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Available phosphorus in poultry. 1. Effect of phosphorus levels on the performance of laying hens and their egg quality, hatchability, bone analysis and strength in relation to calcium and phosphorus in blood plasma

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Summary

Medium heavy layers were housed in individual cages with a constant environment, 432 hens in all. Each group was of 36 hens with 2 replicates. Six diets containing 0.16, 0.20, 0.40, 0.60, 0.80 and 1.00 % available phosphorus were formulated. The simplified low phosphorus basal diet was analysed to contain 0.36 % total phophorus, of wich calculation showed 0.16 % to be available.

1. Egg production was significantly affected by the several phosphorus levels. The highest production was with 0.20 and 0.40 %; the lowest production with 0.16 %.
2. Food consumption did not differ significantly among the six levels of phosphorus.
3. Egg weigt showed a clear significant increase with increasing level of phosphorus: eggs were heaviest with 1.0 %.
4. Shell quality, determined as shell percentage, shell thickness and shell index showed significant depression with the increase in level of phosphorus. With the lowest level, 0.16 % shell quality was best.
5. Albumen and yolk indices, and hatchability did not significantly differ among the several phosphorus levels.
6. Calcium, phosphorus and ash in tibia of one-day-old chicks on a fat-free basis did not differ significantly with increasing phosphorus levels.
7. Calcium in blood plasma of the layers did not differ significantly but inorganic phosphorus in the plasma increased significantly with increasing phosphorus level.
8. Chemical analysis of the tibia of the layers for ash on a fat-free basis, calcium and phosphorus showed a clear significant increase with increasing phosphorus

level. Breaking strength of tibia related significantly to increasing level of phosphorus.
9. There was a clear relationship between inorganic phosphorus in plasma and phosphorus in tibia, between ash in tibia and phosphorus in tibia, between ash in tibia and breaking strength in tibia, and between inorganic phosphorus in plasma and ash in tibia.

Introduction

The quantitative requirements for phosphorus by laying hens have been studied by many research workers during the past fifty years. Factors which influence both the requirement and availability of phosphorus from feed sources and effect of deficiency and excess of dietary phosphorus on the laying hen continue to attract interest.

Singen et al. (1962) working with phosphorus levels from 0.2 % to 0.7 % in steps of 0.1 % found that the egg production was highest at 0.50 % total phosphorus (0.48 % available phosphorus), but there was no significant difference between 0.4, 0.5 and 0.6 %. However egg production was significantly depressed at 0.65 % available phosphorus. Walter & Aitken (1962) showed that egg production on a basal ration of 0.4 % total phosphorus was significantly lower than rations containing either 0.6 or 0.7 %. El Boushy (1974) reported that egg production was highly significantly improved with 0.8 % available phosphorus compared with 0.5 and 0.2 %. Taylor (1965) and Roland et al. (1976) indicated that egg production was not significantly affected by dietary treatments of phosphorus.

Singsen et al. (1962) and Walter & Aitken (1962) reported that egg weight was not influenced by phosphorus levels. Taylor (1965), Roland et al. (1976) and Ingram et al. (1976) concluded that the dietary phosphorus treatments had no significant influence on egg weight. On the other hand, El Boushy (1974) reported a significant difference between 0.2, 0.5 and 0.8 % phosphorus, showing that with 0.8 % eggs were heaviest for two breeds.

Hunt & Chancey (1970) and El Boushy (1974) presented data indicating that a diet low in phosphorus gave less food consumption than diets rich in available phosphorus. Several recent studies have also indicated that the dietary treatments of phosphorus had no significant influence on feed consumption (Roland et al., 1976; Ingram et al., 1976).

Crowly et al. (1961) noticed that the hatchability of fertile eggs was not significantly affected by the dietary treatments applied to the basal diet containing 0.41 % total phosphorus. Singsen et al. (1962) pointed out that hatchability was depressed with 0.2 % phosphorus, but was not affected by the other levels, 0.3 to 0.7 % phosphorus. Harms et al. (1964) demonstrated that addition of 0.35 % phosphorus to hen diets containing 0.34 to 0.39 % phosphorus significantly increased the hatchability of fertile eggs.

