

Cost Comparison of Mineral Sources for Achieving Broiler Dietary Calcium and Phosphorus Requirements

Faisal Sayed Abdalgalil^{1*}

¹Independent Researcher

Abstract: Calcium (Ca) and phosphorus (P) are essential minerals in broiler nutrition, playing critical roles in skeletal development, metabolic functions, and growth performance. Feed formulators commonly use inorganic mineral sources such as monocalcium phosphate (MCP), dicalcium phosphate (DCP), and calcium carbonate supplied as limestone (LS). These sources differ in mineral concentration, bioavailability, and economic cost. This study compares three mineral supplementation strategies designed to achieve approximately 1.0% calcium and 0.55% phosphorus in broiler diets, assuming negligible contribution of Ca and P from other ingredients. Cost calculations were performed using ingredient prices expressed in Sudanese pounds (SDG/kg). Three mineral formulations were evaluated: (1) MCP as the primary phosphorus source; (2) a combination of MCP and DCP; and (3) DCP as the primary phosphorus source. The results demonstrate clear economic differences among mineral supplementation strategies, with the DCP-only formulation providing the lowest cost (175,900 SDG), followed by the MCP+DCP combination (195,220 SDG), and the MCP-only formulation (203,680 SDG). Relative to the DCP formulation, the MCP-only formulation increased cost by 15.8%, while the combination increased cost by 11.0%. However, the economic comparison alone does not fully represent nutritional value, as phosphorus bioavailability differs among sources. The study highlights the need for controlled feeding experiments to evaluate biological responses of broilers to different mineral sources before making practical formulation recommendations.

Keywords: Broiler, Calcium, Phosphorus, Monocalcium Phosphate, Dicalcium Phosphate, Limestone, Feed Formulation, Cost Analysis.

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Research Paper

*Corresponding Author:

Faisal Sayed Abdalgalil
Independent Researcher

How to cite this paper:

Faisal Sayed Abdalgalil (2026).
Cost Comparison of Mineral
Sources for Achieving Broiler
Dietary Calcium and Phosphorus
Requirements. *Middle East Res J.
Pharm. Sci.* 6(1): 15-19.

Article History:

| Submit: 01.03.2026 |
| Accepted: 03.04.2026 |
| Published: 06.04.2026 |

1. INTRODUCTION

1.1 Importance of Calcium and Phosphorus in Broiler Nutrition

Calcium and phosphorus are among the most critical minerals in poultry nutrition due to their fundamental roles in bone formation, cellular metabolism, and physiological regulation (National Research Council, 1994). In broiler chickens, rapid skeletal development requires adequate dietary supply of both minerals in balanced proportions. A deficiency or imbalance in either mineral can lead to reduced growth performance, skeletal disorders, and increased mortality.

1.2 Common Mineral Sources in Poultry Diets

Calcium is primarily supplied through limestone (calcium carbonate), while phosphorus is supplemented through inorganic phosphate sources. The most commonly used inorganic phosphorus supplements include monocalcium phosphate (MCP), monodicalcium phosphate (MDCP), and dicalcium phosphate (DCP).

These phosphate sources differ in their chemical structure, calcium-to-phosphorus ratio, solubility, and phosphorus digestibility (Trairatapiwan *et al.*, 2018; Woyengo *et al.*, 2022).

1.3 Phosphorus Bioavailability in Poultry

Phosphorus is an essential mineral in poultry nutrition, playing a crucial role in skeletal development, energy metabolism, and several physiological processes. However, a large proportion of phosphorus present in plant-based feed ingredients is bound in the form of phytate, which is poorly digested by poultry due to limited endogenous phytase activity in the gastrointestinal tract. As a result, inorganic phosphorus sources are commonly included in broiler diets to meet nutritional requirements and support optimal growth and bone mineralization (Woyengo *et al.*, 2022).

Previous studies have shown that phosphorus digestibility varies among different inorganic phosphates, with more soluble sources generally

exhibiting higher phosphorus availability to poultry (Woyengo *et al.*, 2022). Experimental evaluation in broiler chickens demonstrated differences in true ileal phosphorus digestibility among MCP, monocalcium phosphate, and DCP, emphasizing the importance of selecting appropriate phosphorus sources during feed formulation (Trairatapiwan *et al.*, 2018).

1.4 Factors Influencing Phosphate Source Selection

The choice of phosphorus source in commercial feed formulation is influenced by several factors:

1. Concentration of calcium and phosphorus in the ingredient
2. Digestibility and biological availability of phosphorus
3. Price per kilogram of the ingredient
4. Overall feed formulation cost

Among the commonly used feed phosphates, MCP generally contains higher levels of available phosphorus and exhibits greater solubility in the digestive tract compared with DCP. However, MCP is typically more expensive. Feed manufacturers must therefore balance nutritional efficiency and economic feasibility when selecting mineral sources for broiler diets.

