SYMPOSIUM

Minimum phosphorus requirements for laying hen feed formulations

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ABSTRACT The objective of this contribution was to summarize from scientific literature the optimal concentration of nonphytate phosphorus (**NPP**) in feed for laying hens. The considered studies were one meta-analysis from 2012 and original studies published since then. Dietary treatments in the studies included variation in supplementation with mineral P sources and phytase. The studies investigated different periods of production and varied in duration but data were insufficient to analyze such factors in a systematic way. No study showed a positive effect on performance and eggshell when the NPP concentration was increased above 2.2 g NPP/kg of feed without the use of phytase. At such level, no consistent impairment of various bone quality traits were found but only few studies on bone quality traits were published. Overall, the data suggested that not more than 2.2 g NPP/kg of feed is needed for laying hens in different stages of production. This value can be reduced when phytase is added to the feed. Such reduction may differ depending on factors such as phytate content of the feed and phytase dosage. However, data are insufficient for calculating precise values of reduction. While phytate degradation in laying hens was markedly increased by phytase supplementation in several studies, effects of phytase supplementation on performance and bone traits in laying hens were less conclusive probably because the hens were supplied more than their NPP requirement. Transition to a system based on digestible P for laying hens similar to broiler chickens may support more precise P nutrition and more sustainable egg production in the future.

Key words: laying hen, phytate, phytase, dietary allowances, review

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INTRODUCTION

Laying hens depend on the continuous supply of phosphorus (**P**) in their diets; however, there are differing perspectives on the dietary P requirements for hens as well as optimal dietary P allowances. Feed phosphates are costly. The rock phosphates from which they are derived from are scarce, and P-rich animal proteins are not approved in several regions globally. Moreover, excessive P excretion from animals can harm surface water bodies. Considering this, although hens must be given an adequate amount of dietary P to support their health and productivity, a threshold should be set to avoid oversupply of P. The objective of this contribution was to summarize the outcome of recent studies to identify optimal dietary P levels for laying hens.

One reason for differing views on P requirements is the choice of response traits. Egg laying performance, egg/feed ratio (g/g), and eggshell quality change in response to inadequate P supply within a few wk. However, a mild P undersupply may not affect performance traits during a period of several months because P is mobilized from the skeleton. This increases the risk of hens developing bone disorders over the course of the laying period (Whitehead, 2004) and highlights the necessity of bone development being considered in requirement studies. Perspectives on P requirements also differ due to the varying means of characterizing P: total P, nonphytate-P (**NPP**), available P (which is often used erroneously as synonymous with NPP), digestible P, and retainable P, amongst other (Shastak and Rodehutscord, 2013). These differing P requirement values are based on different quantitative and qualitative experimental and analytical techniques, jointly leading to different conclusions regarding the amount of P in the feed that can be utilized by the bird (WPSA, 2013). Consequently, a standard protocol of P evaluation has been suggested for broilers using digestible P (WPSA, 2013). While broiler chickens have a high potential for utilization of phytate-P owing to endogenous phytase activity (Rodehutscord

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et al., 2022), phytate-P disappearance results indicate that such endogenous potential is low in laying hens (Van der Klis et al., 1997; Marounek et al., 2010). Few studies have reported the effects of different mineral NPP sources on performance, while seemingly no digestibility or availability studies in hens have been conducted. This may be the reason that most studies published on laying hens refer to the supply of NPP and do not consider P digestibility or bioavailability. Therefore, this manuscript refers to NPP due to its significance in the literature. Transition to a digestible P system in laying hens is suggested after more P digestibility data for raw materials are available.

ESTIMATES BASED ON PERFORMANCE TRAITS

A meta-analysis of 14 feeding trials with laying hens fed corn−soybean meal-based diets that were published between 1999 and 2011 indicated that an NPP concentration of 2.2 g/kg of feed without exogenous phytase was adequate to maintain high egg production, egg mass, and egg/feed ratio (Ahmadi and Rodehutscord, 2012). When exogenous phytase was considered in the statistical model, the predicted optimal NPP concentrations were 1.8 g/kg of feed (at 150 FTU/kg) and 1.5 g/kg of feed (at 300 FTU/kg). Phytase supplementation exceeding 300 FTU/kg of feed was not found to have additional beneficial effects. In the underlying trials, hens between 36 and 76 wk of age were observed for a period of 12 wk or longer in the majority of trials except 1 trial that spanned 8 wk.

