THE ROLE OF PHYTIC ACID IN PLANT-BASED INGREDIENTS FOR ANIMAL FEED: A REVIEW

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ABSTRACT: Phytates play pivotal roles in plant physiology, acting as reservoirs for phosphorus and specific cations throughout various stages of plant life cycles. They are essential raw materials for cell wall formation after germination and shield seeds against oxidative stress during storage. However, their chelating effect forms robust bonds with amino acids, starch, and vital minerals, detrimentally affecting nutrient assimilation in feed and consequently diminishing feed yield. This article investigates the antinutritional aspects of phytates, exploring their reactivity, chelating actions, and adverse effects on gastrointestinal metal availability in animals. In addition, the article examines how unutilized phytates during poultry and pig feeding contribute to environmental concerns as they are excreted, contributing to groundwater eutrophication. The European Union now mandates feed supplementation with exogenous microbial phytases to address this issue. The terms phytate, phytic acid, myo-inositol, myo-inositol hexaphosphate, and phytin are used to denote different forms of this antinutritional factor. Despite being hydrolyzed by phytase enzymes, these compounds remain distinct. Inositol, a constituent prevalent in cereals, plays critical roles in various biological processes, including insulin signal transduction, calcium concentration control, and gene expression. This study elucidates the interaction of phytic acid with proteins under variation pH conditions, delineating its role in forming insoluble complexes and impacting enzymatic activities. Phytate is considered one of the most potent antinutritional factors, leading to substantial nutritional losses and diminished protein and energy availability in animals. The content of phytic phosphorus varies among ingredients of plant origin, which influences phosphorus bioavailability. Dietary phosphorous utilization varies across species, with ruminants exhibiting higher utilization due to fermenting microorganisms secreting phytase. Understanding the implications of phytates on nutrient availability is paramount for animal nutrition and environmental conservation. This article underscores the necessity of evaluating phosphorus bioavailability to enhance ingredient utilization and mitigate ecological impacts.
KEYWORDS: anti-nutritional factor, phytic acid, bioavailability, animal nutrition, environmental conservation

1 I INTRODUCTION

Phytates have several important functions in plant physiology during the life cycle of plants, including the storage of phosphorus and some cations, which provide raw material for the formation of the cell wall after germination. In addition, phytate protects the seed against oxidative stress during storage. The greatest negative effect of phytates is their chelating effect or strong bonds with other molecules such as amino acids, starch, and minerals such as calcium, iron, zinc, and magnesium (Figure 01). This effect affects the assimilation of nutrients needed in feed and, consequently, a significant reduction in the yield of the feed used (Yin et al., 2007; Benevides et al., 2011).

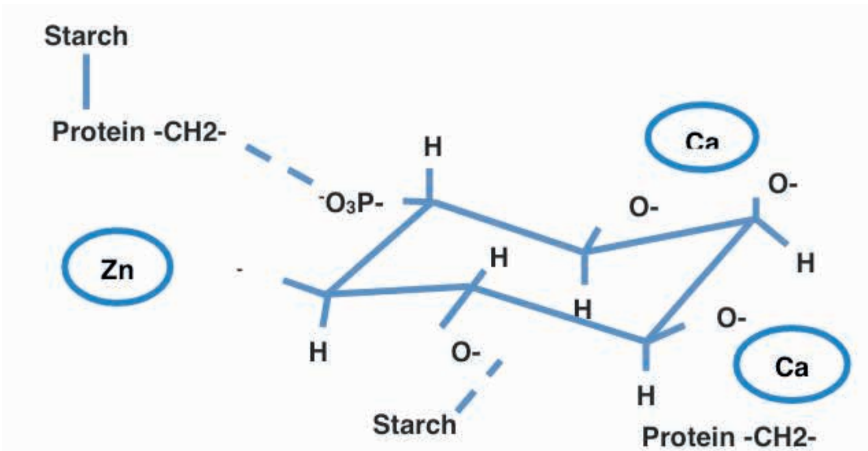

Figure 01. Representation of the phytate-nutrient complex (Reproduced from Bertechini, 2013)

