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Review Article

A Review on Role of Phytic Acid and Phytase in Food and Feed

Sakshi Goyal[1], Sushil Nagar[1]*, Gampa Mallesh[1], Kajal Kumari[1], Sonu[1] and Neeraj Kharor[2]

[1]Department of Biochemistry, College of Basic Sciences and Humanities, CCS Haryana Agricultural University, Hisar, Haryana- 125 004, INDIA
[2]Forage Section, Department of Genetics and Plant Breeding, College of Agriculture, CCS Haryana Agricultural University, Hisar, Haryana- 125 004, INDIA

Abstract

Phytate (myo-inositol hexakisphosphate) is considered as the main source of phosphorous in plants. In cereals, legumes, oilseeds and nuts phytic acid phosphorous accounts for 1–5% of their total weight. Phytate synthesis occurs in endoplasmic reticulum before its deposition in protein storage vacuoles. The non-hydrolyzed phytate when it comes to the excreta of animals as an undigested part of their feed enhanced the level of phosphorous in natural environments and contributes to the accumulation of phosphorus and finally causes the pollution like eutrophication, and greenhouse gases emission. Phytases (myo-inositol hexakisphosphate hydrolases) are very important biocatalysts and significantly used in the animal feed industry to convert phytate to inorganic phosphorous. To date, numerous reports have shown the positive effect of phytase supplementation on the availability of dietary phosphorus and trace minerals within plant-based feeds for monogastric farm animals. Individual feed ingredients may also be improved with phytases as an exogenous treatment. This review presents role of phytic acid and phytase in food and feed.

Keywords: Phytic acid, Phytsae, Physiological roles, Food and Feed

***Correspondence**
Author: Sushil Nagar
Email: sushilnagar@hau.ac.in

Introduction

Plants contain various macronutrients among all phosphorous is a key macronutrient that plays a significant role in metabolism with many physiological functions, such as protein synthesis, transport of fatty acids, appetite control, direct involvement in cellular activities that needs the energy, regulation of osmotic stress as well as acid-base balance, amino acid interchange, proliferation and cell differentiation. Nucleic acids, cell membranes, and structural components of skeletal tissues contain phosphorus. Phytic acid (Myo-inositol 1,2,3,4,5,6 hexa-phosphoric acid, IP6) is the main storage form of phosphorous about 65-80% of total phosphorous in grains present in the form of phytic acid phosphorous [1]. In cereals, legumes, oilseeds and nuts phytic acid phosphorous accounts for 1–5% of their total weight [2] Phytate synthesis occurs in endoplasmic reticulum before its deposition in protein storage vacuoles [3]. Phytate is stored in globoid crystals, which are subcellular inclusions located within the protein storage vacuole [4]. Phytate accounts for 60 to 80% of the dry weight of globoid crystals. Phytic acid act as an anti-nutritional factor due to negative charge of phosphate groups present on it. It bound with metal ions like calcium, magnesium, iron etc. and causes the unavailability of many metal ions [5]. Further at pH below their isoelectric point protein carrying net positive charge will bind to negatively charged phytate molecules to form binary protein phytate complexes. When the pH of proteins exceeds their isoelectric point and they have a net negative charge, a cationic bridge (usually Ca^{+2}) connects phytate and protein in ternary complexes [6]. Calcium binding to phytate lowers trypsin activity as trypsin requires calcium ions to function. This is accomplished by reducing the digestibility of proteins. Phytate consumption lowers blood glucose response in humans. This could be due to phytate forms a complex with feed carbohydrates, lowering solubility and impairing glucose digestion and absorption [7]. Phytate also forms liphophytin (complex with lipids and their derivatives). Lipid and calcium phytate may be involved in the development of metallic soaps in the intestinal lumen of chickens, which is a key constraint for lipid-derived energy use [8]. In monogastric animals like poultry, pig and human beings do not have ability to digest phytic acid due to the absence of phytase enzyme. These animals are unable to digest phytic acid which cannot be absorbed in digestive tract and released into environment through and causes several environmental effects [9]. So, in order to meet their daily needs addition of external source of feed having phosphorous and other and other micronutrients is required but which leads to increase in costs of diets. The reduction of phytic acid content in feed and food by enzymatic treatment is attractive alternative method. It not only reduces the environmental phosphorous 2 pollution but also improves the nutrition value of food [10, 11].

Phytic acid

Phytic acid is the major storage form of phosphorus in cereals, oilseeds and legumes **(Figure 1)**. It plays important role in several physiological functions and also significantly influences the nutritional and functional properties by forming complexes with minerals and proteins [12]. Phytic acid is myoinositol 1, 2, 3, 4, 5, 6-hexakis dihydrogen phosphate [13].

