Effects of Different Inorganic Phosphorus Sources on Apparent Digestibility and Metabolism of Calcium and Phosphorus in Weaned Piglets

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Abstract

This experiment aimed to investigate the effects of different inorganic phosphorus sources on the apparent digestibility and metabolism of calcium and phosphorus in weaned piglets. The experiment selected 200 crossbred (Landrace × Large White) weaned piglets with consistent genetic background, good health status, initial body weight of (8.41±0.97) kg, and age of (28±2) days, which were randomly divided into 5 groups with 4 replicates per group and 10 piglets per replicate (half male and half female). The five groups of piglets were fed diets containing 0.66% powdered dicalcium phosphate (DCP), 0.44% granular monocalcium phosphate (MCP), 0.44% powdered MCP, 0.49% powdered monodicalcium phosphate (MDCP), and 0.49% granular MDCP, respectively, while maintaining consistent dietary calcium and phosphorus levels. The experimental period lasted 28 days. The results showed: 1) There were no significant differences in apparent digestibility of calcium and dry matter among groups ($P>0.05$). The apparent phosphorus digestibility in the powdered MDCP group was significantly higher than that in the powdered DCP, granular MCP, and powdered MCP groups ($P<0.05$), but not significantly different from the granular MDCP group ($P>0.05$); 2) There were no significant differences in serum calcium and phosphorus contents among groups ($P>0.05$), but the serum alkaline phosphatase activity in the powdered MCP group was significantly lower than that in the other groups (P<0.05); 3) There were no significant differences in foot bone weight, foot bone ash weight, foot bone ash percentage, and foot bone phosphorus content among groups (P>0.05), but the foot bone calcium content in the powdered MDCP, powdered MCP, and granular MCP groups was significantly higher than that in the powdered DCP group (P<0.05). It can be concluded that compared with powdered DCP, powdered MDCP, granular MDCP, granular MCP, and powdered MCP can better promote the metabolism and utilization of calcium and phosphorus in weaned piglets, and are good phosphorus sources to replace powdered DCP.

Full Text

Effects of Different Inorganic Phosphorus Sources on Apparent Digestibility and Metabolism of Calcium and Phosphorus in Weaned Piglets

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Abstract

This experiment was conducted to investigate the effects of different inorganic phosphorus sources on the apparent digestibility and metabolism of calcium and phosphorus in weaned piglets. Two hundred crossbred (Landrace × Large White) weaned piglets at (28±2) days of age with consistent genetic background, good health status, and initial body weight of (8.41±0.97) kg were randomly allocated into five groups with four replicates per group and ten piglets per replicate (half male and half female). The five groups were fed diets supplemented with 0.66% powdery dibasic calcium phosphate (DCP), 0.44% powdery monocalcium phosphate (MCP), 0.44% granular MCP, 0.49% powdery mono-dicalcium phosphate (MDCP), or 0.49% granular MDCP, respectively, while maintaining consistent dietary calcium and phosphorus levels across all treatments. The experimental period lasted 28 days. The results showed that: (1) No significant differences were observed among groups in the apparent digestibility of calcium and dry matter (P>0.05). However, the apparent digestibility of phosphorus in the powdery MDCP group was significantly higher than that in the powdery DCP, granular MCP, and powdery MCP groups (P<0.05), though it did not differ significantly from the granular MDCP group (P>0.05). (2) Serum calcium and phosphorus concentrations did not differ significantly among groups (P>0.05), but serum alkaline phosphatase activity in the powdery MCP group was significantly lower than in the other groups (P<0.05). (3) No significant differences were found among groups in coffin bone weight, coffin bone ash weight, coffin bone ash percentage, or coffin bone phosphorus content (P>0.05). However, coffin bone calcium content in the powdery MDCP, powdery MCP, and granular MCP groups was significantly higher than in the powdery DCP group ($P<0.05$). In conclusion, compared with powdery DCP, powdery MDCP, granular MDCP, granular MCP, and powdery MCP can better promote calcium and phosphorus metabolism and utilization in weaned piglets and serve as excellent alternative phosphorus sources.

