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# Role of phytate and phytases in human nutrition

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**Abstract**

Phytates have been considered as a major concern in human diet due to its antinutrient/chelating behaviour for divalent minerals such as $Ca^{2+}$, $Mg^{2+}$, $Zn^{2+}$ and $Fe^{2+}$. Because of having a high potential for binding positively charged proteins, amino acids, and/or multivalent cations or minerals in foods phytic acid form complexes that are insoluble, difficult to hydrolyze during digestion, and thus, typically are nutritionally less available for absorption. Reduction of phytates can be achieved through both enzymatic and nonenzymatic removal. Various food processing techniques like soaking, malting, hydrothermal treatment and fermentation increases the activity of the naturally occurring plant phytases. Biotechnologically produced phytases may be possible for use tomorrow in food processing as well as plant raw material and starter cultures with inserted phytase genes. Role of phytases in dietary nutrition and their application with respect to breadmaking process, probiotics, animal feed supplement and transgenic crops are also emphasised in this paper.

**Keywords:** Inositol hexaphosphate, antinutrients, food processing, phytase, mineral absorption, phytate.

## 1. Introduction

Phosphorus is one of the necessary mineral nutrients for animals during their growth, reproduction and calcification of the bones. The major storage form of phosphorus in plant seeds is phytate (myo-inositol-hexakisphosphate). Monogastric animals, such as swine and poultry, as well as fish, are unable to utilize phytate due to little or no intestinal phytase activity in their digestive tracts (Reddy, 1982) [31]. To prevent dietary phosphorus deficiency, inorganic phosphate is commonly added into the feed for the purpose of phosphorus supplementation (Mullaney and Ullah, 2005) [30]. In addition, undigested phytate reduces mineral bioavailability and impairs protein digestibility in the animal (Chen *et al*., 2004) [7]. The undigested phytate and the unabsorbed inorganic phosphorus in monogastric derived faeces have the potential to cause phosphorus pollution in areas of intensive animal production (Ullah, 2003) [37]. Effective reduction of phytic acid (PA) can be obtained via the action of both enzymatic and nonenzymatic degradation (Greiner and Konietzny, 2006) [14]. Engineering of phytases in order to optimize their catalytic features is seen as a promising strategy to efficient reduction of phytate. Furthermore, breeding with selection of low PA varieties or high phytase varieties is another successful way to reduce level of phytate amount. Phytases (myo-inositol hexakisphosphate phosphohydrolase; EC 3.1.3.8/EC 3.1.3.26) are a group of enzymes which catalyze the sequential hydrolysis of phytate in a stepwise manner to lower inositol phosphate, myo-inositol and inorganic phosphate (Mitchell *et al*., 1997) [28]. This hydrolytic reaction plays an important role in energy metabolism, metabolic regulation and signal transduction pathways in biological system (Vats, and Banerjee, 2002) [39]. Recently, increasing public concern regarding the environmental impact of high phosphorus levels in animal faeces has driven phytase application in animal feed and the biotechnological development of phytase (Lei and Stahl, 2001) [24].

### Phytate issues on human nutrition

Phytic acid is the hexaphosphoric ester of the hexahydric cyclic alcohol meso-inositol. Phytic acid (known as inositol hexakisphosphate (IP6) or phytate when in salt form) is the principal storage form of phosphorus in many plant tissues. Phytate is formed during maturation of the plant seed and in dormant seeds it represents 60–90% of the total phosphate (Loewus, 2002) [25]. Phytate is, therefore a common constituent of plant derived foods like cereals or legumes, which are the main staple food of people in developing countries. The daily intake of phytate for humans on vegetarian diets, on an average, is 2000–2600 mg whilst, for inhabitants of rural areas in developing countries, on mixed diets, it is 150–1400 mg (Reddy, 2002) [25, 32]. Usually legume based food (cooked) items contain higher amounts phytate than do cereal-based food items. Few food items, such as sesame seeds (toasted), soy protein concentrate, rice (unpolished and cooked), maize bread (unleavened) and peanuts have exceptionally high amounts of phytate (Reddy, 2002) [25, 32].