Harms et al. (1961) and Singsen et al. (1962) found that the phosphorus content of the diet did not affect egg shell quality as measured by thickness of egg

shells. On the other hand, Taylor (1965), Gerry & Bird (1967), Hunt & Chancey (1970), Singh et al. (1971), El Boushy (1974) and Charles & Jensen (1975) showed that lower levels of dietary phosphorus produced better shell quality.

Crowley et al. (1961) indicated that phosphorus did not affect egg quality measured in Haugh units. Hunt & Chancey (1970) showed that the albumen height (mm) was not affected by dietary treatments with phosphorus.

Singsen et al. (1962) indicated that hens fed on little phosphorus had less tibia ash than those fed more. Rowland et al. (1967, 1968) demonstrated that both tibia ash and breaking strength were related to bone strength, and that tibia ash was significantly increased with dietary phosphorus; similar increases occurred when the calcium level at each level of phosphorus was increased and breaking strength of the tibia increased with increases in bone ash. Waldroup et al. (1974) observed that dietary levels of inorganic phosphorus (0.12 to 0.52 %, with steps of 0.1 %) did not significantly affect breaking strength of bone.

Harms et al. (1962) working with one-day-old and one-week-old chicks found that tibia ash was significantly increased with dietary phosphorus. On the other hand, Harms et al. (1964) found that addition of 0.35 % phosphorus to hen diets containing 0.34 to 0.39 % phosphorus did not affect ash in tibia of one-day-old chicks, and that phosphorus content of the maternal diet did not affect mineralization of bones when chicks were fed on a phosphorus-supplemented diet.

Gardiner (1962) indicated that inorganic phosphorus in plasma of chicks and ash in bone responded closely to dietary phosphorus levels. El Boushy (1974) reported that phosphorus in blood plasma of laying hens was significantly affected by level of phosphorus in the diet. Recent studies by Reichmann & Conner (1977) demonstrated that dietary phosphorus at 0.45 or 1.42 % did not affect plasma calcium and increasing dietary phosphorus increased plasma phosphorus significantly.

In view of these contradictory observations, we studied the effect of several phosphorus levels in the breeder diet on the reproductieve performance and other characteristics of laying hens.

Materials and methods

A total of 432 laying hens of the same age and of medium heavy breed, a cross of three strains developed at the Department, were randomly distributed in individual cages in a house of a constant environment (10 °C, 80 % rel. humidity and 14 hours light). Each treatment comprised 36 hens replicated twice. The hens were divided into duplicated groups with 0.16, 0.20, 0.40, 0.60, 0.80 and 1.00 % available phosphorus.

The hens received the basal diet (Tables 1 and 2), which was a simplified basal diet low in phosphorus, analysed to contain 0.36 % total phosphorus, of wich 0.16 % was calculated to be available.

The experiment lasted 6 months; the first month after sexual maturity was for adaptation and no data were collected. Data were compiled on egg production on hen-day basis, feed consumption, egg weight, external and internal egg quality

Table 1. Composition of the low phosphorus basal diet for layers.

Ingredients	% (w/w)
Yellow maize	49.40
Barley	10.00
Soya bean oil meal (44%)	21.50
Lucerne meal (20%)	2.50
Dried whey (13%)	1.50
Hydrolysed animal fat	2.00
Iodized salt	0.50
Vitamin/mineral supplement (Farmix 10) *	1.00
Ground limestone (35%)	6.30
	94.70
Variables (Table 2)	5.30
Total	100.00
Calculated analysis	
Crude protein	15.80
Metabolizable energy (MJ/kg)	11.24
Fat	4.12
Crude fibre	3.70
Calcium	2.37
Total phosphorus	0.36
Available phosphorus	0.16
Methionine + cystine	0.54
Lysine	0.80

* Vitamin/mineral supplement (Farmix 10) contains per kilogram: 750 000 I.U. vitamin A; 150 000 I.U. vitamin D_3; 500 I.U. vitamin E; 0.1 g vitamin K_3; 0.4 vitamin B_2; 50 mg vitamin B_6; 1.4 g nicotenic acid; 0.5 g D. Pantothenic acid; 1 mg vitamin B_{12}; 17.5 g choline chlorid; 2 g Fe; 7 g Mn; 1 g Cu; 3 g Zn; 0.1 g I; 0.3 g Co.