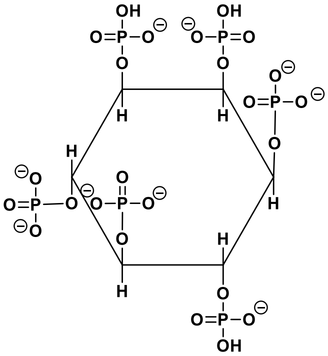

Figure 1: Structure of Phytic acid

Sources of phytic acid

Phytic acid is the major storage form of phosphorous comprising 1–5 % by weight in cereals, legumes, oil seeds and nuts [14]. Phytate rapidly accumulates in seeds during the ripening period. It is stored in leguminous seeds and oil seeds in the globoid crystal within the protein bodies. Sources of phytic acid in food are cereals, legumes, oilseeds and nuts are important for human nutrition (**Table 1**). It represents approximately 40 and 60% of total calorie intake for human in developed and developing countries respectively [15]. Among different antinutrients, phytic acid is found in most of the ingredients commonly used in aquafeed like barley, rice, sorghum, wheat, maize, gram, groundnut, rapeseed, soybean, cottonseed, and sesame. Most foods of plant origin contain 50–80% of their total phosphorus, or even higher in selected varieties, as phytate [16]. The amount of the so-called antinutrient compounds present in malanga tubers interferes with the bioavailability of some nutrients and it could affect the food products acceptance [17]. The amount of oxalates (one of the factors implicated in acridity), phytates and tannin content varied in malanga depending on the varieties, climate, irrigation conditions, location, type of soil, and growing season of the plant.

Table 1 Characterization of phytase from different sources by different scientists

S.N	Phytase source	Optimum pH	Optimum temp.	K_m	V_{max}	Specific activity	Ref
1	*A. oryzae* SBS50	5.0	50 °C	1.14 mM	58 U/mL	5.68 U/mg	[51]
2	*Geobacillus sp*.TF16	4.0	85 °C	1.31 mM	526.28 U/mL	219 U/mg	[61]
3	Soybean	5.0	60 °C	5.0 mM	0.63U/mL	0.17 U/mg	[62]
4	*Bacillus licheniformis*	6.0-6.5	60 °C	1.06 mM	1.32 U/mL	0.77U/mg	[11]
5	Soil metagenome	5.6	45 °C	1.29 mM	-	13.89 U/mg	[63]
6	*Vigna umbellate*	4.0	40°C	0.62 mM	3.42 U/mL	-	[64]
7	*Aspergillus niger* S2	5.0	40 °C	-	196 U/mL	52.8 U/mg	[65]
8	*Aspergillus niger*	5.0	58 °C	0.929 µM	52 nkat/cm³	190 nkat/mg	[66]
9	*Sporotrichum thermophile*	5.0	60 °C	0.156 mM	83 $nmLmg^{-1}s^{-1}$	3.82 U/mg	[67]
10	Enterobacter	6.0	55 °C	0.48 mM	0.157 U	1.56 U/mg	[12]
11	*Aspergillus niger*	5.5	50 °C	56 µM	401 U/mL	-	[68]
12	*Aspergillus foetidus*	5.5	37 °C	42 µM	20 U/mL	-	[69]
13	*Rhodotorula mucilagiosa*	5.0	50 °C	-	205 U/mL	31635 U/mg	[22]
14	*Lactobacillus coryniformis*	5.0	60 °C	1.0 mM	3736 U/mL	21.22 U/mg	[56]

Physiological functions of phytic acid

Phytic acid plays an important role in several physiological activities. These include phosphorus storage, energy storage, cation storage, myo-inositol storage, and dormancy initiation [18]. Cations such as calcium (Ca), iron (Fe), magnesium (Mg), copper (Cu), zinc (Zn) and potassium (K) are strongly chelated by phytic acid to form their respective soluble salts [19]. It acts as a natural antioxidant in dormant seeds. This antioxidant property of phytic acid is due to the fact that it effectively prevents the generation of iron-driven hydroxyl radicals [20]. Phytic acid is present ubiquitously in eukaryotic cells in form of monovalent and divalent salts [21]. In plant and animal cells, phytic acid, especially inositol triphosphates, plays a crucial role in signalling and cell function regulation [22]. Phytate inhibits kidney stone formation by complexing with calcium and preventing crystallization. Younger women (NHS II) with higher phytate intake had a lower risk of kidney stones compared to those with lower phytate intake [23].

Pathways and Enzymes Involved In Phytate Synthesis

Biosynthesis of phytic acid

Various factors such as the geographical location of cultivated crop, climate and environmental variations, type of soil, fertilizer use, irrigation conditions, and plants genotypic variation effect the synthesis of phytic acid. The synthesis of phytic acid mainly occurs in cytosol by two pathways, i.e., lipid dependent and lipid independent manner **(Figure 2)**. The precursors for these pathways are different from each other. Phosphatidylinositol and Phosphatidylinositol phosphate are precursors for lipid dependent pathway, whereas myo-inositol and soluble inositol phosphates for lipid independent pathway. The synthesized phytic acid, as well as it's salt and protein complexes are stored in globoids located inside protein bodies [24]. It was reported that functional wheat inositol pentakisphosphate kinase (TaIPK1) is involved in PA biosynthesis, however, the functional roles of the IPK1 gene in wheat remains elusive. In this study, RNAi-mediated gene silencing was performed for IPK1 transcripts in hexaploid wheat [25].

Inositol lipid-independent pathway

In this pathway, after InsP3s formation, InsP3s and myo-inositol-4-phosphate (InsP4s) are converted into myo-inositol-1,3,4,5,6-5-phosphate [Ins(1,3,4,5,6)P5] catalysed by inositol tris/tetrakisphosphate kinase (ITPK), also known as inositol-1,3,4-triskisphosphate 5/6-kinase (ITP5/6 K). This pathway involves the sequential phosphorylation of 1 D-myo-inositol 3-phosphate (Ins(3)P) leads to formation of phytic acid [26].

