# Enhancing phosphorus utilization for better animal production and environment sustainability

**C. S. Prasad[1,*], A. B. Mandal[2], N. K. S. Gowda[1], Kusumakar Sharma[3], A. K. Pattanaik[4], P. K. Tyagi[2] and A. V. Elangovan[1]**

[1]National Institute of Animal Nutrition and Physiology, Bengaluru 560 030, India
[2]Central Avian Research Institute, Izatnagar 243 122, India
[3]Indian Council of Agricultural Research, Pusa, New Delhi 110 012, India
[4]Indian Veterinary Research Institute, Izatnagar 243 122, India

**Phosphorus (P) is a key element in farm animal productivity and has a close relationship with calcium and vitamin D. Major part of P in feeds of plant origin is in the form of phytate which is not degraded in gut of monogastric animals and excreted in faeces contributing to environmental pollution. Studies have shown that exogenous supplementation of phytase enzyme to diet will improve phytate utilization. Genetic studies have proven the efficacy of low phytate grain with high available P content. Combination of phytase enzyme supplementation with use of low phytate feed ingredients is a practical and effective method of enhancing P utilization in monogastrics. Improved manure management to effectively recycle nutrients including P, needs further efforts to minimize pollution.**

**Keywords:** Animals, phosphorus, phytase, phytate, pollution.

PHOSPHORUS (P) is known as 'master mineral' because of its involvement in most metabolic and reproductive processes. This mineral which is stored in bones and teeth, is often discussed in conjunction with calcium (Ca) and vitamin D due to their close inter-relationship. About 80% of P in animal body is present in skeleton and constitutes 22% of the mineral ash. Phosphorus is present in every living cell and is essential for transfer and utilization of energy as part of phosphorylated glucose compounds and high-energy components such as ATP and ADP. It plays important roles in the metabolism of carbohydrates, amino acids (AA) and lipids. Common signs of P deficiency are anorexia, lowered blood P, reduction in weight gain and 'pica' in which the animals tend to lick and eat inanimate objects. In severe deficiency, there will be skeletal problems and long-term P deficiency results in bone disorders, lameness and stiff joints. This mineral is provided in the diet either as a natural constituent of feed ingredients in the form of supplemental P or added as an inorganic salt, viz. dicalcium phosphate.

Adequate Ca and P nutrition depends on factors such as supply of each nutrient, ratio of Ca and P and the adequate vitamin D status. Vitamin in $D_3$ form is essential for Ca utilization and any insufficiency will negatively influence the Ca : P ratio. Adequate intake of Ca and P is required for lactation as both constitute about 50% of the total mineral content in milk. The ideal ratio between total Ca and available P should be 2.8 : 1 to 3.3 : 1. However, Ca : P ratio is not critical, unless the ratio is >7 : 1 or <1 : 1 (ref. 1). A major consideration with respect to P availability is the presence of P in the plants in the form of phytate, which must be degraded by phytase enzyme to produce phosphoric acid to make it available to the animals. The inability or limited ability of monogastric animals, such as poultry and pigs to degrade phytate in gut, results in excretion of large amounts of P in the excreta[2]. According to various reports, utilization of phytate-P by poultry ranges from 0–50% depending on the age of birds, nature of diet and level of inorganic P present. During the plant growth, P is usually adequate in forages, but as the plant matures, the level declines and gets accumulated in seeds. Phosphorus deficiency is a major challenge for agricultural productivity on many tropical soils throughout the world. Most often, P is a limiting mineral, particularly for grazing livestock in the tropics. Micronutrient survey conducted in different agro-climatic zones of India has revealed that P is the most limiting micronutrient in the feed, fodder and biological materials of farm animals[3].

