ISSN: 2456-2912
VET 2023; 8(4): 301-305

www.veterinarypaper.com
Received: 19-04-2023
Accepted: 23-05-2023

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Physiological significance of phosphorous as a key element for production and reproduction in ruminants: A review

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Abstract
After the consumption of feedstuff by ruminants, only 0.73 of dietary phosphorus is absorbed. The remaining variability is probably due to feedstuffs or diets, differences in phosphorus digestive availability, and also differences among species and physiological states. Phosphorus absorbed from cereal, cereal by-products, silage, and hay differs greatly. The chelation of phosphorus with amino acid increases its absorption as well as providing organic phosphorus through animal-based phosphorus sources such as meat meal & bone meal and inorganic phosphorus through dicalcium phosphate, monocalcium phosphate & some fluorinated phosphate also enhances absorption of phosphorus via the gut of ruminants. Due to faster absorption and availability of phosphorus from the gut of ruminants, they are super benefited with respect to productivity and reproductivity. The physiological significance of the same is discussed.

Keywords: Phosphorus, ruminants, production, reproduction

Introduction
Hennig Brand in 1669 discovered phosphorus and its Greek meaning is 'bringer of light or light bearer'. Phosphorus is an essential element/nutrient for all ruminants, and has many essential physiological functions in the body of ruminants that include energy transfer (regulation of RBC glycolysis by the formation of ATP), buffering pH changes in the rumen (salivary phosphate), involved in the synthesis of phospholipids, maintain muscle tone, appetite and feed utilization, a structural component of the skeletal system, teeth, cell membrane, nucleic acids and also involved in cell signalling [1]. It is a vital mineral that is not replaced by any other nutrients in the diet, however, due to its highest price, it is typically the second or third biggest cost component of all dietary supplements followed by energy & protein supplements. The phosphorus content of ruminant diets has tended to increase over time as the feeding of grain, protein supplements, and by-products fed to beef and dairy cattle has increased. Production of higher-quality forages on phosphorus-enriched soils has also contributed to the higher phosphorus content of some ruminant diets. The bioavailability of phosphorus varies according to the animal physiology and functional variability within the species, animal to animal variation, according to their sex, age, and disease conditions. Also, these factors affect the absorption of phosphorus in ruminants. Ruminants use a larger proportion of dietary phosphorus than nonruminants due to microbial phytase production in the rumen.

Phosphorous is mainly supplied to animals in two different forms i.e., organic phosphorus and inorganic phosphorus. Organic phosphorus is mainly taken by animals through different feeds and feed supplements like grasses, roughages, and concentrates. While, inorganic one is mainly supplied through the mineral mixture. In some areas, conventional feeding methods are adopted by regional farmers, where we need to provide dietary phosphorous in the form of concentrate and mineral mixture as they help to overcome the daily phosphorus requirements which are not fully filled through conventional low-quality dietary feedstuff. The objective of this article is to explore the physiological significance of faster availability and absorption of phosphorus in ruminants.

Source of phosphorus, its distribution in feedstuff and phosphorus absorption coefficient of different feedstuff

The different chemical forms of phosphorus found in the feedstuff, are inorganic phosphate (chemically solubilise), organic phosphate (release of phosphorus by digestion of organic matter for example phosphorus in nucleic acids, in lipids, phytate phosphorus (released in rumen by specific hydrolysis reaction catalyzed by phytase enzyme). Plant species, stage of maturity, soil fertility, climate, and fertilization are responsible for variable levels of phosphorus in crops and forages. Tropical grasses have low phosphorus contents than temperate grasses, and mature forage has lower phosphorus contents. The average phosphorus content of grain is 3.5-4.5 g/kg dry matter which is 3-4 times more than straw. Forage and mineral supplements contain phosphorus in a partially inorganic form. The organic portion includes phytate phosphorus as well as phosphorus contained in plant molecules such as nucleic acids, phospholipids, etc. The feedstuffs have variable proportions of the different forms of phosphorus. For example, grains as well as their by-products contain 50 to 70% phosphorus in the form of phytate phosphorus, 20 to 30% as phospholipids, phosphoproteins, and nucleic acids and 8 to 12% as inorganic phosphorus. In general, concentrate containing grains and high proteins contain more phosphorus than forages and low protein feeds. Fodder grown on soils deficient in phosphorus have lower phosphorus content than those grown on phosphorus-rich soils. Phosphorus frequently has been added to forage and grain-based ruminant diets in the form of mineral supplements, such as monosodium phosphate, dicalcium phosphate, phosphoric acid, or bone meal.