Keywords: inorganic phosphorus; weaned piglets; apparent digestibility of calcium and phosphorus; calcium and phosphorus metabolism

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Phosphorus is the second most abundant mineral element in animal bodies after calcium, constituting 0.7%-1.1% of body weight and serving as a primary component of bones and teeth. Biologically, phosphorus participates in the formation of energy storage and supply substances such as phosphocreatine and ATP, and is a constituent of numerous coenzymes and body fluid buffering substances, playing crucial roles in regulating energy metabolism, maintaining cell membrane function, and preserving acid-base balance and normal osmotic pressure. Numerous studies have demonstrated that phosphorus deficiency in animals impairs calcium deposition in cartilage tissue, manifesting as poor bone and tooth development, reduced appetite, pica, and in severe cases, osteoporosis, paralysis, and death. Therefore, meeting animal phosphorus requirements is essential for maintaining healthy growth. In piglet production, large quantities of inorganic phosphorus sources are typically added to diets to meet the demands of rapid growth. However, unabsorbed phosphorus excreted into the environment not only wastes resources but also causes severe pollution. Phosphate rock is the primary source of inorganic phosphorus in feed, yet it is a non-renewable resource, making the search for effective alternative inorganic phosphorus sources an urgent priority. The main feed-grade inorganic phosphorus sources in China include feed-grade dibasic calcium phosphate (DCP), monocalcium phosphate (MCP), and bone meal. Mono-dicalcium phosphate (MDCP) is a co-crystalline compound of DCP and MCP, representing a novel feed additive that combines citrate-soluble and water-soluble phosphates. While widely used in Europe and America, the biological efficacy of MDCP (particularly domestically produced MDCP) has not been adequately evaluated in China. This study utilized weaned piglets as experimental animals to investigate the effects of different inorganic phosphorus sources (MDCP, MCP, and DCP) on calcium and phosphorus digestion and utilization, aiming to provide a theoretical basis for the development and scientific application of inorganic phosphorus sources.

1.1 Experimental Materials

The inorganic phosphorus sources used in this experiment were provided by Sinochem Yunlong Co., Ltd., including powdery DCP (phosphorus content 17%), powdery MCP (phosphorus content 22%), granular MCP (phosphorus content 22%), powdery MDCP (phosphorus content 21%), and granular MDCP (phosphorus content 21%).

1.2 Experimental Animals and Design

Two hundred crossbred (Landrace × Large White) weaned piglets at (28±2) days of age with consistent genetic background, good health status, and initial body weight of (8.41±0.97) kg were selected as experimental animals. The piglets were randomly divided into five groups with four replicates per group and ten piglets per replicate (half male and half female). The five groups were fed diets containing powdery DCP, powdery MCP, granular MCP, powdery MDCP, or granular MDCP, respectively.

1.3 Experimental Diets

The experimental diets were corn-soybean meal-based, with nutrient levels formulated according to NRC (2012) nutrient requirements for piglets. When preparing diets with different inorganic phosphorus sources, the contents of different phosphorus sources and limestone were adjusted to maintain consistent calcium and phosphorus levels across all groups. The composition and nutrient levels of the experimental diets are presented in Table 1 .

1.4 Feeding Management

Experimental piglets were housed in nursery pens with room temperature maintained at 25–28 °C and humidity at 55%–65%. All piglets had ad libitum access to feed and water. Powdered feed was provided 4–5 times daily, and feed intake was recorded. Other routine management procedures followed conventional pig farm practices. The experimental period lasted 28 days.

1.5 Sample Collection and Processing

From days 26 to 28 of the experiment, total fecal samples were collected from each pig using the total collection method. Collected feces were thoroughly mixed, and 200 g was sampled. For every 100 g of feces, 20 mL of 10% sulfuric acid and a few drops of toluene were added, mixed thoroughly, spread in a porcelain tray, and dried in a 65 °C oven. After drying, samples were equilibrated at room temperature for 24 hours, ground, passed through a 40-mesh sieve, and stored at 4 °C for subsequent analysis.

On the morning of day 28, all piglets were weighed after overnight fasting. Two piglets were randomly selected from each replicate, and 8 mL of blood was collected from the anterior vena cava. Blood samples were placed in an ice-packed foam box at 4 °C for 30 minutes, then centrifuged at 3,000 r/min for 10 minutes to separate serum, which was stored at -20 °C for determination of calcium and phosphorus concentrations and alkaline phosphatase (ALP) activity. Coffin bone samples were collected and prepared according to the method described by Cao Guibin [4].