### Nutritional disadvantages and advantages of phytate in nutrition

The capacity of phytic acid to bind minerals reduces the digestion and absorption of P, Ca, Zn and Fe from plant-derived ingredients by single-stomached animals. Bioavailability of nutrients, especially minerals, has received much attention since the discovery of phytic acid about 150 years ago. In animal nutrition the interest in phytic acid, or phytate, has centered around its effect on P utilization. By reducing P availability, phytate contributes to environmental pollution by the loss of undigested P in effluent from pig and poultry units, (Mohebbifar and Torki, 2010) [29]. In relation to mineral availability in human subjects the consequences of the dietary intake of phytate have caused some controversy. Some researchers argue that there are risks of Zn and Ca deficiencies from high-phytate diets, while other researchers suggest such claims are exaggerated (Selle *et al*., 2000) [34]. However, knowledge gained in developing methods of extracting phytate for the manufacture of protein isolates with reduced phytate content for human consumption has increased the appreciation of protein ±phytate interactions, as they interfere with phytate extraction procedures (Cheryan, 1980) [8].

Paradoxically, phytate may have some benefits in human nutrition, particularly in relation to carcinogenesis as it has been shown to have protective effects against colonic cancers (Graf and Eaton, 1985) [12]. Phytic acid seems only to affect cancer cells and not normal cells. Phytic acid and inositol improves the effectiveness of chemotherapy (Vucenik and Shamsuddin, 2003) [19]. According to Midorikawa (2001) [27], phytic acid is one of the most promising cancer chemo preventive agents. Phytic acid did not cause damage to DNA. They concluded that phytic acid acts as an antioxidant and anticancer agent by chelating metals. Phytic acid is also known to help catalyze the breakdown of fat during metabolism. Both myo-inositol and phytic acid inhibited the increase of lipids in the liver cells and might protect against fatty liver (Katayama, 1999) [21]. The complexing of Fe by phytate may reduce the Fe-catalyzed production of free radicals in the colon. In pigs it has been shown that phytate derived from maize and soyabean meal was protective against lipid peroxidation in the colon associated with Fe (Minihane and Rimbach, 2002) [1]. High-fiber diets contain substantial phytate concentrations, and this factor may partially explain the epidemiological association of high-fiber diets with lower incidences of certain cancers (Greiner and Konietzny, 2006) [14]. Phytate and its lower esters, and inositol, have a function in secondary messenger transduction systems. Recent evidence suggests that signal transduction pathways, cell-cycle regulatory genes, differentiation genes, oncogenes and perhaps tumor-suppressor genes are involved in the anti-neoplastic effects of phytate (Greiner and Konietzny, 2006) [14].

**Reduction of phytate: Enzymatic and Non-enzymatic**

Effective reduction of phytic acid (PA) can be obtained via the action of both enzymatic and nonenzymatic degradation (Greiner and Konietzny, 2006) [14].

**Enzymatic degradation of phytate during food processing**

Enzymatic degradation involves addition of either isolated form of wild type or recombinant exogenous PA-degrading enzymes from various sources of fungi and bacteria. Biological processing techniques, which increase the activity of native enzymes of cereals and legumes are soaking, malting, hydrothermal processing and lactic fermentation.

**Addition of enzymes**

Phytate hydrolysis can occur during food preparation and production, either by phytase from plants, yeasts or other micro-organisms. An alternative to activation of the intrinsic enzymes of foods is the addition of phytase during food processing. Microbial phytase enzyme preparations are now available commercially making their use in food processing technically feasible. Moreover, the phytase encoding gene *A. niger* (phyA) has been cloned and over-expressed resulting in a more than tenfold increase in phytase activity per biomass unit compared with the wild-type strain. Addition of *A. niger* phytase in amounts which almost completely removed phytate in soy isolates increased iron absorption 4–5-fold (Sandberg and Andlid, 2002) [2]. A novel strain of *Bacillus cereus* producing phytase at considerable high temperature has recently been screened and optimized (Dahiya and Singh 2014) [11].