Table 1: Phosphorus absorption coefficients of different feeds utilisation [3-6]

Sr. No.	Feed Type	Coefficient of phosphorus absorption	Sr. No.	Feed Type	Coefficient of phosphorus absorption
01	Alfalfa hay.	55%	07	Corn gluten.	70%
02	Hay diet.	60%	08	Dicalcium phosphate.	75%
03	Forages.	64%	09	Corn silage.	75%
04	Concentrates.	70%	10	Bone meal.	80%
05	Silage-based diet.	70%	11	Monosodium phosphate.	90%
06	Cereals and cereal by-products.	70%	12	Wheat bran.	90%

Phosphorus requirements of ruminants

Ruminants require phosphorus for maintenance and production (lactating, pregnant, and beef-purpose ruminants). The phosphorus requirement for maintenance is directly related to dry matter intake. The phosphorus requirement of lactating ruminants collectively includes the sum required for maintenance, growth, pregnancy, and milk production. The requirement of absorbed phosphorus for growth is equal to the phosphorus deposited in the body during growth. The absorbed phosphorus requirement in ruminants is 7.3 gm per 100 kg body weight per day for growth. The requirement for absorbed phosphorus for milk production equals the amount of phosphorus secreted in milk (1 gm per liter of milk). Most lactating dairy cows can meet their phosphorus requirement with diets containing 0.32 to 0.38% phosphorus on a dry matter basis. Dry cows need about 0.22 to 0.26% dietary phosphorus. Many lactation diets formulated for high-producing cows contain 0.35 to 0.40% phosphorus before phosphorus supplementation.

Table 2: Species and physiological states affect on the efficiency of dietary phosphorus absorption [7].

Sr. No.	Species	Period	Coefficient of phosphorus absorption.
01	Sheep.	Growth	0.72
		Maintenance	0.71
		Pregnancy	0.56
		Lactation	0.71
02	Cattle.	Growth	0.76
		Maintenance	0.42
		Lactation	0.69
03	Goat.	Growth	0.87
		Lactation	----

Absorption, metabolism, and excretion of phosphorus in ruminants

In ruminants, absorption of phosphorus depends on the ability of the animal to convert organic phosphorus into an inorganic form or more acceptable organic form. Rumen microbial phytase helps in the hydrolysis of the phytate form of plant phosphorus into inorganic phosphorus, which is absorbed rapidly. Organic phosphorus which is not hydrolyzed in the rumen becomes soluble in the low pH of the abomasum [8] [9]. In the case of heat-treated or formaldehyde-treated seeds, microbial phytase activity get decreased hence, there is a saturation of phytate phosphorus in the rumen [10]. Absorption of phosphorus mainly depends on its solubility at the point of contact with the absorbing membranes. The Duodenum and jejunum of the small intestine are primary sites for the absorption of phosphorus [9], but the relationship between phosphorus intake and phosphorus absorption is still inconclusive whether it is curvilinear or inverse relationship. A very little amount of phosphorus is absorbed from rumen, omasum and abomasum which still need to be researched thoroughly [8]. Phosphorus absorption mainly takes place in two ways depending upon the availability of phosphorus in diets, when dietary phosphorus is low, a Vitamin D-driven active transport system work for maximum absorption of phosphorus while passive transport of phosphorus is in the picture when the diet has abundant phosphorus.