According to Nagashiro (2007), the antinutritional nature of phytate can be attributed to several factors, such as: high reactivity of the molecule, providing a strong chelating action, making metals such as Ca^{+2}, Mg^{+2}, Zn^{+2}, Fe^{+2} unavailable in the gastrointestinal tract of animals; formation of complexes with amino acids that resist enzymatic hydrolysis, because the phosphate groups of phytic acid can electrostatically bind to the terminal amine groups or to the residues of the amino acids lysine and arginine; interaction with amylase, trypsin, and acid phosphatase enzymes, among others, resulting in reduced activity and inhibition; formation of a phytate–mineral– protein complex that can be formed with multivalent cations, making the bound proteins less susceptible to proteolytic hydrolysis.

Another negative factor of phytates is that they are not used during the feeding of poultry and pigs, leading to their direct excretion into the environment. Phytates are hydrolyzed by microorganisms that are part of the soil microbiota, and the phosphorus released flows into the groundwater, causing eutrophication of water in areas where animals are intensively produced. In recent years, the European Union has passed important environmental laws obliging poultry and pig producers to supplement their feed with exogenous microbial phytases (Leal et al., 2010).

Phytate, phytic acid, *myo-inositol*, *myo-inositol* hexaphosphate (Figure 02) and phytin as terms used to refer to different forms of an anti-nutritional factor (Figure 02). Although phytase enzymes hydrolyze all these substances, they are distinct compounds: *myo-inositol* hexaphosphate, phytic acid or phytate, a term used to refer to the mixed salt of phytic acid; *myo-inositol* is the free form of the aromatic ring of phytate (inositol), without the phosphate groups (PO43-); phytin, on the other hand, refers specifically to the complex of *myo-inositol* hexaphosphate with potassium, magnesium and calcium, as occurs in vegetables (Valle, 2010).

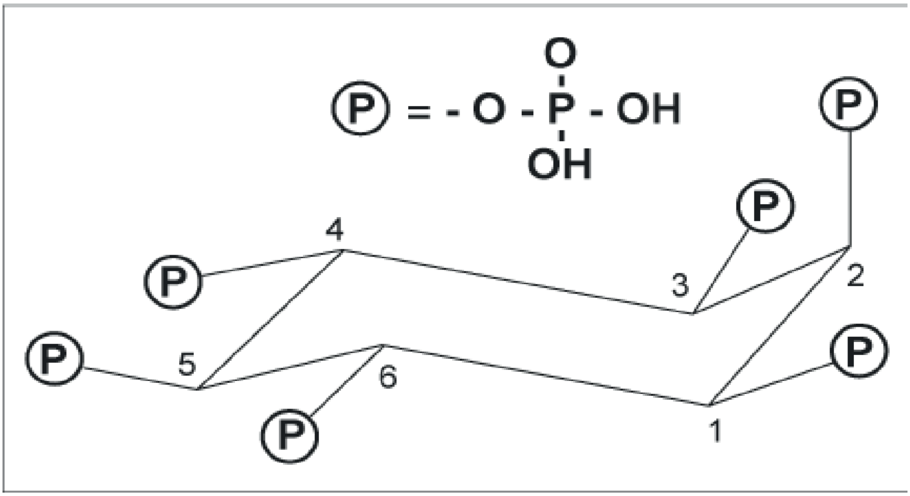

Figure 02. Molecular structure of phytate, *myo-inositol* 1,2,3,4,5,6-hexakis(dihydrogen phosphate) acid (Reproduced from Faria et al., 2006).

Phytate, phytic acid, myo-inositol, myo-inositol hexaphosphate (Figure 02), and phytin are terms used to refer to different forms of an antinutritional factor (Figure 02). Although phytase enzymes hydrolyze all these substances, they are distinct compounds: myo-inositol hexaphosphate, phytic acid, or phytate, a term used to refer to the mixed salt of phytic acid; myo-inositol is the free form of the aromatic ring of phytate (inositol), without the phosphate groups (PO_4^{3-}); phytin, on the other hand, refers specifically to the complex of myo-inositol hexaphosphate with potassium, magnesium, and calcium, as occurs in vegetables (Valle, 2010).