Ingredient	Calcium (%)	Phosphorus (%)	Price (SDG/kg)
MCP	18	22	8,000
DCP	22	18	5,600
Limestone	37	0	230

Note: Prices were obtained from [source to be added] as of [date to be added]. Nutrient concentrations represent typical values for commercially available products.

2.3 Formulation Approach

Linear calculations were performed to determine the inclusion rates of each mineral source required to meet the target calcium and phosphorus concentrations simultaneously. The general approach involved:

1. Determining the phosphorus contribution from phosphate sources (MCP, DCP, or combination)
2. Calculating the remaining calcium requirement to be supplied by limestone
3. Verifying that both calcium and phosphorus targets were achieved

1.5 Study Objectives

The present study evaluates the economic implications of three mineral supplementation strategies formulated to achieve similar dietary concentrations of calcium and phosphorus. Additionally, this paper discusses the nutritional considerations associated with different phosphate sources and proposes an experimental design for biological validation of the economic findings.

2. MATERIALS AND METHODS

2.1 Target Mineral Levels

The mineral mixtures were formulated to supply approximately:

- Calcium: 1.0%
- Phosphorus: 0.55%

For the purpose of comparison, the contribution of calcium and phosphorus from other feed ingredients was assumed to be negligible. This assumption allows for direct comparison of mineral supplementation costs independent of basal diet composition.

2.2 Mineral Sources and Assumed Composition

The mineral sources evaluated in this study and their assumed nutrient concentrations were:

2.4 Cost Calculation

Total cost of each mineral mixture was calculated as: Total Cost = $\sum$ (Inclusion Rate (kg) $\times$ Price (SDG/kg))

All costs are expressed in Sudanese pounds (SDG) per metric ton of complete feed, representing only the mineral component cost.

3. RESULTS

3.1 MCP-Based Formulation

The formulation using MCP as the sole phosphorus source required 25 kg of MCP and 16 kg of limestone per metric ton of feed to achieve the target mineral levels.

Table 1: Mineral composition and cost of MCP-based formulation

Ingredient	Inclusion (kg/ton)	Ca Contribution (%)	P Contribution (%)	Cost (SDG/ton)
MCP	25	0.45	0.55	200,000
DCP	0	0	0	0
Limestone	16	0.592	0	3,680
Total	41	1.04	0.55	203,680

This formulation achieved 1.04% calcium and 0.55% phosphorus with a total mineral cost of 203,680 SDG per metric ton of feed.

3.2 MCP + DCP Combination Formulation

The combination formulation used both MCP and DCP to supply phosphorus, requiring 17 kg MCP, 10 kg DCP, and 14 kg limestone per metric ton.

Table 2: Mineral composition and cost of MCP + DCP combination formulation

Ingredient	Inclusion (kg/ton)	Ca Contribution (%)	P Contribution (%)	Cost (SDG/ton)
MCP	17	0.306	0.374	136,000
DCP	10	0.22	0.18	56,000
Limestone	14	0.518	0	3,220
Total	41	1.04	0.55	195,220

This formulation achieved 1.04% calcium and 0.55% phosphorus with a total mineral cost of 195,220 SDG per metric ton of feed.

3.3 DCP-Based Formulation

The formulation using DCP as the sole phosphorus source required 31 kg of DCP and 10 kg of limestone per metric ton.

Table 3: Mineral composition and cost of DCP-based formulation

Ingredient	Inclusion (kg/ton)	Ca Contribution (%)	P Contribution (%)	Cost (SDG/ton)
MCP	0	0	0	0
DCP	31	0.682	0.558	173,600
Limestone	10	0.37	0	2,300
Total	41	1.05	0.56	175,900

This formulation achieved 1.05% calcium and 0.56% phosphorus with a total mineral cost of 175,900 SDG per metric ton of feed. The slightly higher mineral levels result from the discrete nature of ingredient inclusion rates.

4. Economic Comparison

The three mineral supplementation strategies showed clear differences in total formulation cost.

Table 4: Summary of total mineral costs by formulation strategy

Strategy Difference (%)	Total Cost (SDG/ton feed)	Cost Difference (SDG)	Relative
MCP only	203,680	+27,780	+15.8%
MCP + DCP	195,220	+19,320	+11.0%
DCP only	175,900	Reference	Reference

1. MCP-only formulation increased cost by 27,780 SDG (15.8%)
2. MCP + DCP formulation increased cost by 19,320 SDG (11.0%)

The DCP-based formulation therefore provided the lowest direct mineral cost under the assumed ingredient prices. The cost advantage of DCP is primarily attributable to its lower price per kilogram (5,600 SDG/kg) compared with MCP (8,000 SDG/kg), despite requiring a higher inclusion rate due to lower phosphorus concentration.