Lipid dependent pathway

This pathway involves the sequential phosphorylation of inositol 1,4,5-trisphosphate (Ins (1,4,5) P3), which leads to the formation of phytic acid. In this pathway, Phospholipase C enzyme is involved and hence, called the lipid dependent pathway [27].

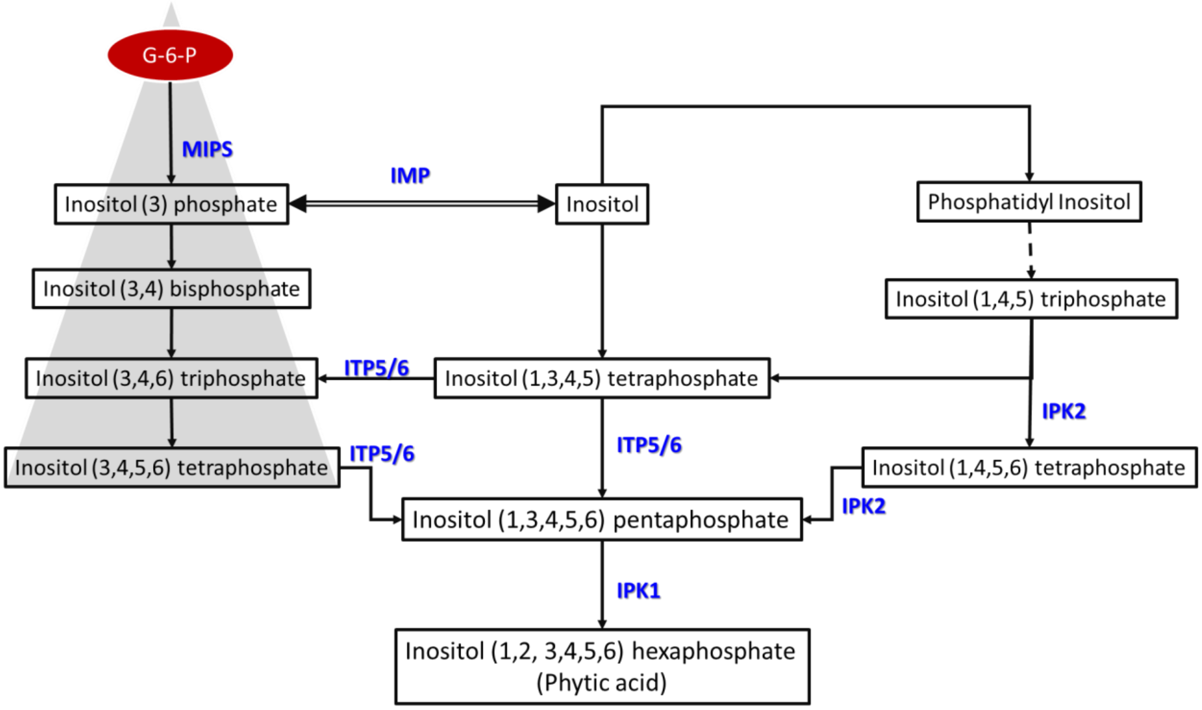

Figure 2 Phytic acid synthesis pathways in plants. The enzymes catalysing the reactions are as follows: MIPS- Myo-inositol-3-phosphate synthase, IMP- Inositol monophosphate phosphatase, IPK2- Inositol 1,4,5-tris-phosphate kinase, IPK1- Inositol 1,3,4,5,6-penta*kis*phosphate 2-kinase.

Anti-nutritive effects of phytic acid

Phytic acid has been shown to have a strong antinutritive effect [28]. The antinutritive effect of phytic acid is because of unusual molecular structure as on complete dissociation, the six phosphate groups of phytic acid contain a total of twelve negative charges. It effectively binds to different mono, di- and trivalent cations and their mixtures, forming insoluble complexes [29]. The formation of insoluble phytate mineral complexes in the intestinal tract prevents mineral absorption. It reduces the bioavailability of many essential minerals [15]. Phytic acid interacts with proteins over a wide range of pH, forming phytate protein complexes. At acidic pH, phytic acid has a strong negative charge due to complete dissociation of phosphate groups. Under these conditions, there is formation of ionic bonding between the basic phosphate groups of phytic acid and protonized amino acid residues [29]. In addition to forming complex with minerals and proteins, phytic acid cause the decrease in the activity of many digestive enzymes by interacting with them such as trypsin, pepsin, α- amylase and β-galactosidase, lead to decrease in activity of these important digestive enzymes [30]. Phytate also interacts with proteins, which may negatively affect protein digestibility. Strong evidence exists which shows negative impact on protein digestibility because of phytate–protein interactions in vitro. The extent of this effect depends on the protein source. The inhibition of digestive enzymes such as alpha-amylase, lipase, or proteinase by phytate may also be of significance, as shown in in vitro studies [31]. Phytic acid is the major storage form of phosphorous in cereals, legumes, oil seeds and nuts. Phytic acid is known as a food inhibitor as it chelates with micronutrient and prevents it’s bio-availability for monogastric animals, including humans, because they lack enzyme phytase in their digestive tract [15].