The kidney excretes excess inorganic phosphate liberated during the resorption of bone tissue or formed in the process of the exchange. The kidney is the main organ for the excretion of phosphorus in young ruminants (during the first two weeks of their life) while in adult ruminants nearly all phosphorus is excreted through faces. In the case of dairy cows, 58% of ingested phosphorus is excreted in faeces, 0.44% in urine, and 40% in milk. Mainly three fractions are excreted in faeces, dietary phosphorus which is not absorbed, phosphorus excreted under actual nutritional and physiological conditions which are endogenous in nature, and endogenous phosphorus excreted to maintain homeostasis [11]. Salivary glands of ruminants secrete enormous amounts of phosphorus which is sometimes more than the total amount of endogenous phosphorus excreted in faces.

Factors affecting absorption of phosphorus in ruminants

The various factors which affect the absorption of phosphorus mainly include animal physiology, functional variability within the species, animal-to-animal variation, according to their sex, age, disease conditions, availability of vitamin D, type of feed, amount of phosphorus in diets, dietary ratio of phosphorus with other nutrients and minerals etc. The acidic pH of intestine supports the maximum absorption of phosphorus. Ruminants absorb more phosphorus as compared to simple stomach animals due to the presence of microbial phytase enzymes in the rumen. Genetic factors are also involved in the absorption of phosphorus which can vary among the animal of the same species [12]. Female ruminants require more phosphorus for the maintenance of pregnancy and milk production hence absorption of phosphorus in females surpasses the absorption of phosphorus in males. In young ruminants' the absorption coefficient of phosphorus is 80 to 100% while in adult ruminants it is 50 to 60%. Various pathological conditions of the digestive tract, and deficiency of vitamin D affect the absorption of phosphorus. Dry feed decreases phosphorus absorption. Monosodium phosphate, wheat bran, bone meal, and corn silage has maximum phosphorus absorption coefficient compared to hay, forages, cereals etc. Addition of heat-treated or formaldehyde-treated seeds in diets, phosphorus absorption decreases due to low phytase activity. If diet has plenty of phosphorus, its absorption is saturated and remained phosphorus get excreted in faeces while a diet containing limited amount of phosphorus, almost all absorbable form of phosphorus gets absorbed. However, maximum microbial synthetic and degradative activities can be maintained if ruminal inorganic phosphorus levels are at least 75-100 mg/L. For effective absorption of phosphorus calcium to phosphorus ratio in diet should be 2:1, if ratio increases phosphorus absorption gets hampered. If the energy and protein content of diet are low then absorption of phosphorus is minimum and vice versa. Excessive aluminium, iron, and molybdenum in diets decrease the absorption of phosphorus [18]. For faster availability of phosphorus to ruminants above factors should be managed in such a way that there should be maximum absorption of phosphorus and minimum loss in faecal excretion.