5. DISCUSSION

5.1 Economic Implications

The results of this formulation exercise demonstrate that substantial cost savings can be achieved through strategic selection of phosphorus sources in broiler diets. The difference of 27,780 SDG per metric ton between the most expensive (MCP-only) and least expensive (DCP-only) formulations represents a significant economic consideration for commercial feed

manufacturers, particularly in markets with narrow profit margins.

The intermediate cost of the MCP + DCP combination formulation (195,220 SDG) suggests that blended approaches may offer flexibility in managing both cost and nutritional specifications. This strategy could be particularly valuable when price relationships between phosphate sources fluctuate or when supply availability varies.

5.2 Bioavailability Considerations

The economic comparison alone does not fully represent the nutritional value of mineral sources. The biological effectiveness of dietary phosphorus depends on its digestibility and availability to the animal. Phosphate sources differ in their solubility and chemical structure, which directly affect phosphorus absorption in the gastrointestinal tract.

Studies in poultry nutrition have shown that phosphorus from MCP is generally more digestible than

phosphorus from DCP. Trairatapiwan *et al.*, (2018) reported true ileal phosphorus digestibility values for feed phosphates ranging from approximately 64% to 70%, depending on the source and processing method. The higher solubility of MCP in the digestive tract facilitates phosphorus release and absorption.

The higher bioavailability of MCP can influence several physiological parameters:

1. Bone mineralization
2. Skeletal strength
3. Feed efficiency
4. Phosphorus retention

Similarly, calcium supplied through limestone typically exhibits high digestibility when particle size and solubility are appropriate. However, calcium availability may be influenced by particle size distribution, gastrointestinal pH conditions, interaction with dietary phosphorus, and the presence of phytate in feed ingredients (Woyengo *et al.*, 2022). Maintaining a balanced Ca:P ratio remains essential for optimal mineral metabolism and skeletal development in broiler chickens (National Research Council, 1994).

5.3 Advantages of Using Multiple Phosphate Sources

Using a combination of MCP and DCP in broiler diets can provide several formulation advantages beyond simple cost optimization:

Cost Optimization: Blending mineral sources can reduce overall feed cost while maintaining adequate phosphorus supply, as demonstrated by the intermediate cost of the combination formulation.

Nutritional Complementarity: MCP contributes highly available phosphorus, while DCP supplies both calcium and phosphorus. Combining both sources allows more flexibility in balancing dietary minerals and may provide a more consistent release of phosphorus along the gastrointestinal tract.

Supply Stability: Using multiple phosphate sources reduces dependency on a single ingredient and helps mitigate fluctuations in raw material availability or price, an important consideration for commercial feed manufacturing operations.

Environmental Considerations: Phosphorus sources with higher digestibility may improve nutrient utilization and reduce phosphorus excretion, which is important for environmental sustainability. If the higher bioavailability of MCP allows for lower total phosphorus inclusion while maintaining available phosphorus levels, the economic comparison might shift in favour of MCP despite its higher unit cost.

5.4 Study Limitations

The present study has several limitations that should be acknowledged:

1. **Assumption of negligible basal contributions:** In practical diets, ingredients such as soybean meal, corn, and other feedstuffs contribute measurable

amounts of calcium and phosphorus, which would reduce the required supplemental mineral levels.

2. **Static price assumptions:** Ingredient prices fluctuate over time and across locations. The economic ranking of formulations may change with different price relationships between MCP and DCP.
3. **Bioavailability not considered in cost calculations:** The analysis treats all phosphorus as equivalent, whereas actual phosphorus availability differs among sources. An "available phosphorus" basis would provide a more accurate economic comparison.
4. **Lack of biological validation:** Differences in ingredient cost and chemical composition do not necessarily translate directly into differences in biological performance or economic efficiency measured as cost per unit of weight gain.

6. Need for Biological Validation

The formulation exercise presented here evaluates mineral supplementation strategies from a nutritional and economic perspective. However, variations in phosphorus digestibility and calcium utilization may influence growth performance, feed conversion efficiency, bone mineralization, and nutrient retention. Therefore, controlled feeding trials are required to evaluate the biological responses of broilers to diets containing different phosphate sources before definitive recommendations can be made.

6.1 Proposed Experimental Design

A feeding experiment should be conducted to assess the biological effects of mineral source on broiler performance and mineral utilization.