Table 2. Experimental details of the variables for layers.

	1	2	3	4	5	6
Phosphorus available % [1]	0.16	0.20	0.40	0.60	0.80	1.00
Calcium %	3.70	3.70	3.70	3.70	3.70	3.70
Ca : P (available)	23.10	18.50	9.25	6.17	4.63	3.70
Basal diet	94.70	94.70	94.70	94.70	94.70	94.70
Calcium hydrogen phosphate dihydrate,[2] $CaHPO_4 \cdot 2H_2O$ (23.3 % Ca, 19 % P)	0.00	0.23	1.36	2.50	3.64	4.77
Ground limestone (35 % Ca)	3.80	3.70	2.90	2.10	1.30	0.50
Yellow maize	1.50	1.37	1.04	0.70	0.36	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1] Phosphorus availability is calculated according to the tables of Scott et al. (1976).
[2] Trivial name: dicalcium phosphate.

(one day's production per month), hatchability of fertile eggs (artificial insemination with pooled semen). Each month, all eggs produced during a 7-day period were incubated to determine hatchability. Blood plasma of the layers was analysed for inorganic phosphorus by the method of Gardiner (1962), and for calcium by the method of Fales (1953). Once a month, blood samples were drawn regularly after laying from 5 duplicated hens per group. Ash, calcium, phosphorus and breaking strength (Rowland et al., 1967; AOAC, 1970) of the right tibia of the layers were determined at the end of the experiment; 5 hens were duplicated per group. From the hatched chicks, 5 hens in 2 replicates per group were killed for estimation of calcium and phophorus in the plasma, calcium and phosphorus in the tibia, and ash on a fat-free basis by the methods of Gardiner (1962) and AOAC (1970).

All data were submitted to a factoral analysis of variance and when applicable, treatment means were separated by Duncan's multiple range test (1965).

Results and discussion

The results of the experiments (Table 3) clearly demonstrate that egg production showed a significant difference among the several levels of phosphorus. The highest production was with 0.20 % and 0.40 % phosphorus; low levels and high levels of phosphorus depressed egg production. Our results agree with the work

Table 3. The effect of phosphorus on reproductive performance and other characteristics of laying hens.[1]

	Available phosphorus (%)					
	0.16	0.20	0.40	0.60	0.80	1.00
Egg production (%) Hen-day basis	59.25^{a}	66.50^{b}	66.55^{b}	60.30^{a}	65.05^{b}	63.55^{ab}
Food consumption (g/day)	121.00	123.45	129.95	124.40	126.00	128.70
Egg weight (g)	59.920^{a}	60.115^{a}	60.720^{ab}	60.745^{ab}	61.050^{ab}	62.215^{b}
Shell (%)	9.340^{a}	9.125^{abc}	9.120^{abc}	9.000^{bc}	9.175^{ab}	8.900^{c}
Shell thickness (mm)	36.555^{a}	35.680^{ab}	35.910^{ab}	35.380^{b}	35.860^{ab}	35.315^{b}
Shell index[2]	0.3901^{a}	0.3810^{ab}	0.3821^{ab}	0.3762^{b}	0.3844^{ab}	0.3767^{b}
Albumen index	0.1090	0.1225	0.1205	0.1205	0.1125	0.1215
Yolk index	0.4005	0.4175	0.4170	0.4135	0.4040	0.4080
Hatchability of fertile eggs (%)	88.800	92.675	90.750	90.700	91.650	91.900
Ca in tubia of one-day-old chick (%)	33.200	32.850	32.050	33.250	34.300	34.005
P in tibia of one-day old chick (%)	18.10	18.10	18.35	18.15	18.45	17.95
Ash in tibia of one-day-old chick (%)	27.80	28.15	27.60	26.55	27.55	28.60

[1] Means with different subscripts are significantly different ($P < 0.05$).