Studies published since then have generally confirmed these estimates of NPP requirement for laying performance, although some have suggested a lower requirement. When studied from 30 to 70 wk of age, laying hens did not exhibit differences in laying performance or egg/feed ratio when the NPP concentration was reduced from 3.6 to 2.2 g/kg of feed (Bello and Korver, 2019). Similarly, in younger hens investigated from 25 to 37 wk of age in two phases, NPP reduction from 4.5 to 2.2 g/kg (phase 1) and 3.8 to 1.9 g/kg of feed (phase 2) had no negative effect on performance traits (Pongmanee et al., 2020). However, a reduction from 3.4 to 1.7 g NPP/kg of feed, significantly reduced egg production in 26 to 36-wk-old hens (Wei et al., 2022). In older hens (68−78 wk), egg production and egg/feed ratio were not impaired by a reduction to 2.1 g NPP/kg of feed, but egg production was significantly reduced at 1.6 g NPP/kg of feed (Bello et al., 2020). In the very early phase of the laying period (22 to 34 wk), including graded levels of monocalcium phosphate in the feed of laying hens did not induce significant changes (Jing et al., 2018). The authors took this as an indication that 1.5 g/kg of feed NPP was adequate to maintain health and performance of laying hens in their study. This is not consistent with the other studies mentioned earlier. The ingredient composition of the feed perhaps led to differences in estimated minimum NPP requirements among the studies because different P fractions can contribute to the NPP in plant feed ingredients and may also have variable P digestibility. Another possible reason is the age of the birds. In hens older than 70 wk, Boling et al. (2000) reported a decrease in egg production due to ‘available’ P reduction from 4.5 to 1.0 g/kg of feed within 3 wk, whereas in hens starting low-P feeding at 18 wk of age showed the first signs of deficiency after 8 wk. In another study, first-cycle hens required approximately 1.8 g NPP/kg of feed, and molted hens in their second cycle had a requirement that was greater than 2.0 g NPP/kg of feed (Snow et al., 2004). The authors speculated that this was due to a decrease in P utilization or depletion of body P stores in older hens. However, it remains unclear why the NPP requirement may be higher for second-cycle hens compared to first-cycle hens.

EGGSHELL QUALITY TRAITS

Eggshell quality traits were not affected when the NPP concentration was reduced from 3.6 to 2.2, 2.1, or 1.9 g/kg of feed in 25 to 78 wk-old hens, but were impaired in some experimental periods when NPP was reduced from 3.1 to 1.6 g/kg of feed in 68 to 78 wk-old hens (Bello and Korver, 2019; Bello et al., 2020; Pongmanee et al., 2020). Negative effects on eggshell thickness and specific gravity were reported at NPP concentrations ≥3.5 g/kg of feed but not when NPP was reduced to 1.5 g/kg of feed in the period of 22 to 34 wk of age (Jing et al., 2018). The data do not indicate that NPP supply exceeding the requirement for laying performance increases eggshell quality, and in fact suggest a detrimental effect of excess NPP.

BONE QUALITY TRAITS

Reducing NPP in the feed from 3.6 to 2.2 g/kg of feed did not negatively affect tarsometatarsus, femur densities, mineral contents, and femur breaking strength in a feeding trial from wk 30 to 70 with laying hens (Bello and Korver, 2019). In a study on older hens (68−78 wk), a similar reduction of NPP concentration caused a mild but significant reduction of some femur density traits and mineral content (Bello et al., 2020). Such effects on the femur were stronger in that study when the NPP concentration was reduced from 3.1 to 1.6 g/kg of feed. Moreover, in a study with younger hens aged 25 to 37 wk, significant decreases were reported in mineral density, mineral content, and cross-sectional areas of the proximal metaphysis when NPP was reduced from 3.8 to 1.9 g/kg of feed (Pongmanee et al., 2020). Tibia measurements, such as those of ash and mineral content, and mineral density were not affected by graded supplements of monocalcium phosphate to a basal diet that contained 1.5 g NPP/kg of feed that was fed from wk 22 to 34 (Jing et al., 2018). However, from the data presented in that study on the amount of P contained in excreta and eggs, a mobilization from the body of approximately 40 mg P/d was calculated without consistent differences between NPP concentrations of the feed. Keel bone damage in laying hens increased overall throughout the period from 24 to 36 wk of age, but when the NPP concentration was 1.7 g/kg of feed, instances of damage were more frequent and the keel bones became shorter with less mineral density compared to 3.4 g NPP/kg of feed (Wei et al., 2022). As only 2 NPP concentrations were used in that study, an optimum concentration to avoid keel bone damages specifically related to P supply could not be derived.