Phytase

Phytase (Myo-inositol 1,2,3,4,5.6-hexakisphosphate phosphohydrolase) is a special group of phosphatases involved in catalyzing the step wise removal of phosphate group from phytic acid and forms lower myo-inositol phosphates, free myo-inositol and mono phosphate [14]. Phytase enzyme has been found in plants, animals and micro-organisms like yeast, fungi and bacteria. There are four different classes of phytases which have been classified based on catalytic mechanisms, 3-D structure and specific sequence attributes, they are: Histidine acid phosphatases (HAP), Beta propeller phytases (BPPhy), Purple acid phytases (PAPhy) and protein tyrosine phosphatase like-Cysteine phytases (Cphy) [32]. The HAPhy class contains the vast majority of known phytases. These HAPhy have been isolated from bacteria, plants, yeast, and filamentous fungi [10]. The first example of β-propeller phytase were orginally cloned from Bacillus species [33]. These enzymes are known as BPPs because of their three-dimensional structure resembles that of a propeller with six blades [34]. BPPhy plays important role on phytate-phosphorus cycling because this is major phytate degrading enzyme in soil and water [35]. Purple acid phosphatases have recently separated from cotyledons of germinating soybean. Protein tyrosine phosphatase like phytases is newly discovered class. This phytase have been isolated from bacteria, which normally lives in gut of ruminant animals [36].

Phytase is an enzyme that is used in a wide range of industries. According to worldwide market research, the animal feed enzymes business generated $1.1 billion in sales in 2016 and is expected to exceed $2 billion by 2024 [37]. Cellulase, xylanases, phytases, carbohydrases and proteases are some of the enzymes utilised in the animal feed industry. However, among all enzymes, the phytase segment has the highest revenue share (83%) of the whole industry [38]. The most important industrial application of phytase is to act as a feed supplement for animals including chicken, fish and pig [39]. In food processing industries, the products which are prepared from phytate rich compounds for human consumption are subjected to hydrolysis of phytate, which increases the content of phosphorous and the availability of minerals, proteins and vitamins to human body [40]. The instability of phytase is a key issue in commercial applications since the industrial processes need high temperatures, pressures, and shear forces to pelletize the feed, resulting in phytase activity being reduced [41]. A number of phytase genes and proteins have been identified from plants and microbes including bacteria, yeast, and fungi. The first and most probably the best characterized phytase is *Aspergillus niger* PhyA which is encoded by a 1.4 kb DNA fragment and has a molecular mass of 80 kDa, with 10 N-glycosylation sites [42].

Sources of Phytases

Phytate-degrading enzymes are widespread in nature, occurring in plants, microorganisms, as well as in some animal tissues. Phytases can have a variety of biophysical and biochemical features depending on their source and expression host [43].

Fungal phytases

Fungal sources are mainly used for phytase production among all microorganisms. They have a molecular mass of 35–500 kDa, and are optimally active within the pH and temperature ranges of 4.5 to 6.0 and 45 to 70°C, respectively [5]. Shieh and Ware (1968) reported the first systematic investigation of fungal phytase, in which numerous microorganisms were tested for extracellular phytase synthesis, and *Aspergillus ficuum* NRRL 3135 proved to be highly efficient [44]. Aspergillus species is still favoured for the synthesis of phytase, other enzymes, and organic acids. The basis for this decision is it's generally recognized as safe status (GRAS), having wider knowledge of growth cultivation, and high secretory potential [45]. The following are some of the fungal sources of phytase: *Penicillium oxalicum* [46], *Mucor hiemalis* [47], *Aspergillus tubingensis* SKA [48], *Rhizopus oryzae* [49], and *Aspergillus oryzae* SBS50 [50].

Yeast phytases

Yeasts are suitable sources of phosphatase and phytase study due to their non-pathogenic, however they were not been used fully. Although yeasts have been discovered to be rich genetic sources as they were resistant to heat, but there phytases were not properly used at industrial level. *Kodamea ohmeri* BG3, yeast strain was isolated from the intestine of marine fish, it showed maximum enzyme activity at pH 5.0 and temperature of 65°C [52]. The following are some of the yeast sources of phytase: *Hanseniaspora guilliermondii* [53], *Saccharomyces cerevisiae* [54], *Rhodotorula mucilaginosa* JMUY 14 [22], and *Debaryomyces castellii* [55].

Bacterial phytases

Bacterial phytases are substrate specific, necessitating Ca^{2+} ions for activity. Furthermore, bacterial phytases are resistant to the action of proteases found in the gastrointestinal tract of monogastric animals. They have a molecular mass of 37–55 kDa, and are usually active within the pH and temperature ranges of 4.5 to 8.5 and 25 to 70°C, respectively [38]. The following are some of the bacterial sources of phytase: *Lactobacillus coryniformis* [56], *Escherichia coli* [57], and *Lactobacillus plantarum* [58].

Plant phytases

Most of plant phytases are optimally active within the pH and temperature ranges of 4.0 to 7.2 and 45 to 60°C, respectively. From the pollen grains of the *Lilium longiflorum*, a phytase was isolated which is active under alkaline conditions [59]. The following are some of the plant sources of phytase: *Arabidopsis thaliana* AtPAP15 [60], and *Medicago turniculata* MtPHY1 [26].