**Biological processing techniques**

Soaking of wheat bran, whole wheat flour and rye flour at optimal conditions for wheat phytase activity (pH 4.5–5, 55 °C) resulted in complete phytate hydrolysis (Sandberg and Svanberg, 1991) [33] and to a marked increase in *in vitro* iron availability.

Malting is a process during which the whole grain is soaked and then germinated. The amount of phytate in malted grains of wheat, rye and oats intended for the production of flour was only reduced slightly or not at all. However, when the malted cereals were ground and soaked at optimal conditions for wheat phytase there was a complete degradation of phytate (Larsson and Sandberg, 1992) [23]. Hydrothermal processing comprising of two wet steps of whole barley kernels to degrade phytate was studied and developed by Bergman *et al*., (1999) [3].

Lactic- yeast, and mixed fermentations are old methods for food processing and preservation. Because of the production of lactic acid and other organic acids, the pH is lowered and the phytase activity increased. Svanberg *et al*., (1993) [14] have shown that combined germination and lactic fermentation of white sorghum and maize gruels can yield an almost complete degradation of phytate. Acidity of the dough, addition of different additives to the dough is of great importance for phytate degradation during scalding and sourdough fermentation of breads these conditions during bread fermentation disfavor yeast phytase expression (Turk *et al*., 2000) [36].

**Non-enzymatic reduction of phytate in diet**

In nonenzymatic hydrolysis of phytate, reduction of phytate occurred in the final food during food processing or physical separation of phytate-rich parts of the plant seed. Engineering of phytases in order to optimize their catalytic features is seen as a promising strategy to efficient reduction of phytate. Approaches to problems represented by seed phytic acid include engineering crops to express high levels of phytase enzyme in seeds (Brinch-Pedersen, 2002) [6], or breeding crops with reduced levels of seed phytic acid (low-phytate or high-available phosphorus (Cichy and Raboy, 2008) [9]. Nearly 20 years ago the first low-phytic acid (lpa) genotypes of crop species were isolated in maize (*Zea mays* L.), using chemical mutagenesis and classical genetics. Today there are numerous lpa genotypes of various crop species. The molecular genetics of seed phytic acid metabolism and phytase enzymes has also advanced, adding genetic engineering tools to approach this problem area (Bilyeu, 2008) [4].

Human nutrition studies have documented 30% to 50% increases in ‘‘fractional absorption’’ of Fe, Zn and Ca, in subjects consuming low-phytate maize types versus normal-phytate types (Hambidge, 2005) [16]. An alternative plant breeding approach to dealing with mineral deficiency in human populations is to breed for increased mineral content i.e. biofortification (Bouis, H.E. 2003) [5]. As a result, engineering seed phytate levels while maintaining plant and seed function, quality and yield could prove challenging.

**Phytases**

Phytase is one of the many essential enzymes necessary for the digestive process, and a key enzyme for bone health. Commonly found in plant material, phytase is a natural enzyme often used for breaking down and increasing the nutritional quality of grains, legumes, seeds and corn. Studies confirm that the use of this enzyme can help reduce the need for calcium phosphate and increase digestive health. Phytase reduces the antinutritional properties of phytic acid and eutrophication (Dahiya *et al*., 2009) [10], caused by the excretion of undigested phytic acid by monogastrics because of the lack of adequate levels of phytase in their digestive tracts (Greiner and Konietzny, 2006) [14]. Due to the non-availability of phosphorus to the animals present in the feed, phytases are used as feed supplements in order to improve the digestion and absorption of the phosphorus and certain other poorly available nutrients. Especially, phytate-degrading enzymes from microorganisms offer technical and economical feasibility for their production and application. Because of the interest in the use of microbial phytate-degrading enzymes in feed applications, highly efficient and cost-effective processes for their production by recombinant microorganisms have been developed.