PHYTASE SUPPLEMENTATION EFFECTS

When laying hens were fed corn−oat−soybean meal-based diets with graded levels of monocalcium phosphate, almost all phytate-P contained in the feed was excreted by the hens independent of the P concentration of the feed (Jing et al., 2018). Consistent with this result, *myo*-inositol hexakisphosphate ($InsP_6$) concentrations in the small intestine digesta of laying hens were not affected by the P and Ca concentration of the feed (Sommerfeld et al., 2020). A marked increase in prececal and total tract $InsP_6$ degradation in hens from a level of approximately 20% to a level of 50 to 83% was found upon supplementation of phytase to the complete feed (Van der Klis et al., 1997; Agbede et al., 2009; Siegert et al., 2022). Phytase supplementation effects were also investigated using single ingredients as the only source of P in the diet (Leske and Coon, 1999). Upon supplementation of 300 FTU/kg phytase, $InsP_6$ degradation measured in excreta increased from 26 to 62% in soybean meal, 23 to 52% in corn, and 4 to 51% in rice bran. In the gizzard and ileum digesta of hens, concentrations of *myo*-inositol were significantly higher, and those of $InsP_6$ and $InsP_5$ were lower when wheat-based diets were supplemented with 1,500 FTU/kg phytase (Taylor et al., 2018). These authors did not report prececal $InsP_6$ degradation; however, prececal P digestibility was increased from 39 to 70% by 1,500 FTU/kg phytase. Phytase supplementation significantly increased the prececal P digestibility in laying hens from a level of approximately 40 to approximately 60% depending on the dose of the enzyme (Bello and Korver, 2019; Pongmanee et al., 2020), but such an effect was not associated with differences in any performance trait and was not consistent with bone traits, indicating that NPP supply of the hens was high enough in the diet without phytase. In another study on older hens (68−78 wk) that found negative effects of NPP reduction, phytase supplementation alleviated the observed negative effects on performance traits and most of those on studied bone traits (Bello et al., 2020). While the effects of phytase supplementation on $InsP_6$ degradation and P digestibility in laying hens are well documented, the effects of phytase supplementation on performance and bone health are likely to be observed only when the NPP concentration of the feed is below the hen's requirement, (i.e., when there is no mineral P supplemented to the layer feed), and the activity of phytase can liberate phytate-P to contribute to the hen's requirement. In such low-NPP conditions, low levels of phytase supplementation (≤300 FTU/kg) were sufficient to maintain performance and bone data at the level of the control diet that contained mineral P (Francesch et al., 2005; Lei et al., 2011; Meyer and Parsons, 2011).

EFFECTS OF CALCIUM CONCENTRATION OF THE FEED

Most studies used to estimate the NPP requirement had a calcium (**Ca**) concentration of the feed in the range of 35 to 40 g/kg of feed. Of note, Ca concentrations higher than this range may cause an increased NPP requirement of laying hens. In the study by Fernández et al. (2019), the estimated NPP requirement of hens was higher than 2.2 g/kg of feed when the feed contained 42 g Ca/kg of feed. Phytase supplementation effects on $InsP_6$ degradation were lower at a Ca concentration of 40 g/kg compared to 30 g/kg of feed (Van der Klis et al., 1997). Accordingly, in a diet with 41 g Ca/kg of feed and 150 FTU/kg, 2.1 g NPP/kg of feed was found to be sufficient for performance and bone ash (Englmaierová et al., 2014).

To conclude, the literature surveyed herein indicates that an NPP concentration of 2.2 g/kg of feed in diets without phytase and 35 to 40 g Ca/kg of feed is adequate to maintain laying performance of laying hens throughout the laying cycle. With phytase supplementation, NPP concentrations can be reduced up to the complete omission of mineral P depending on the phytase dose. At such levels of NPP and Ca, negative effects on bone health and eggshell quality are unlikely to occur.

DISCLOSURES

Authors declare they have no conflict of interest.

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