Phosphorous distribution in ruminant's body and its metabolic role in ruminants

In the case of ruminant body, about 80% of the phosphorus resides in bones and teeth [11] and 20% actively participates in numerous functions throughout the body [8]. Less than 1% of body phosphorus is in the blood. Blood serum contains 1.3 to 2.6 mM phosphorous in inorganic form. Mostly phosphorus resides in cells of blood and whole blood phosphorus level is 350-450 mg/L. The concentration of phosphorus in the blood cell of cattle is 78 mg/dL hence blood contains 6-8 times more phosphorus than plasma [11]. The salivary gland also concentrates phosphorus 3-4 times in comparison with plasma inorganic phosphorus [8]. Ruminal fluid has 200-600 mg/L phosphorus levels. The bone acts as a storehouse of phosphorus in the body, and from this, as much as 30% of bone phosphorous can be mobilized in lactating beef cows to meet phosphorous needs in early lactation [14]. Based on this estimate for beef cows, a dairy cow weighing 600 kg could mobilize approximately 1000 g of bone phosphorus in early lactation. Phosphorus mobilized from bone would need to be restored in later lactation, but the sizeable bone reserve provides a buffer against short-term P deficiencies. Phosphorus metabolism in ruminants and non-ruminants differs somewhat. Ruminants secret large amounts of inorganic phosphorous in saliva which acts as a buffer to maintain ruminal fermentation. Salivary inorganic phosphorus is mainly reabsorbed from the small intestine and again recycled to the salivary gland for further secretion. Adult cows will secrete 30 to 60 g of salivary phosphorus per day into the rumen [8], which is equal to an amount 50 to 75% of daily phosphorus intake. In ruminant phosphorus absorption mainly take place in the small intestine. Transport across the gut consists of both an active saturable and a passive non saturable component [8]. The active form of vitamin D (1,25-dihydroxycholecalciferol) is essential for the active portion of phosphorus transport. In addition, parathyroid hormone along with calcitonin are responsible for regulating phosphorus absorption and phosphorus homeostasis in ruminants. Predominantly passive absorption takes place when ruminants consume high amounts of absorbable phosphorus. A high amount of phosphorus is excreted in faeces as well as in urine in non-ruminants while in ruminants, normally > 95% of the phosphorus is excreted in faeces, with perhaps 25 to 50% of faecal phosphorus contained in microbial residues originating from gut fermentation activity [15]. With high dietary phosphorus, however, some animals will excrete more phosphorus in urine [15]. Also, high-concentrate diets, typical of those fed to feedlot cattle, can result in elevated urinary phosphorus concentrations [14], and in some cases, urinary excretion of phosphorus can equal faecal excretion.

Deficiency of phosphorus in ruminants

Of all the mineral deficiencies in cattle, the deficiency of P is the most common one on a global level. Deficiency of phosphorus causes many physio-pathological derangements in ruminant, like weight loss, poor body condition score, poor feed conversion ratio, low bone density i.e bone become brittle, poor fertility rate or infertility (in long-standing case), postparturient haemoglobinuria, phosphorus deficiency haemoglobinuria, pica, allotriophagia, osteophagia, sarcophagia, Peg-leg, rupturing of Achilles tendon in young bulls etc. Subclinical deficiencies of phosphorus are associated with reduced milk production, energy-deficient reproductive problems, deprived appetite etc. The diet containing extremely low phosphorus content may be responsible for inhibition of microbial growth in rumen leads to reduced digestibility of rumen content. When body needs phosphorus, in absence of dietary phosphorus animal body mobilizes 30% phosphorus from bone to meet out the deficiency of phosphorus. But, in pregnant and lactating cattle the further deficiency may leads to reduced calf body weight, underdeveloped calf and reduced milk production is there. Ruminants having the lowest dietary phosphorus also had the lowest first-service conception rates. Extremely low dietary phosphorus can inhibit microbial growth, leading to reduced protein and energy supply to the ruminants which further influence reproductive performance. In case of acute phosphorus deficiency stiffness of muscle is there along with lameness.