Cereal grains and oilseed meals contain moderate to high levels of P, however, about 70% of it is phytate bound and hence less available to monogastric species of livestock. Bioavailability of P in grains is variable, from less than 15% in maize grain to as high as 46% in wheat grain. The P in a standard corn–soybean meal diet is only about 20% bioavailable, and supplementation of phytase certainly increases the utilization to about 46%. In ruminants due to phytase activity by the rumen microbes, the phytate is degraded and is subjected to further changes.

*For correspondence. (e-mail: cadaba_prasad@yahoo.co.in)

**Table 1.** Performance of cows fed diets with two levels of phosphorus[8]

| | Dietary treatment (%) | | | |
|---|---|---|---|---|
| Item | 0.36 | 0.24 | SE | *P*-value |
| DM intake (kg/d) | 18.6 | 18.0 | 0.77 | Non-significant |
| Milk yield (kg/d) | 34.1 | 33.0 | 1.80 | Non-significant |
| P-balance (g/d) | | | | |
| Intake | 69.20 | 50.90 | 2.10 | <0.05 |
| P in faeces | 49.10 | 25.70 | 2.30 | <0.05 |
| P in milk | 30.50 | 27.40 | 0.04 | Non-significant |
| P retained | –10.4 | –2.2 | 4.4 | Non-significant |
| P-digestibility (%) | 29.0 | 49.8 | 4.4 | <0.05 |
| Plasma P (mmol $l^{-1}$) | 1.79 | 1.52 | 0.02 | <0.05 |

Failure to provide sufficient quantity of P is physiologically and nutritionally disadvantageous. Hence, to ensure adequate supply of available P, nutritionists provide a margin of safety to this mineral in the diet. However, there are a growing number of evidences and concerns regarding potential contribution of P in the faecal matter of poultry, pigs and dairy animals, polluting water and ecological resources through eutrophication[4]. Hence, there is a need to reduce the faecal output of P, by promoting phytate degradation, judicious selection of dietary P levels and increasing its gut absorption[5]. This essentially involves an integrated activity for quality control of supplements, inclusion of inorganic sources of P and use of effective phytase enzymes. However, the breakdown of phytate and excretion of non-phytin P in manure, may not be advantageous to soil, as the later is not strongly fixed in the soil and hence likely to be lost through leaching. Reducing the excessive intake of P in farm animals and enhancing its bioavailability are the key issues.

Farm owners are sceptical about low P-containing diets because they believe that it may affect reproductive efficiency and production performance. This has led many dairy producers to use 0.48% P as against the recommended levels of 0.32% to 0.42% in the diets. Higher P inclusion has not shown any additional benefits, but leads to increased P excretion to the environment. Higher P digestibility on low P diets has been consistently reported[3]. Reduction in the dietary P level from 0.43% to 0.32% increased P digestibility, neither induced bone resorption nor affected milk yield in dairy cows[6]. A reduction in P supply during the first 4 months of lactation to 0.32% of dry matter (DM) intake was reported to increase the apparent digestibility of P and reduced faecal excretion, without affecting the amount retained in the body (Table 1). Phosphorus digestibility of less than 40% is indicative of surplus supply of P in the diet.

It is a common practice under Indian feeding system to include oilseed meals and cereal by-products (wheat bran, rice bran, rice polish) at higher proportion with limited grains in the rations of livestock. The oilseed meals and brans are rich in P and the cereal grains are low in calcium leading to an imbalanced Ca : P ratio. This contributes to higher P-intake, lower digestibility and higher faecal excretion. Excess feeding of P has shown to affect the utilization of several other minerals due to antagonistic effects. Lowering P level in the diet by replacing part of cereal by-products with grains has shown better utilization of P along with other minerals[7]. Though rumen ecosystem possesses large microbial phytase activity, the degradation of phytate is subjected to rumen motility, passage rate and other associated factors. The absorbed P is recycled in saliva and the salivary phosphate is less soluble in the gut. Under roughage-based feeding systems, saliva production is more in ruminants, and hence salivary excretion of P is much more leading to decreased utilization. Extensive poultry rearing may lead to pollution of water by nitrogen (N) and P, and air due to ammonia odours and dust within the poultry houses. One of the major challenges to the poultry industry is the accumulation of P in the soil and the threat to surface water quality.