Animal phytases

Only few animal phytases have been identified, [61] which showed the presence of the first animal phytase in the blood and liver of calves.

Applications of Phytase

Nutritional value of phytase in animal feed

HAPs are the most commonly utilized phytases in animal feeds. Dietary phytase was added primarily to release feed phytate-phosphorus, eliminating the need for inorganic phosphorus supplementation to meet the phosphorus requirements of the target animals [71,72]. About 300–600 phytase activity units/kg of diet release nearly 0.8 g of digestible phosphorus and can substitute either 1.0 or 1.3 g/kg of phosphorus from mono and dicalcium phosphate, respectively [73]. Supplemental phytase, on the other hand, improves iron, calcium, and zinc utilization by animals [74]. Supplementing with phytase increases calcium digestibility from 60 to 70% in control diets to 70–80% in experimental diets. Copper or manganese, on the other hand, have less uniform digestibility responses, and phytase's ability to enhance amino acid availability still has been controversial [75].

The environmental and economic benefits of feed phytase

Numerous animal experiments had demonstrated that when phytase was added to feed at a rate of 500– 1000 phytase units/kg, it can substitute for inorganic phosphorous supplementation in pigs and poultry, reducing phosphorous excretion by around 50% [11]. Phytase is an enzyme that is used in a variety of industries. According to worldwide market research, the animal feed enzymes business generated $1.1 billion in sales in 2016 and is expected to exceed $2 billion by 2024 [37]. Cellulase, xylanases, phytases, carbohydrates and proteases are some of the enzymes utilized in the animal feed industry. However, among all enzymes, the phytase segment has the highest revenue share (83%) of the whole industry [38].

Other applications

There is high demand for phytase in industrial applications such as food processing and biofuel production [76]. Many successful attempts have been made to use phytase in brewing to enhance alcohol production [77]; in bread making to enhance proofing time, crumb firmness, width/height ratio of bread slice, and specific volume [78]; in soy milk dephytination [79] and in the separation of soybean b-conglycinin and glycinin [39].

Conclusion

Phytic acid being the major storage form of phosphorous in grain plants which constitutes about 65-80% of total phosphorous. Mostly animals and humans depend on plant-based diet for phosphorous which is stored in form of phytic acid. Phytic acid is usually considered as anti-nutritional factor, but in small amount is beneficial for animals and humans. Phytic acid have immunological properties also which include anti-bacterial, anti-angiogenic, hypolipidemic and anti-diabetic. The interactions of phytic acid with dietary minerals have many beneficial health effects in food processing and nutritional implications. Phytic acids possess chelating property which is usually considered as detrimental for human health, but it is one of the powerful abilities to bind minerals. Various methods are utilized for fine tuning phytic acid in food products which includes soaking, fermentation, germination, treatment with phytase enzyme, malting, milling and other food processing methods. There is requirement of optimum level of phytic acid in food products and above certain level it becomes harmful for animal and human health. The bio-fortification is important method which should be done in moderation to prevent excessive loss of phytic acid from the grain to retain its beneficial properties in staple crops. There are both positive and negative impacts of phytate, but still there is requirement of further insights about the dosage healthy for human beings and clinical trials should be conducted for validation.

References

[1] A. kumari, L. K. Chugh, V. Kumar, S. Nagar, N. Kharor. Phytase from pearl millet: its partial purification and characterization. Forage Research, 2020, 46 (1):78-83.
[2] B. Singh. Phytase production by Aspergillus oryzae in solid-state fermentation and its applicability in dephytinization of wheat ban. Appl Biochem Biotechnol, 2014, 173:1885–1895.
[3] J. N. A. Lott, J. S. Greenwood, G. D. Batten. Storage During Seed Development, Seed Development and Germination. 2017,
[4] A. Saxena, M. Verma, B. Singh, P. Sangwan, A. N. Yadav, H. S. Dhaliwal, V. Kumar. Characteristics of an acidic phytase from Aspergillus aculeatus APF1 for dephytinization of biofortified wheat genotypes. Appl Biochem Biotechnol, 2020, 191:679–694.
[5] B. Singh, T. Satyanarayana, Fungal phytases. Characteristics and amelioration of nutritional quality and growth of non-ruminants. J Anim Physiol Anim Nutr (Berl). 2015, 99:646–660.
[6] P. H. Selle, A. J. Cowieson, N. P. Cowieson, V. Ravindran. Protein–phytate interactions in pig and poultry nutrition: a reappraisal. Nutr Res Rev, 2012, 25:1–17.
[7] V. Kumar, A. K. Sinha, H. P. S. Makkar, K. Becker. Dietary roles of phytate and phytase in human nutrition: A review. Food Chem, 2010, 120:945–959.
[8] Y. Okazaki, T. Katayama. Phytic acid actions on hepatic lipids and gut microbiota in rats fed a diet high in sucrose is influenced by dietary fat level. Nutrition Research, 2020, 74:45–51.
[9] A. Sharma, S. Trivedi. Evaluation of in vitro probiotic potential of phytase-producing bacterial strain as a new probiotic candidate. Int J Food Sci Technol, 2015, 50:507–514.
[10] B. Singh, G. Kunze, T. Satyanarayana. Developments in biochemical aspects and biotechnological applications of microbial phytases. Biotechnol Mol Biol Rev, 2011, 6:69–87.
[11] V. Kumar, P. Sangwan, A.K. Verma, S. Agrawal. Molecular and biochemical characteristics of recombinant β-propeller Phytase from Bacillus licheniformis strain PB-13 with potential application in aquafeed. Appl Biochem Biotechnol, 2014, 173:646–659.
[12] H. K. Kalsi, R. Singh, H. S. Dhaliwal, V. Kumar. Phytases from Enterobacter and Serratia species with desirable characteristics for food and feed applications. 3 Biotech, 2016, 6:1–13.