6.1.1 Dietary Treatments

Three experimental diets should be formulated corresponding to the mineral strategies evaluated in this study:

1. Diet based on MCP as the primary phosphorus source
2. Diet containing a combination of MCP and DCP
3. Diet based on DCP as the primary phosphorus source

All diets should contain similar levels of:

- Calcium (approximately 1.0%)
- Available phosphorus (approximately 0.55%, adjusted for digestibility differences)
- Metabolizable energy (e.g., 3,000 kcal/kg)
- Crude protein (e.g., 21%)

6.1.2 Experimental Design

A Completely Randomized Design (CRD) is recommended with the following structure:

- 3 treatments
- 5 replicates per treatment

- 10-15 birds per replicate
- Total birds: 150-225 broilers
- Duration: 0-21 or 0-35 days of age

6.1.3 Measured Parameters

Performance parameters:

1. Body weight gain (g/bird)
2. Feed intake (g/bird)
3. Feed conversion ratio (g feed/g gain)

Mineral utilization parameters:

1. Tibia ash percentage
2. Bone mineral density
3. Calcium retention (%)
4. Phosphorus retention (%)

Economic parameters:

1. Feed cost per kilogram of weight gain
2. Economic efficiency (income over feed cost)

6.2 Statistical Analysis

Data obtained from the feeding experiment should be analysed using Analysis of Variance (ANOVA) to evaluate treatment effects. When significant differences are detected ($P < 0.05$), treatment means may be compared using post-hoc tests such as the Tukey test or Duncan's multiple range test.

7. CONCLUSIONS

This study compared three mineral supplementation strategies for meeting broiler calcium and phosphorus requirements using MCP, DCP, and limestone. Under the assumed ingredient prices (MCP: 8,000 SDG/kg; DCP: 5,600 SDG/kg; limestone: 230 SDG/kg), the DCP-only formulation provided the lowest mineral cost (175,900 SDG/ton feed), followed by the MCP+DCP combination (195,220 SDG/ton), and the MCP-only formulation (203,680 SDG/ton). The DCP formulation resulted in cost savings of 15.8% compared with MCP alone.

However, these economic differences must be interpreted in the context of phosphorus bioavailability, as MCP generally exhibits higher digestibility than DCP. The optimal phosphate source selection depends on the specific price relationship between sources, the digestibility values applied in formulation, and the performance responses of birds. Controlled feeding trials are necessary to validate whether the lower cost of DCP translates into equivalent or superior economic efficiency when measured as cost per unit of weight gain.

For practical feed formulation, a blended approach using both MCP and DCP may offer an optimal balance of cost, nutritional adequacy, and supply stability. Feed manufacturers should periodically re-evaluate phosphate source selection as ingredient prices

fluctuate and as new research becomes available on phosphorus digestibility and bird performance.

8. Conflict of Interest Statement

The authors declare no conflicts of interest regarding the publication of this paper.

Appendix A

Detailed Calculation Methodology

A.1 MCP-Only Formulation Calculations

Target P: 0.55% MCP P content: 22% MCP required = $0.55 \div 0.22 = 2.5$ kg per 100 kg = 25 kg/ton

Ca from MCP: $25 \text{ kg} \times 0.18 = 4.5$ kg Ca per ton = 0.45%

Target Ca: 1.0% Additional Ca required = $1.0\% - 0.45\% = 0.55\%$ Limestone Ca content: 37% Limestone required = $0.55 \div 0.37 = 1.486$ kg per 100 kg = 14.86 kg/ton (rounded to 16 kg in original table)

A.2 MCP + DCP Formulation Calculations

Let x = MCP inclusion (kg/ton), y = DCP inclusion (kg/ton) P equation: $0.22x + 0.18y = 5.5$ kg P/ton (0.55% of 1000 kg) Ca equation: $0.18x + 0.22y + 0.37z = 10$ kg Ca/ton (1.0% of 1000 kg) where z = limestone inclusion (kg/ton)

Solving with x = 17, y = 10: P: $0.22(17) + 0.18(10) = 3.74 + 1.8 = 5.54$ kg/ton (0.554%) Ca from phosphates: $0.18(17) + 0.22(10) = 3.06 + 2.2 = 5.26$ kg/ton (0.526%) Remaining Ca required: $10 - 5.26 = 4.74$ kg/ton Limestone required: $4.74 \div 0.37 = 12.81$ kg/ton (rounded to 14 kg in original table)

A.3 DCP-Only Formulation Calculations

Target P: 0.55% DCP P content: 18% DCP required = $0.55 \div 0.18 = 3.056$ kg per 100 kg = 30.56 kg/ton (rounded to 31 kg)

Ca from DCP: $31 \text{ kg} \times 0.22 = 6.82$ kg Ca per ton = 0.682% Target Ca: 1.0% Additional Ca required = $1.0\% - 0.682\% = 0.318\%$ Limestone required = $0.318 \div 0.37 = 0.859$ kg per 100 kg = 8.59 kg/ton (rounded to 10 kg in original table)

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