Inositol is found in many foods, especially cereals. As the basis of many signaling and secondary messenger molecules, inositol is implicated in many biological processes, including insulin signal transduction, control of intracellular calcium concentration, cell membrane potential, modulation of serotonin activity, fat metabolism, and reduction of blood cholesterol levels and gene expression (Larner, 2002).

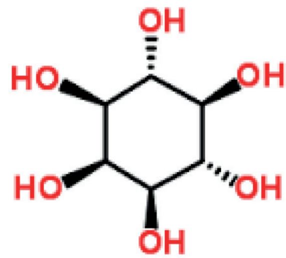

Figure 03. Chemical structure of the *myo-inositol* molecule (IUPAC, 1968)

According to Silva (2004), at neutral pH, orthophosphate groups have one or two negatively charged oxygen atoms; consequently, several cations can be strongly chelated between two phosphate groups or weakly chelated with one phosphate group. The interaction with the protein is dependent on pH conditions, as is done by ionic bonding, as shown in Figure 4. Under acidic conditions, phytic acid has a negative charge and can bind to basic residues through strong electrostatic interactions, resulting in an insoluble complex. At neutral pH, the protein will not bind to phytic acid because its charge is neutral. At basic pH, phytic acid forms a complex with the protein in the presence of divalent cations, which act as a bridge between the negatively charged carboxyl group and phytic acid. Several studies have shown that proteins from soy, corn, wheat, rapeseed, sunflower meal, and rice form complexes with phytic acid (Ravindran et al., 2001).

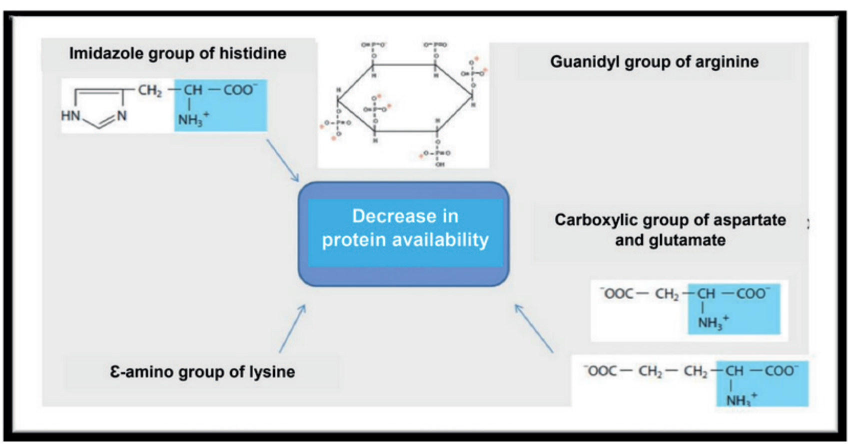

Figure 04. Schematic representation of the interaction between phytic acid and amino acids (Personal archive).

Phytate is a complex compound that is considered to be one of the most potent antinutritional factors. It is responsible for significant nutritional losses, reducing protein and energy availability to the animal as well as increasing mucin production and cell turnover in the digestive tract (Cowieson et al, 2006). Phytic phosphorus is the phosphorus that forms part of the inositol hexaphosphate (IP_6) molecule, which is only found in plants. The inositol phosphates found in cereal grains contain approximately 90% of the inositol in the hexa phosphorus form (IP_6), with the remaining 10% corresponding to the sum of the penta (IP_5), tetra (IP_4), and triphosphates (IP_3). Consequently, only IP_5 and IP6 have a negative effect on mineral bioavailability. The other inositol phosphatides formed have a low capacity to bind to minerals (Valle, 2010).

