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Review

Phytate in feed ingredients and potentials for improving the utilization of phosphorus in ruminant nutrition

E. Humer, Q. Zebeli*

Institute of Animal Nutrition and Functional Plant Compounds, Department for Farm Animals and Veterinary Public Health, University of Veterinary Medicine Vienna, Veterinaerplatz 1, 1210 Vienna, Austria

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ABSTRACT

Phosphorus (P) nutrition has received renewed interest due to its potential environmental effects in terms of eutrophication and the limitations of the global raw phosphate stores. At the same time, in ruminants, P has more known key functions in the body and rumen microbes than any other mineral nutrient. Thus, although continuous P supply is of crucial importance, dietary P supply should not exceed the requirement of the animal. Sound knowledge regarding availability of P from different feedstuffs is a prerequisite to optimize the supply of dietary P. Phosphorus is primarily stored in the form of phytates in plant seeds, thus potentially reducing its ruminal solubility and consequently availability in ruminants, in particular when rumen functioning is suboptimal. The enzyme phytase catalyzes the stepwise hydrolysis of phytate. In respect to ruminant nutrition there are five possible sources of this enzyme available for the animals: ruminal microbial phytase, endogenous mucosal phytase, large intestinal microbial phytase, plant phytase and exogenous microbial phytase. Latest studies showed that the ruminal microbial phytase does not enable complete hydrolysis of phytate-bound P, although it is more efficient regarding phytate hydrolysis compared to endogenous mucosal phytase. Furthermore, plant phytase activity varies greatly among species of plants. Approaches to reduce the phytate contents of concentrates are the supplementation of microbial phytase as well as the application of diverse feed processing techniques like germination, fermentation and the treatment of feeds with organic acids. However, further research is warranted to evaluate the potential of these technologies. The main focus herein is to review the available literature on the role of phytate in ruminant nutrition, its degradation throughout the gastrointestinal tract and opportunities to enhance the utilization of feed P and to reduce the excretion of this main polluting nutrient.

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Abbreviations: ADG, average daily gain; CA, citric acid; DDGS, dried distillers grains with solubles; DM, dry matter; DMI, dry matter intake; LA, lactic acid; NDF, neutral detergent fiber; FTU, phytase activity expressed in units; InsP, inositol phosphate; InsP6, myo-inositol hexakisphosphate; P, phosphorus; TMR, total mixed ration.

* Corresponding author.
E-mail address: Qendrim.Zebeli@vetmeduni.ac.at (Q. Zebeli).

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1. Introduction

Phosphorus (P) is one of the most important mineral nutrients in animal nutrition. It is also considered as one of the most polluting nutrients in areas of intensive animal production, because high levels of dietary P are excreted in the feces (Eastridge, 2006). Although it is essential that sufficient P is fed, it is also critical that dietary P supply does not exceed the requirement of the animal, due to the role of P in environmental pollution and the significant cost of adding inorganic P to the diet (Mijoun et al., 2008). Phosphorus solubility differs widely between plant feedstuffs, which is mainly related to their phytate contents, the salts of phytic acid (*myo*-inositol hexakisphosphate, $InsP_6$) (Humer et al., 2015a). The enzyme phytase catalyzes the stepwise hydrolysis of phytate to inorganic phosphates and inositol with lower phosphorylated inositol phosphates (InsP) as intermediates (Schlemmer et al., 2009). As P contained in the $InsP_6$ molecule requires longer fermentation before released, the nutritional value of feedstuffs can be increased when $InsP_6$ contents are reduced. The low availability of $InsP_6$-P is well known in swine and poultry, due to the very low phytase activity found in the digestive tract in monogastric livestock (Humer et al., 2015a). However, $InsP_6$-P appears to be more available in ruminants such as cattle and sheep. Nevertheless, $InsP_6$ must be hydrolyzed to free inorganic P to enable absorption by ruminants.

An efficient utilization of P is critical to minimize the pollution risk associated with overfeeding of P. As the inherent phytase activity of the rumen microbes digests nearly all the $InsP_6$ into inorganic P (Raun et al., 1956), previously $InsP_6$-P was considered to be fully available to ruminants (Morse et al., 1992). However, in high-producing ruminants, especially in dairy cows, faster passage rate and suboptimal rumen fermentation conditions may limit ruminal $InsP_6$ degradation, because of the short-duration exposure of the $InsP_6$ molecule to microbial phytase (Jarrett et al., 2014). In addition, high-grain diets are also associated with reduced secretion of saliva, thus possibly decreasing the salivary P available for microbial use and for absorption in the small intestine (Scott and Buchan, 1985).

Hence, intensive research in the last years has aimed at establishing ways of improving the sustainability in the use of P in livestock production. First of all, the knowledge of the P requirement for a given level of animal production as well as reliable information on P availability of different feed ingredients are of utmost importance for precise diet formulation. Moreover, feed treatment procedures, like acid treatment, fermentation or germination techniques, can lead to phytate degradation in seeds (Haraldsson et al., 2004; Sokrab et al., 2012; Humer et al., 2013; Metzler-Zebeli et al., 2014; Harder et al., 2015a). Furthermore, the widespread inclusion of exogenous phytases in monogastric rations (Selle and Ravindran, 2007, 2008) is also discussed as possible method to dephosphorylate phytate and liberate the inherent P component for ruminant diets (Knowlton et al., 2007; Brask-Pedersen et al., 2013).

The objective of this review is to update the current knowledge concerning the relevance of phytate in ruminant nutrition. One main part summarizes experimental results of the physiological relevance of different sources of phytases and the hydrolysis of phytate along the gastrointestinal passage. Finally, the impacts of diverse feed processing techniques on phytate degradation are discussed.

2. Phosphorus

2.1. Relevance for the organism and microbes

Phosphorus is an essential mineral, as it is present in a number of structural components and is intimately involved in a wide variety of physiological processes (Tayyab and McLean, 2015). Additionally, rumen microbes have a requirement for