1.6 Measurement Indicators and Methods

Serum calcium and phosphorus concentrations and alkaline phosphatase activity were measured using assay kits from Nanjing Jiancheng Bioengineering Institute. Coffin bone weight, coffin bone ash weight, and calcium and phosphorus contents in coffin bone were determined according to the method of Cao Guibin [4], and coffin bone ash percentage was calculated. Calcium content in diets and feces was determined by potassium permanganate method, and phosphorus content was determined by molybdate yellow colorimetric method. The apparent digestibility of calcium and phosphorus was calculated using the following formulas:

Apparent digestibility of calcium = 100 × (total calcium intake - calcium excreted in feces) / total calcium intake
Apparent digestibility of phosphorus = 100 × (total phosphorus intake - phosphorus excreted in feces) / total phosphorus intake

1.7 Statistical Analysis

Experimental data were processed using Excel 2003. Results for apparent digestibility of calcium and phosphorus and related indicators of calcium and phosphorus metabolism were analyzed using one-way ANOVA in SPSS 17.0, followed by Duncan' s multiple comparison test. Results are expressed as "mean ± standard deviation," with $P<0.05$ as the criterion for statistical significance.

2.1 Effects of Different Inorganic Phosphorus Sources on Apparent Digestibility of Calcium and Phosphorus in Weaned Piglets

The effects of different inorganic phosphorus sources on apparent digestibility of calcium and phosphorus in weaned piglets are shown in Table 2 . The data indicate that the apparent digestibility of dietary calcium in the powdery DCP group was 55.10%, which was 14.94% higher than that in the granular MDCP group, but no significant differences were observed among groups ($P>0.05$). The apparent digestibility of phosphorus in the powdery MDCP group was significantly higher than that in the powdery DCP, granular MCP, and powdery MCP groups ($P<0.05$), with the powdery MDCP group showing a 13.68% improvement over the powdery DCP group, though no significant difference was found between powdery and granular MDCP groups ($P>0.05$). No significant differences were detected among groups in apparent digestibility of dietary dry matter ($P>0.05$).

2.2 Effects of Different Inorganic Phosphorus Sources on Serum Calcium and Phosphorus Contents and Alkaline Phosphatase Activity in Weaned Piglets

The effects of different inorganic phosphorus sources on serum calcium and phosphorus contents and alkaline phosphatase activity are presented in Table 3 . The data show that no significant differences existed among groups in serum calcium and phosphorus concentrations (P>0.05). However, serum alkaline phosphatase activity was lowest in the powdery MCP group, which was significantly lower than in all other groups (P<0.05).

2.3 Effects of Different Inorganic Phosphorus Sources on Trotter Bone Quality in Weaned Piglets

The effects of different inorganic phosphorus sources on trotter bone quality are shown in Table 4 . No significant differences were observed among groups in trotter bone weight, trotter bone ash weight, trotter bone ash percentage, or trotter bone phosphorus content (P>0.05). However, trotter bone calcium content in the powdery MCP, granular MCP, and powdery MDCP groups was significantly higher than in the powdery DCP group (P<0.05), with the powdery MCP group reaching 6.13%, representing a 22.6% increase over the powdery DCP group. No significant differences were detected among the powdery MCP, granular MCP, and powdery MDCP groups in trotter bone calcium content (P>0.05).

3.1 Effects of Different Inorganic Phosphorus Sources on Apparent Digestibility of Calcium and Phosphorus in Weaned Piglets

The jejunum and duodenum are the primary sites for phosphorus absorption in livestock and poultry. Inorganic phosphorus absorption in the small intestine is influenced by factors including the calcium-to-phosphorus ratio, phosphorus form, small intestine pH, and interactions with other mineral elements. Research indicates that the biological efficacy of inorganic phosphorus follows the order DCP < MCP, and since MDCP is a complex of MCP and DCP, theoretically, phosphorus digestibility in MDCP should be higher than in DCP [5-6]. Cao Hui [7] reported that the apparent digestibility of phosphorus in MCP and MDCP was (88.33±3.44)% and (82.83±3.00)%, respectively, with no significant difference between them, but both were significantly higher than that in DCP (69.66±5.38)%. These findings are consistent with our results, likely because MCP and MDCP exhibit weak acidity, which reduces dietary acid-binding capacity. When MCP and MDCP enter the animal stomach with feed, the released hydrogen ions activate gastrointestinal digestive enzymes, thereby improving apparent phosphorus digestibility [5].

Generally, the apparent digestibility of calcium in pigs varies with growth stage but positively correlates with phosphorus apparent digestibility overall. This positive correlation becomes more pronounced when dietary calcium and phosphorus levels approach the animal' s nutritional requirements [8]. However, some studies have found that phosphorus apparent digestibility does not positively correlate with calcium apparent digestibility at different growth stages [9], similar to our findings. This discrepancy may be related to dietary calcium-to-phosphorus ratio and calcium content. In this experiment, the dietary calcium-to-phosphorus ratio was approximately 1.4, and when this ratio exceeds 1.3, calcium apparent digestibility tends to decline [10]. Additionally, the calcium content in our experimental diets was 0.83%, which may exceed the actual requirement for weaned piglets. When calcium intake surpasses the animal' s requirement, parathyroid C-cells are stimulated to promote calcitonin secretion, which inhibits active calcium absorption in the intestine and ultimately reduces calcium apparent digestibility.