The amount of phytic phosphorus in cereal grains and oilseeds depends on their location. In maize, phytate is found in large quantities in the germ; in legumes, it accumulates in the cotyledons and soybeans; in particular, it is found attached to protein bodies distributed throughout the seed (Selle et al., 2003; Valle, 2010).

Animal nutrition is mainly based on ingredients of plant origin, in which 66% of the phosphorus is in the form of inositol hexaphosphate, which is unavailable for absorption by non-ruminant animals. The phytate content varies between ingredients (Table 02), directly affecting the bioavailability of phosphorus. According to the NRC (1994), only 33% and 42% of this mineral is bioavailable in corn and soybean meal, respectively (Borgatti et al., 2009). Determining the bioavailability of phosphorus is essential for assessing the use of ingredients by animals and protecting the environment, as the ecological impact of eliminating fecal phosphorus is considerable (Borgatti et al., 2009).

Ingredients	Total phosphorus (%)	Phytic phosphorus (%)	Non-phytic phosphorus (%)	Phosphorus digestibility (%)	Digestible phosphorus (%)
Corn	0,24	0,17	0,07	29,0	0,07
Wheat	0,27	0,19	0,08	38,0	0,1
Rice bran	1,31	1,05	0,26	16,0	0,24
Wheat bran	0,99	0,79	0,20	37,0	0,37
Soybean meal	0,39	0,23	0,16	42,0	0,16
Meat and bone meal	5,0	0,0	5,0	61,0	3,05
Fish meal	2,20	0,0	2,20	74,0	1,63

Table 02. Contents of total phosphorus, phytic phosphorus, non-phytic phosphorus and phosphorus digestibility in ingredients used in poultry and pig feed (Borgatti et al., 2009).

level of utilization of dietary phosphorus also varies according to species and is directly related to the anatomical and physiological characteristics of the gastrointestinal tract. Therefore, in the descending order of utilization of dietary phosphorus, there are ruminants, monogastric herbivores , poultry, and pigs. It should be noted that, for poultry and pigs, the bioavailability of dietary phosphorus is approximately 30% and 20%–60%, respectively. Younger animals are less able to use phytic phosphorus and are even more susceptible to a reduction in dietary digestibility (Silva, 2012).

In ruminant animals, phytic phosphorus is made available by fermenting microorganisms, which secrete the enzyme phytase, which has an intensive action on phytates (Dvoraková et al., 1997). However, phosphorus that may not have been made available by rumen microorganisms flows into other gastric compartments, remains in an unavailable form, and is finally excreted (Silva, 2012).

2 I CONCLUSION

In conclusion, the multifaceted role of phytates in plant physiology is undeniable, encompassing the storage of phosphorus and cations, formation of the cell wall, and protection of seeds against oxidative stress. However, their substantial negative impact stems from their chelating effect, forming strong bonds with essential molecules and minerals, preventing the assimilation of nutrients in food and consequently reducing food yields. The anti-nutritional nature of these compounds is attributed to their high reactivity, strong chelating action, and formation of complexes with amino acids, hindering enzymatic hydrolysis and leading to a reduction in the activity of critical enzymes. In addition, there are environmental consequences, such as the eutrophication of groundwater, when phytates not used in poultry and pig feed result in direct excretion into the environment. In this context, it is important to meet the requirements for supplementing animal feed with exogenous microbial phytases. Inositol, abundant in cereals, plays pivotal roles in various biological processes, underscoring the broader implications of phytates in nutritional contexts. The intricate interaction of phytic acid with proteins under different pH conditions further elucidates its impact on forming complexes and affecting enzymatic activities. Ultimately, the potent antinutritional nature of phytates, responsible for substantial nutritional losses and diminished protein and energy availability in animals, prompts a critical reevaluation of dietary phosphorus utilization. The variable utilization across species highlights the importance of considering anatomical and physiological characteristics in assessing dietary phosphorus bioavailability.

Understanding the complex interplay of phytates in plant and animal systems is essential not only for optimizing animal nutrition but also for mitigating the ecological impacts associated with their presence in feed and subsequent excretion into the environment.

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