Effect of faster bioavailable phosphorus on milk production in ruminants

Constant supply of faster bioavailable phosphorus maintains constant and prolonged milk production in lactating ruminants as well as it also maintains cow health, or body condition score. Moderate to high milk-producing cows require minimum 0.30% of phosphorus in their diet [16], [2], [15], but to maintain 10 to 20% margin of safety according to National Research Council [11] we add 0.32 to 0.38% dietary P, depending on the level of milk production. The current NRC recommendations for early to mid-lactation diets are 0.36% phosphorus (on dry matter basis) for cows milking 45 kg/day and 0.35% phosphorus for cows milking 35 kg/day. A dairy cow weighing approximately 600 kg could mobilize 600 to 1000 g of phosphorus during the first few weeks of lactation to compensate for such huge phosphorus requirement in them we need faster bioavailable phosphorus. In average to high-producing cow phosphorus deficiency symptoms are not likely to be observed until dietary phosphorus concentration is reduced to approximately 0.31% of diet on dry matter basis [2] [15]. The NRC (2001) [11] suggests feeding a slightly higher instant available dietary phosphorus concentration during the first several weeks of lactation to avoid deficiency of phosphorus as well as to maintain margin of safety. To restore the phosphorus mobilized from bone during early lactation, elevated levels of instantly bioavailable phosphorus should be incorporated in diets of early lactating animals. Feeding of phosphorus in excess of 0.37% of diet (on dry matter basis), an amount corresponding closely to NRC (2001) [11] phosphorus requirements, did not affect milk production, milk composition, or animal health as well as will not increase milk production. Though milk composition was not affected by dietary phosphorus content. There have been reports of reduced protein content of milk with low dietary content [17]. Since phosphorus is part of the casein micelle [18], blood serum phosphorus concentration could influence milk protein content. So, we need instantly bioavailable phosphorus to maintain constant milk production in ruminants.

Effect of faster bioavailable phosphorus on reproduction in ruminants

The deficiency of phosphorus or its level below the normal level in blood severely impairs the reproductive performance of ruminants like very low conception rate, irregular oestrus cycle, subnormal functioning of the reproductive tract, aberrations in ovulation and fertilization as well as depression in feed intake, especially during late lactation and early pregnancy [19]. It also responsible for lighter birth weight as well as the weaning weight of the calf. Low body mass, lesser viability, and high mortality rate in newborn calf and weaned calves can be overcome by providing faster available phosphorus to ruminants. The mortality rate per year increased at an increasing rate in the phosphorus deficiency, indicating a more rapid deterioration in the condition of the cattle with increasing age and by a prolonged deprivation of phosphorus. The anorexia in cattle due to reduced phosphorus may be related to decreased microbial digestion caused by poor availability of phosphorus for the rumen micro-organisms resulting in depressed feed intake, resulting in stunted growth, high mortality rates and very poor reproductive performance. Besides these intraluminal effects, the stiff-legged gait, which is one of the characteristic symptoms of aphosphorosis, severely impaired locomotion and therefore grazing behaviour and probably feed intake. Perhaps a more often cited reason for not reducing phosphorus to NRC (2001) [11] requirement amounts is concern about the reproductive performance of cows fed reduced dietary phosphorus. While there is ample evidence [19] that feeding of extremely low dietary phosphorus can impair reproductive performance, there is no suggestion in the literature that feeding performance in excess of current NRC (2001) [11] recommendations will improve reproductive performance.

Physiological significance of faster availability and absorption of phosphorus in ruminants

The feed designed with proper ratio of phosphorus with other minerals and nutrients as well as addition of phosphorus supplement with high absorption coefficient leads to faster availability of phosphorus to ruminants via oral route. Also, we can administer phosphorus to ruminants by intravenous, intramuscular and subcutaneous routes for its faster availability. Due to instantly available phosphorus (along with balanced diets) animal body maintains bone reservoir, bone strength, muscle tone, constant milk production, proper body growth, proper fetal growth, and higher reproductive performance, animal can be recovered easily from phosphorus deficiency disorder as mentioned earlier. Besides this, a constant regular supply of instant phosphorus seen beneficial in pregnant and lactating ruminants. Instant phosphorus supply increases conception rate at first artificial insemination, overcoming subnormal fertility, depressed or irregular oestrus and delayed conception in cattle. Also, it helps in gaining desirable body weight along with proper growth rate in post-weaning calves, increases survival rate, and overcomes pica and inappetence in them.

Conclusion

The faster availability and absorption of phosphorus helps to overcome the phosphorus deficiency disorders in ruminants, it also overcomes problem-related to subclinical phosphorus deficiency like inappetence, and reduced milk production, also animal body maintains bone reservoir, bone strength, muscle tone, constant milk production, proper body growth, proper fatal growth, higher reproductive performance. In case of post-weaning calf instant phosphorus availability helps in proper growth rate, and increased survival rate.

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