3.2 Effects of Different Inorganic Phosphorus Sources on Serum Calcium and Phosphorus Contents and Alkaline Phosphatase Activity in Weaned Piglets

Blood calcium and phosphorus concentrations are commonly used to evaluate phosphorus nutritional status in animals. Through regulation by bones, intestines, and kidneys during digestion and absorption, blood calcium and phosphorus levels generally maintain dynamic equilibrium. Reduced serum phosphorus concentration is a direct indicator of phosphorus deficiency. When dietary calcium and phosphorus levels are low, absorbed calcium and phosphorus are first utilized to meet blood requirements, with the remainder deposited in bone matrix. Conversely, when dietary calcium and phosphorus levels are high, bone deposition increases, and calcium and phosphorus released from bone into blood also increase. Our results showed no significant differences in serum calcium and phosphorus concentrations among groups fed diets containing DCP, MCP, or MDCP. This may be because dietary calcium and phosphorus levels in all groups already met animal requirements, satisfying blood calcium and phosphorus demands with surplus deposited in bone matrix. Alternatively, when dietary calcium-to-phosphorus ratio is fixed, phosphorus source type may not significantly affect serum calcium concentration [11].

Serum alkaline phosphatase activity is an important biochemical indicator for assessing calcium and phosphorus status, with sensitivity second only to bone ash, calcium and phosphorus content, and bone mechanical properties [12]. Generally, serum alkaline phosphatase activity is inversely related to serum phosphorus and calcium concentrations. Hurwitz et al. [13] confirmed in chickens that inadequate bone mineralization leads to elevated serum alkaline phosphatase activity. Our study also showed that serum alkaline phosphatase activity was lowest in the powdery MCP group, possibly because powdery MCP 更有利于钙、磷的沉积 (facilitates calcium and phosphorus deposition), thereby reducing bone mineral release. This finding is supported by the significantly increased trotter bone calcium content in the powdery MCP group. However, some studies have reported that different phosphorus sources do not significantly affect serum alkaline phosphatase activity in chickens [14-15].

3.3 Effects of Different Inorganic Phosphorus Sources on Calcium and Phosphorus Deposition in Trotter Bone of Weaned Piglets

Since the early 1950s when phosphate rock began to be used as a feed ingredient in animal compound feed, numerous studies have confirmed that phosphate rock plays an irreplaceable role in calcium and phosphorus deposition in animal bones [16-19]. Bone ash consists primarily of calcium and phosphate salts with relatively stable elemental composition, making bone ash weight a common indicator for calcium and phosphorus deposition. Huang Abin [20] investigated the role of inorganic phosphorus in finishing pig diets and found that humerus and femur calcium content in the MCP group was 13.42% and 20.10% higher, respectively, than in the DCP group, while humerus and femur phosphorus content was also 11.84% and 13.95% higher, respectively, suggesting that MCP is more conducive to bone calcium and phosphorus deposition than DCP. However, Tan Zhankun [12] reported that MDCP and DCP did not significantly affect tibia calcium and phosphorus content, tibia strength, or tibia ash content in chickens. Our results indicate that while powdery MCP, granular MCP, powdery MDCP, and granular MDCP had limited effects on trotter bone quality, they all showed beneficial effects on promoting bone calcium and phosphorus deposition in piglets, with powdery MCP demonstrating the most favorable outcome.

4 Conclusion

1. The apparent digestibility of phosphorus in the powdery MDCP group was significantly higher than that in the powdery DCP, granular MCP, and powdery MCP groups, but did not differ significantly from the granular MDCP group. Compared with powdery DCP, powdery MDCP, powdery MCP, and granular MCP significantly improved trotter bone calcium content in weaned piglets.

2. Different inorganic phosphorus sources did not significantly affect trotter bone phosphorus content or serum calcium and phosphorus concentrations, but serum alkaline phosphatase activity was significantly reduced in the powdery MCP group compared with other groups.

3. Considering the comprehensive effects on apparent digestibility of calcium and phosphorus and bone growth in weaned piglets, powdery MDCP, granular MDCP, granular MCP, and powdery MCP are excellent alternative phosphorus sources to replace powdery DCP.

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Note: Figure translations are in progress. See original paper for figures.