[13] I. I. C. on B. Nomenclature, The nomenclature of lipids: Recommendations (1976), Lipids. 12 (1977) 455–468.

[14] P. Vats, U. C. Banerjee. Production studies and catalytic properties of phytases (myo-inositolhexakisphosphate phosphohydrolases): an overview, Enzyme Microb Technol, 2004, 35:3–14.

[15] R. K. Gupta, S. S. Gangoliya, N. K. Singh. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. J Food Sci Technol, 2015, 52:676–684.

[16] K. Baruah, P. Norouzitallab, A. K. Pal. Development of low cost and eco-friendly feed for various candidate species for the sustainability of commercial aquaculture and reduction of aquatic pollution, in: Developing New Functional Food and Nutraceutical Products, Elsevier, 2017, 441–453.

[17] V. Kumar, A. Kumari, K. Angmo, T. C. Bhalla. Isolation and characterization of lactic acid bacteria from traditional pickles of Himachal Pradesh, India. J Food Sci Technol, 2017, 54:1945–1952.

[18] S. Rebello, L. Jose, R. Sindhu, E. M. Aneesh. Molecular advancements in the development of thermostable phytases. Appl Microbiol Biotechnol, 2017, 101:2677–2689.

[19] V. Raboy. Low phytic acid crops: Observations based on four decades of research. Plants, 2020, 9:140.

[20] B. D. Oomah, C. Blanchard, P. Balasubramanian. Phytic acid, phytase, minerals, and antioxidant activity in Canadian dry bean (Phaseolus vulgaris L.) cultivars. J Agric Food Chem, 2008, 56:11312–11319.

[21] A. Kumar, V. Kumar, V. Krishnan, A. Hada, A. Marathe, M. Jolly, A. Sachdev. Seed targeted RNAi-mediated silencing of GmMIPS1 limits phytate accumulation and improves mineral bioavailability in soybean. Sci Rep, 2019, 9:1–13.

[22] P. Yu, X. Wang, J. Liu. Purification and characterization of a novel cold-adapted phytase from Rhodotorula mucilaginosa strain JMUY14 isolated from Antarctic. J Basic Microbiol, 2015, 55:1029–1039.

[23] N. K. Dahl, D. S. Goldfarb, Nutritional prevention and treatment of urinary tract stones, in: Nutritional Management of Renal Disease. Elsevier, 2022, 685–697.

[24] A. P. M. Bloot, D. L. Kalschne, J. A. S. Amaral, I. J. Baraldi, C. Canan. A review of phytic acid sources, obtention, and applications. Food Reviews International, 2021, 1–20.

[25] S. Aggarwal, A. Kumar, K. K. Bhati, G. Kaur, V. Shukla, S. Tiwari, A. K. Pandey. RNAi-mediated downregulation of inositol pentakisphosphate kinase (IPK1) in wheat grains decreases phytic acid levels and increases Fe and Zn accumulation. Front Plant Sci, 2018, 9:259.

[26] K. Xiao, M. J. Harrison, Z. Y. Wang. Transgenic expression of a novel M. truncatula phytase gene results in improved acquisition of organic phosphorus by Arabidopsis. Planta, 2005, 222:27–36.

[27] M. Suzuki, K. Tanaka, M. Kuwano, K. T. Yoshida. Expression pattern of inositol phosphate-related enzymes in rice (Oryza sativa L.): implications for the phytic acid biosynthetic pathway. Gene, 2007, 405:55–64.

[28] G. Rimbach, J. Pallauf, J. Moehring, K. Kraemer, A. M. Minihane. Effect Of Dietary Phytate And Microbial Phytase On Mineral And Trace Element Bioavailability-A Literature Review. Curr Top Nutraceutical Res, 2008, 6.

[29] V. Sommerfeld, M. Schollenberger, I. Kühn, M. Rodehutscord. Interactive effects of phosphorus, calcium, and phytase supplements on products of phytate degradation in the digestive tract of broiler chickens. Poult Sci, 2018, 97:1177–1188.

[30] R. K. Gupta, S. S. Gangoliya, N. K. Singh; Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. J Food Sci Technol, 2015, 52:676–684.

[31] R. Greiner, U. Konietzny, K. D. Jany. Phytate-an undesirable constituent of plant-based foods? Journal Für Ernährungsmedizin, 2006, 8:18–28.

[32] K. Roopesh, S. Ramachandran, K. M. Nampoothiri, G. Szakacs, A. Pandey. Comparison of phytase production on wheat bran and oilcakes in solid-state fermentation by Mucor racemosus. Bioresource Technology, 2006, 97(3):506-511.

[33] V. Kumar, A. Kumari, K. Angmo, T. C. Bhalla. Isolation and characterization of lactic acid bacteria from traditional pickles of Himachal Pradesh, India. J Food Sci Technol, 2017, 54:1945–1952.