[2] Shell index $= \left(\frac{\text{shell weight}}{\text{egg weight} - \text{shell weight}}\right)^{2/3}$

of Singsen et al. (1962) but contradict the work of Walter & Aitken (1962).

Table 3 shows that egg weight increased with phosphorus in diet, and that a phosphorus level of 1.00 % gave the heaviest eggs. Our results agree with the work of El Boushy (1974) and contradict those of Walter & Aitken (1962), Taylor (1965), Roland et al. (1976) and Ingram et al. (1976).

This increase in egg weight seems due to the decrease in egg production with the high level of available phosphorus.

Data on feed consumption are also presented in Table 3. The results did not differ significantly among the several levels of phosphorus. Our results agree with the work of Roland et al. (1976) and Ingram et al. (1976) and disagree with the work of Hunt & Chancey (1970) and El Boushy (1974).

The egg shell quality was measured by shell percentage, shell thickness and shell index; 0.16 % phosphorus produced significantly better shells than 1 %. The results therefore agree with those of Crowley et al. (1961), Taylor (1965), Gerry & Bird (1967), Hunt & Chancey (1970), Singh et al. (1971), El Boushy (1974) and Charles & Jensen (1975).

Albumen index and yolk index (Table 3) did not vary significantly with dietary phosphorus. Hunt & Chancey (1970) noted that the albumen height (mm) was not affected by dietary treatments of phosphorus. Quantitative comparison of our results with theirs was not possible.

Hatchability also failed to show significant differences among the several levels of phosphorus, but it was lower with less phosphorus (0.16 %). Our results agree with Singsen et al. (1962).

There were no significant differences in the Ca, P and ash in tibia of one-day-old chicks with phosphorus levels. Our results agree with the work of Harms et al. (1964). The carry-over from the maternal phosphorus depots does not seem to play much role in this matter.

Inorganic phosphorus in the plasma of the layers was highly significantly affected with each increase in dietary phosphorus, and it was related to the increase of phosphorus in the tibia as shown in Table 4, but calcium in the plasma

Table 4. The effect of phosphorus on blood plasma and tibia characteristics of laying hens[1].

	Available phosphorus (%)					
	0.16	0.20	0.40	0.60	0.80	1.00
Ca in blood plasma (%)	29.95	30.25	30.95	29.35	29.65	29.45
Inorganic P in blood plasma (%)	4.35^{a}	4.45^{a}	5.70^{b}	5.95^{c}	6.15^{d}	7.20^{e}
Ash in tibia (%)	63.60^{a}	64.65^{ab}	65.50^{bc}	66.20^{c}	66.30^{c}	67.50^{d}
Ca in tibia (%)	37.70	38.85	38.90	39.00	38.60	38.75
P in tibia (%)	16.10^{a}	17.35^{bc}	17.25^{b}	17.70^{cd}	18.10^{d}	18.95^{e}
Breaking strength of tibia (kgf)[2]	13.00^{a}	14.70^{b}	17.30^{c}	18.05^{cd}	19.20^{de}	20.30^{e}

[1] Means with different subscripts are significantly different ($P < 0.05$).
[2] 1 kgf ~ 9.8 N.

did not respond. Our results correspond to those of Gardiner (1962), El Boushy (1974) and Reichmann & Connor (1977).

Table 4 shows that ash, phosphorus and breaking strength of the tibia of laying hens increased significantly with increasing dietary phosphorus with clear relations between ash and phosphorus contents, and between ash and breaking strength of the tibia. Our work agrees with the work of Rowland et al. (1967, 1968).

Table 4 shows a clear relation between inorganic phosphorus in plasma and ash content of the tibia. Our results are similar to those of Gardiner (1962).

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