**The Health Benefits of Phytase**

Here are some of the health benefits and studies that support the benefits of phytase:

**1. Boosts Mineral Absorption and Bioavailability**

Supplementing with phytase can significantly increase the body's ability to absorb and assimilate vital minerals such as calcium, magnesium and iron (Kuhar *et al*., 2009) [22].

**2. Reduction of Phytic Acid in the Body**

Phytase helps reduce the negative effects of phytic acid in the body. Many of the plants that we eat such as corn, grains, seeds, legumes, soybeans and most cereals contain high amounts of this acid. Referred to as an "anti-nutritional factor," these phytates (phytic acid) reduce our ability to absorb nutrients. Phytic acid has been shown to create insoluble complexes with these minerals through its negatively charged phytic acid. This acid has the ability to bind to positively charged molecules in these minerals, as well as in proteins (Greiner and Konietzny, 2006) [14].

**3. Reduces Mineral Deficiency**

Phytase supplementation could create strong increases in mineral uptake and reduce phytate content in both cereals as well as for legume-derived food products (Greiner and Konietzny, 2006) [14]. Moreover, the phytase from the fungus, *Aspergillus*, was found to have a broad pH range with at least 80% of the maximal activity at pH values, and optimal results for phytate hydrolysis. This study concluded that phytase supplementation, while typically and traditionally used for the enhanced mineral content in animal feed, had a promising and wide variety of applications for human digestion, particularly for human intestinal alkaline phosphatase. It may also be a way to reduce mineral deficiency in vulnerable groups such as child-bearing women, vegans, vegetarians and people in the developing world.

**4. Reduction in Toxic Build-up in the Digestive Tract**

Because phytase can break down phytic acid, our digestive process is streamlined and we have less chance of building up excess insoluble complexes in the digestive tract (Selle *et al*., 2000) [34]. Phytase also breaks down bound forms of phosphorus, another way in which it helps us absorb this mineral, as well as iron (Kuhar *et al*., 2009) [22].

**5. Boosts Bone Health**

Phytase may help prevent bone loss and reduce osteoporosis. As we all know, phosphorus is an essential element for the growth and protection of bone density. Phytase not only increase the availability of phosphorous, but also lead to better body weight, digestive efficiency, and overall bone strength in lab animals. It is also found that Phytase could significantly increase performance in animals (Jorquera *et al*., 2008).

**6. Probiotics**

FAO/WHO working group suggest the definition of probiotics as live microorganisms that when administered in adequate amounts confer a health benefit on the host (Vasiljevic and Shah, 2008). Hirimuthugoda *et al.,* (2007) have isolated a novel microbial marine phytase from the gastrointestinal tract of sea cucumbers, *Holothuria scabra*. Industrial application of this species is limited, although extracted phytase can be used as an industrial product for digesting phytate phosphorous as well as a probiotics form.

**Implications**

The presents of phytic acid in food matrices has become the major concerns due to its negative effect on mineral bioavailability and protein digestibility in human nutrition. Furthermore, the baby-boomers generation and several developed countries people have been applying unhealthy lifestyle with indelicate meal diet eating which may lead to inadequate nutrient intakes. Thus, the inclusion of exogenous phytase in food medium and reduction of phytate level in plant based food via genetic engineering have been seen as promising area. Application of phytase in food business seems to be a gifted approach nutritionally and economically. However, it is not an easy task to simply assign any commercially available phytase to food application as many tests yet to be conducted to approve its effectiveness. Scientist has to become more vigorous in isolating novel and best phytate hydrolyzing enzymes microorganisms and optimizing their catalytic features, thermal tolerance and specific activity via genetic engineering to generate an idyllic phytase for food application.

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