[34] A. H. J. Ullah, K. Sethumadhavan, E. J. Mullaney. Unfolding and refolding of Aspergillus niger PhyB phytase: role of disulfide bridges. J Agric Food Chem, 2008, 56:8179–8183.

[35] N. C. Ha, B. C. Oh, S. Shin, H. J. Kim, T. K. Oh, Y. O. Kim, K. Y. Choi, B. H. Oh. Crystal structures of a novel, thermostable phytase in partially and fully calcium-loaded states. Nat Struct Biol, 2000, 7:147–153.

[36] B. L. Lim, P. Yeung, C. Cheng, J. E. Hill. Distribution and diversity of phytate-mineralizing bacteria. ISME J, 2007, 1:321–330.

[37] B. A. Nakashima, T. A. McAllister, R. Sharma, L. B. Selinger. Diversity of phytases in the rumen. Microb Ecol, 2007, 53:82–88.

[38] U. M. Vasudevan, A. K. Jaiswal, S. Krishna, A. Pandey. Thermostable phytase in feed and fuel industries. Bioresour Technol, 2019, 278:400–407.

[39] J. Jain, B. Singh. Characteristics and biotechnological applications of bacterial phytases. Process Biochemistry, 2016, 51:159–169.

[40] X. G. Lei, J. D. Weaver, E. Mullaney, A. H. Ullah, M. J. Azain. Phytase, A New Life for an" Old" Enyzme. Annu Rev Anim Biosci, 2013, 1:283-309.

[41] V. Handa, D. Sharma, A. Kaur, S. K. Arya. Biotechnological applications of microbial phytase and phytic acid in food and feed industries. Biocatal Agric Biotechnol, 2020, 25:101600.

[42] R. E. Cian, C. Bacchetta, J. Cazenave, S. R. Drago. Extruded fish feed with high residual phytase activity and low mineral leaching increased P. mesopotamicus mineral retention. Anim Feed Sci Technol, 2018, 240:78–87.

[43] S. Zhou, Z. Liu, W. Xie, Y. Yu, C. Ning, M. Yuan, H. Mou. Improving catalytic efficiency and maximum activity at low pH of Aspergillus neoniger phytase using rational design. Int J Biol Macromol, 2019, 131:1117–1124.

[44] D. Rao, K. V. Rao, T. P. Reddy, V. D. Reddy. Molecular characterization, physicochemical properties, known and potential applications of phytases: an overview. Crit Rev Biotechnol, 2009, 29:182–198.

[45] T. R. Shieh, J. H. Ware. Survey of microorganisms for the production of extracellular phytase. Appl Microbiol, 1968, 16:1348–1351.

[46] G. B. Shivanna, V. Govindarajulu. Screening of asporogenic mutants of phytase-producing Aspergillus niger CFR 335 strain. Microb Ecol Health Dis, 2009, 21:57–63.

[47] R. Kaur, A. Saxena, P. Sangwan, A. N. Yadav, V. Kumar, H. S. Dhaliwal. Production and characterization of a neutral phytase of Penicillium oxalicum EUFR-3 isolated from Himalayan region. Nusantara Bioscience, 2017, 9:68–76.

[48] A. Boyce, G. Walsh. Purification and characterisation of an acid phosphatase with phytase activity from Mucor hiemalis Wehmer. J Biotechnol, 2007, 132:82–87.

[49] S. S. Qasim, K. A. Shakir, A. B. Al-Shaibani, M. K. Walsh. Optimization of culture conditions to produce phytase from Aspergillus tubingensis SKA. Food Nutr Sci, 2017, 8:733.

[50] S. Ramachandran, K. Roopesh, K. M. Nampoothiri, G. Szakacs, A. Pandey. Mixed substrate fermentation for the production of phytase by Rhizopus spp. using oilcakes as substrates. Process Biochemistry, 2005, 40:1749–1754.

[51] B. Singh. Purification and characterization of a protease-resistant phytase of Aspergillus oryzae SBS50 whose properties make it exceptionally useful as a feed supplement. Int J Biol Macromol, 2017, 103:458–466.

[52] X. Li, Z. Chi, Z. Liu, K. Yan, H. Li. Phytase production by a marine yeast Kodamea ohmeri BG3. Appl Biochem Biotechnol, 2008, 149:183–193.

[53] A. M. Hellström, R. Vázques-Juárez, U. Svanberg, T. A. Andlid. Biodiversity and phytase capacity of yeasts isolated from Tanzanian togwa. Int J Food Microbiol, 2010, 136:352–358.

[54] G. Kłosowski, D. Mikulski, O. Jankowiak. Extracellular phytase production by the wine yeast S. cerevisiae (Finarome Strain) during submerged fermentation. Molecules, 2018, 23:848.

[55] M. Ragon, V. Neugnot-Roux, P. Chemardin, G. Moulin, H. Boze. Molecular gene cloning and overexpression of the phytase from Debaryomyces castellii CBS 2923. Protein Expr Purif, 2008, 58:275–283.

[56] Y. Demir, N. Dikbaş, Ş. Beydemir. Purification and biochemical characterization of phytase enzyme from Lactobacillus coryniformis (MH121153). Mol Biotechnol, 2018, 60:783–790.