## Phytic acid

Phytic acid (PA) is found in the ingredients and byproducts of all the plants such as sorghum, wheat, maize, groundnut, rapeseed, soybean, cottonseed and sesame. PA is a combination of calcium–magnesium salt of inositol hexaphosphoric acid (Figure 1), also known as phytin and salts of PA are termed phytate. Most foods of plant origin contain 50% to 80% of their total P as phytate. On an average, the phytate-phosphorus content of cereals and oilseed meals varies from 51% to 84% of the total P (Table 2).

## Environmental concerns

Phosphorus is primarily associated with pollution of surface water. This pollution may be caused by runoff of P when application to land is in excess of crop requirements and excess P excretion takes place through dung of farm animals. Intensive animal agriculture (dairy, poultry and pigs) has been identified as a significant source of P contamination of surface water. Eutrophication has been identified as the main cause of impaired surface water quality and increased growth of undesirable algae and aquatic weeds due to P accumulation. Agricultural runoff, erosion from high P-containing soils and P from animal manure, are the major contributing factors of surface water eutrophication. The aim should be to reduce P loss from agriculture to water through increased use efficiency by plants and animals. Effective manure management also plays a greater role in minimizing the P runoff to water bodies. Avoiding over fertilization by P and manuring of soils by ascertaining the status of P is very important in this regard. Shifting the manure to P-deficit areas and storing the manure in deep pits thereby avoiding contact with running water are the other options.

## Phytate-phosphorus and its utilization

A major part of the excreted P is contributed by the phytate-P present in diets. Several approaches have been tried and implemented to ameliorate the problem of lower P use-efficiency and support economical production and environment protection.

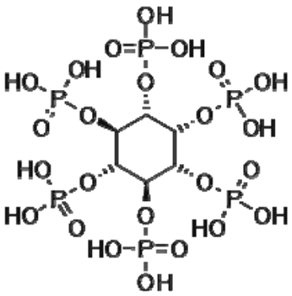

**Figure 1.** Phytic acid.

**Table 2.** Phytin content of common feed stuffs[2,9]

| Ingredient | Total P (%) | Phytate P (%) | Phytate P (% of total P) |
|---|---|---|---|
| Cereals | | | |
| Bajra | 0.31 | 0.23 | 74 |
| Barley | 0.39 | 0.20 | 61 |
| Maize | 0.39 | 0.25 | 64 |
| Rice (broken) | 0.15 | 0.09 | 60 |
| Sorghum | 0.30 | 0.22 | 73 |
| Wheat | 0.44 | 0.27 | 61 |
| Cereal by-products | | | |
| Deoiled rice bran | 1.77 | 1.49 | 84 |
| Wheat bran | 1.11 | 0.81 | 73 |
| Oilseed meals | | | |
| Cottonseed meal | 0.93 | 0.76 | 82 |
| Groundnut meal | 0.60 | 0.46 | 77 |
| Soybean meal | 0.88 | 0.56 | 64 |
| Sunflower meal | 0.90 | 0.45 | 51 |

## Phytase

Phytases (myo-inositol hexaphosphate hydrolase) are phosphatase enzymes that sequentially break orthophosphate from the inositol ring of PA and release free inorganic P, a series of lower phosphoric esters (inositol pentaphosphate and inositol monophosphate) forming intermediates, thereby decreasing phytates' affinity for different cations. Phytase enzymes can originate from gut or endogenous phytase present in feeds. Phytase is known to be produced by fungi, bacteria, yeast, rumen and soil microbes. Some feeds also have endogenous phytase activity, but the degree of phytate hydrolysis is highly variable (Table 3). Many reports revealed that supplementation of phytase is beneficial in augmenting availability of plant P; and thereby reducing supplementary need of inorganic P source and feed cost. The effect of supplemental microbial phytase enzyme, is always influenced by level of inclusion, Ca : P ratio in diet, phytate and Ca contents and concentration of vitamin $D_3$ in the diet. The effective sources of plant phytases are to be identified and those ingredients should be judiciously used to curtail dicalcium phosphate and addition of microbial phytase, can also reduce environmental P pollution by improving the absorption of phytate P and decreasing faecal P. The use of immobilized microorganisms as an enzyme source generally eliminates the high cost of enzyme production and is economical as the immobilized enzyme can be easily removed from the reaction making it easy to recycle the biocatalyst. Immobilized enzymes typically have greater thermal and operational stability than the soluble form of the enzyme.

