32	0.031	0.451	0.471
ADFI, lb		0.30	0.29	0.32	0.32	0.32	0.35	0.023	0.715	0.878
F/G		1.07	2.15	1.29	1.16	1.05	1.11	0.453	0.241	0.188
Phase 2 period (d 10 to 24)										
ADG, lb		0.88	0.88	0.85	0.92	0.89	0.90	0.055	0.677	0.446
ADFI, lb		1.16	1.17	1.14	1.19	1.16	1.24	0.052	0.292	0.259
F/G		1.32	1.33	1.35	1.30	1.32	1.38	0.036	0.359	0.657
Experimental period (d 0 to 24)										
ADG, lb		0.63	0.60	0.61	0.66	0.64	0.65	0.027	0.655	0.936
ADFI, lb		0.80	0.78	0.79	0.83	0.81	0.85	0.029	0.516	0.602
F/G		1.27	1.30	1.30	1.26	1.26	1.31	0.019	0.751	0.129
Common period (d 24 to 38)										
ADG, lb		1.22	1.22	1.24	1.29	1.28	1.28	0.035	0.693	0.966
ADFI, lb		1.83	1.83	1.82	1.88	1.85	1.89	0.037	0.766	0.561
F/G		1.50	1.50	1.48	1.46	1.46	1.48	0.023	0.301	0.513
Overall (d 0 to 38)										
ADG, lb		0.85	0.82	0.84	0.89	0.87	0.87	0.026	0.904	0.736
ADFI, lb		1.17	1.15	1.16	1.21	1.19	1.22	0.029	0.736	0.775
F/G		1.39	1.40	1.39	1.37	1.36	1.40	0.015	0.281	0.160
Fecal DM, % ³										
d 7		27.5	30.4	29.8	28.1	27.3	28.3	1.313	0.303	0.159
Serum ⁴										
Ca, mg/dL		10.7	11.2	11.6	11.0	11.3	11.6	0.206	0.355	0.942
P, mg/dL		11.0	10.6	11.0	10.9	11.3	10.8	0.321	0.897	0.156

¹ A total of 360 weaned barrow pigs (200 × 400, DNA; initially 13.6 ± 0.07 lb) approximately 21 days of age were used in a 38-d experiment with 5 pigs per pen and 12 pens per treatment.

² DSM Nutritional Products, Parsippany, NJ.

³ Feces from three piglets from each pen were pooled, weighed, and dried to measure fecal dry matter.

⁴ Blood was collected from 1 pig per pen on d 21 and submitted to the Kansas State University Veterinary Diagnostic Lab for Ca and P analysis.

Table 4. Main effects of calcium carbonate and benzoic acid on nursery pig growth performance, fecal dry matter and blood calcium and phosphorus concentrations¹

Item	CaCO ₃ %			SEM	P =		Benzoic acid ²		SEM	P =
	0.45	0.90	1.35		Linear	Quadratic	Without	With		
BW, lb										
d 0	13.7	13.6	13.6	0.06	0.793	0.283	13.7	13.6	0.06	0.257
d 10	16.5	16.4	16.7	0.22	0.598	0.403	16.4	16.7	0.20	0.156
d 24	29.3	28.9	29.0	0.56	0.620	0.665	28.8	29.3	0.52	0.294
d 38	46.8	46.4	46.6	0.85	0.821	0.678	46.0	47.3	0.78	0.059
Phase 1 period (d 0 to 10)										
ADG, lb	0.29	0.28	0.30	0.026	0.550	0.529	0.28	0.31	0.025	0.092
ADFI, lb	0.31	0.31	0.33	0.019	0.228	0.245	0.30	0.33	0.018	0.042
F/G	1.11	1.60	1.20	0.335	0.485	0.990	1.50	1.11	0.286	0.293
Phase 2 period (d 10 to 24)										
ADG, lb	0.90	0.88	0.88	0.052	0.397	0.832	0.87	0.90	0.050	0.188
ADFI, lb	1.17	1.16	1.19	0.045	0.595	0.566	1.56	1.20	0.043	0.174
F/G	1.31	1.33	1.37	0.032	0.022	0.611	1.33	1.33	0.030	0.799
Experimental period (d 0 to 24)										
ADG, lb	0.64	0.62	0.63	0.023	0.519	0.451	0.61	0.65	0.021	0.056
ADFI, lb	0.81	0.79	0.82	0.023	0.690	0.288	0.79	0.83	0.021	0.071
F/G	1.26	1.28	1.31	0.014	0.014	0.595	1.29	1.28	0.012	0.374
Common period (d 24 to 38)										
ADG, lb	1.25	1.25	1.26	0.026	0.846	0.839	1.23	1.28	0.022	0.045
ADFI, lb	1.85	1.84	1.86	0.028	0.849	0.607	1.83	1.87	0.024	0.091
F/G	1.48	1.48	1.48	0.016	0.883	0.851	1.49	1.47	0.013	0.159
Overall (d 0 to 38)										
ADG, lb	0.87	0.85	0.85	0.021	0.531	0.485	0.83	0.88	0.019	0.011
ADFI, lb	1.19	1.17	1.19	0.023	0.982	0.288	1.16	1.21	0.020	0.030
F/G	1.38	1.38	1.40	0.011	0.163	0.550	1.39	1.38	0.010	0.096
Fecal DM, % ³										
d 7	27.8	28.8	29.0	1.09	0.249	0.657	29.2	27.9	1.00	0.126
Serum ⁴										
Ca, mg/dL	10.8	11.3	11.6	0.15	<0.001	0.808	11.2	11.3	0.13	0.470
P, mg/dL	10.9	11.0	10.9	0.23	0.959	0.941	10.9	11.0	0.19	0.591

¹ A total of 360 weaned barrow pigs (DNA 200 × 400, DNA; initially 13.6 ± 0.07 lb) approximately 21 days of age were used in a 38-d experiment with 5 pigs per pen and 24 pens per calcium carbonate treatment and 36 pens per benzoic acid treatment. There was no calcium carbonate × benzoic acid interaction ($P > 0.10$).

² DSM Nutritional Products, Parsippany, NJ.

³ Feces from three piglets from each pen were pooled, weighed, and dried to measure fecal dry matter.

⁴ Blood was collected from 1 pig per pen on d 21 and submitted to the Kansas State University Veterinary Diagnostic Lab for Ca and P analysis.