[57] M. S. Kim, X. G. Lei. Enhancing thermostability of Escherichia coli phytase AppA2 by error-prone PCR. Appl Microbiol Biotechnol, 2008, 79:69–75.

[58] Garchow, B. G., Jog, S. P., Mehta, B. D., Monosso, J. M. and Murthy, P. P. (2006). Alkaline phytase from Lilium longiflorum: purification and structural characterization. Protein Expression and Purification, 46(2): 221-232.

[59] D. Bhagat, P. S. Slathia, N. Raina, P. Sharma. Production of phytase from Lactobacillus paracasei strain and its probiotic profile. Indian J. Exp. Biol, 2019, 57:839-851.

[60] R. J. Li, W. J. Lu, C. J. Guo, X. J. Li, J. T. Gu, X. Kai. Molecular Characterization and Functional Analysis of OsPHY1, a Purple Acid Phosphatase (PAP)–Type Phytase Gene in Rice (Oryza sativa L.). J Integr Agric, 2012, 11:1217–1226.

[61] E. v McCollum, E. B. Hart. On the occurrence of a phytin-splitting enzyme in animal tissues. Journal of Biological Chemistry, 1908, 4:497–500.

[62] E. Dokuzparmak, Y. Sirin, U. Cakmak, N. Saglam Ertunga. Purification and characterization of a novel thermostable phytase from the thermophilic Geobacillus sp. TF16. Int J Food Prop, 2017, 20:1104–1116.

[63] E. B. Çelem, S. Önal. Immobilization of phytase on epoxy-activated Sepabead EC-EP for the hydrolysis of soymilk phytate. J Mol Catal B Enzym, 2009, 61:150–156.

[64] G. A. Castillo Villamizar, H. Nacke, L. Griese, L. Tabernero, K. Funkner, R. Daniel. Characteristics of the first

protein tyrosine phosphatase with phytase activity from a soil metagenome. Genes, 2019, 10:101.
[65] K. Belho, P. K. Ambasht. Immobilization of phytase from rice bean (Vigna umbellata Thunb.) on glutaraldehyde activated chitosan microspheres. J Sci Res, 2021, 65:111–119.
[66] A. Sandhya, A. Sridevi, P. Suvarnalathadevi. Biochemical characterization of phytase purified from Aspergillus niger S2. Eurasian J Biosci, 2019, 13:99–103.
[67] M. V. Sariyska, S. A. Gargova, L. A. Koleva, A. I. Angelov. Aspergillus niger phytase: purification and characterization. Biotechnology & Biotechnological Equipment, 2005, 19:98–105.
[68] B. Singh, T. Satyanarayana. Plant growth promotion by an extracellular HAP-phytase of a thermophilic mold Sporotrichum thermophile. Appl Biochem Biotechnol, 2010, 160:1267–1276.
[69] J. Harati, S. O. R. Siadat, H. Taghavian, S. Kaboli, S. Khorshidi. Improvement in biochemical characteristics of glycosylated phytase through immobilization on nanofibers. Biocatal Agric Biotechnol, 2017, 12:96–103.
[70] S. Ajith, J. Ghosh, D. Shet, S. ShreeVidhya, B. D. Punith, A. V. Elangovan. Partial purification and characterization of phytase from Aspergillus foetidus MTCC 11682. AMB Express, 2019, 9:1–11.
[71] V. Kumar, A.K. Sinha, H.P.S. Makkar, G. de Boeck, K. Becker. Phytate and phytase in fish nutrition. J Anim Physiol Anim Nutr, 2012, 96:335–364.
[72] O. Adeola, A.J. Cowieson, Board-invited review: opportunities and challenges in using exogenous enzymes to improve nonruminant animal production, J Anim Sci. 89 (2011) 3189–3218.
[73] E. Esteve-Garcia, A. M. Perez-Vendrell, J. Broz. Phosphorus equivalence of a consensus phytase produced by Hansenula polymorpha in diets for young turkeys. Arch Anim Nutr, 2005, 59:53–59.
[74] C. Jondrevillea, R. Hayler, D. Feuerstein. Replacement of zinc sulphate by microbial phytase for piglets given a maize-soya-bean meal diet. Animal Science, 2005, 81:77–83.
[75] P.H. Selle, V. Ravindran. Microbial phytase in poultry nutrition. Anim Feed Sci Technol, 2007, 135:1–41.
[76] Y. Hubenova, M. Mitov. Potential application of Candida melibiosica in biofuel cells. Bioelectrochemistry, 2010, 78:57–61.
[77] J. Fujita, H. Fukuda, Y. Yamane, Y. Kizaki, S. Shigeta, K. Ono, O. Suzuki, S. Wakabayashi. Critical importance of phytase for yeast growth and alcohol fermentation in Japanese sake brewing. Biotechnol Lett, 2001, 23:867–871.
[78] M. Haros, C. M. Rosell, C. Benedito. Use of fungal phytase to improve breadmaking performance of whole wheat bread. J Agric Food Chem, 2001, 49:5450–5454.
[79] M. V. Ushasree, P. Gunasekaran, A. Pandey. Single-step purification and immobilization of MBP–phytase fusion on starch agar beads: application in dephytination of soy milk. Appl Biochem Biotechnol, 2012, 167:981–990.

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