## Enzymes in animal feeds

Use of exogenous enzymes in animal diets has attracted considerable interest over the last two decades and the benefits have been greatly realized. Microbial phytases are one of the most commonly used enzymes in monogastric animal diets. Ruminants inhabit microbes that can produce phytase to degrade phytin. However, monogastric animals produce little or no phytase in the intestine for phytate degradation. Hence, supplementation of such

**Table 3.** Phytase activity of commonly used feedstuffs[2]

| Feed | Phytase activity (units/kg) |
|---|---|
| Wheat | 1193 |
| Barley | 582 |
| Rye | 5130 |
| Maize/corn | 15 |
| Sorghum | 24 |
| Wheat bran | 2957 |
| Soybean meal | 8 |
| Rapeseed meal | 16 |
| Peanut meal | 3 |

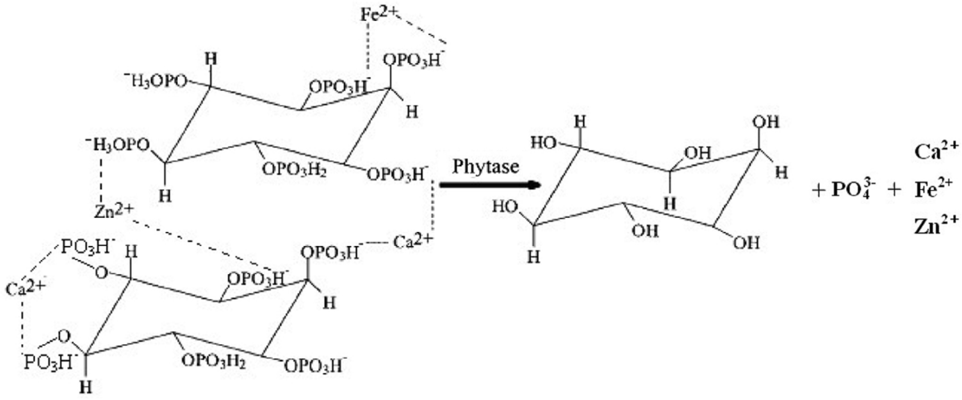


**Figure 2.** Pathway of phytase activity.

diets with optimum phytase is essential to provide the animal with necessary nutrients. Phytase is also being used in combination with other enzymes to improve growth performance and nutrient digestibility. Simultaneous addition of phytase and carbohydrases (xylanase, glucanase) improves feed efficiency, nutrient digestibility and nutritional value of oilseed meals such as soybean meal, rapeseed meal and cottonseed meal. Phytase and xylanase are reported to have a synergistic effect for enhancing amino acid digestibility in broilers.

A broiler starter diet formulated to meet recommended standards for non-phytate P and phytate-bound P would contain 0.45% and 0.23% respectively[10]. It is assumed that most of the phytate-P will be excreted in faeces and supplementation of exogenous phytase in diets is effective in enhancing the bioavailability of phytate-bound P. The phytate-P utilization is again influenced by dietary Ca and P levels. Wider Ca and P ratios, beyond 2 : 1 reduce phytate-P utilization. Phytate-P utilization can be improved by incorporating plant-derived ingredients with higher phytase activity. Microbial phytases are more effective under a wide range of variables, and their inclusion in diets of poultry and pigs has established their utility to degrade phytate-P (Figure 2). With the advent of recombinant DNA technology, production of microbial phytases has reduced the cost of production and enhanced its adoption. Depending on the level and source of phytase, the reported improvements in P availability ranges from 20% to 45%. Other influential factors include Ca : P ratio, level of vitamin D and fibre in the diet.

## Vitamin D isomers

Research findings suggest that the form of vitamin D present in the diet may be an influential factor in lowering P excretion. New isomers of vitamin D have been demonstrated to improve intestinal phytase activity and also act additively with supplemented exogenous phytase to further improve P utilization in chicks.

## High available phosphate corn

Another alternative approach to lower dietary P levels and minimizing P in the faeces is to develop feeds with lower levels of phytate-bound P. A variety of maize grain with low phytate P and more bioavailable P content has been developed at the United States Department of Agriculture (USDA) using low phytic acid (LPA) 1-1 (Ipal-1) allele of the corn LPA I gene and bred into a hybrid. This maize hybrid, designated as 'high available phosphate corn' (HAPC) contained approximately 0.27% total P, of which 0.17% was estimated to be bioavailable to the chicken. However, a near isolgenic normal corn hybrid contained similar levels of total P but had only 0.03% bioavailable P. Replacement of normal corn with the low-phytate hybrid corn would hence reduce the amounts of phytate-bound corn in the diet and help to reduce P excretion in the faecal matter.

The utilization of phosphorus in the non-phytate portion of HAPC is similar to that of feed grade dicalcium phosphate and can aid in reducing overall P excretion with similar performance. In comparison to chicks fed with diets containing normal corn, faecal P excretion by the chicks fed with diets containing HAPC was decreased by 28.57% without dietary phytase supplementation and 24.22% with phytase supplementation. Biofortification could be another approach in developing grains having better bioavailable P as was done in case of quality protein maize (QPM) with high lysine content.

## Low phytate crops

With the advent of genetics and biotechnology tools, it has been possible to develop crop varieties (e.g. corn, soybeans and barley) to express significantly low phytic acid (LP)[11]. Some mutant genes were identified to suppress the synthesis of PA in the seed without changing the total amount of seed P. However, the yields of these LP hybrids have been persistently low with a reported figure of 12%. For the last few decades, phytase has been supplemented in diets; however, more recently, the phytase producing gene has been transgenically introduced into crops, thereby hypothetically eliminating the need for phytase supplementation[12]. Further evidence suggests that phytase might increase the absorption of Ca, Mg, Zn and amino acid. The combination of microbial phytase and low-phytate feed ingredients, has also shown to be highly effective in enhancing P utilization in monogastrics.

While LP crops can become more economically viable in areas with a high demand for P-reduction, its adoption may be much limited due to effective phytase enzyme production using modern biotechnology. Phytase provides similar efficacy in LP crops, but it is used as an exogenic supplement; thereby, if overcomes difficulties associated with LP crops. For better adoption of LP crops, they will necessarily have to perform agronomically better than conventional crops[13].

## Conclusions

A multifaceted approach integrating nutrition, genetics, manure management and innovative soil and crop management practices is required to lower faecal-P excretion and reduce P-transport to surface water. Use of genetic engineering/breeding strategies to improve P uptake and use-efficiency of crop cultivars and biofortification are other priority areas of research. Reducing dietary P inputs through judicious use of feedstuffs and improving gut utilization of P by innovative measures is an alternative managemental tool to reduce faecal-P excretion. Desired dietary level of P in ruminant and monogastric animals and improving gut bioavailability using better bioavailable inorganic sources and balancing of different micronutrients and phytase supplementation need more research attention. Improved manure management from animal husbandry to effectively recycle nutrients including P, needs further efforts. Efforts towards nutrient recapture from animal wastes to prevent pollution of soil and water quality requires specific attention.


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