Comparative Studies with Three-Week-Old Chickens, Turkeys, Ducks, and Quails on the Response in Phosphorus Utilization to a Supplementation of Monobasic Calcium Phosphate[1]

M. Rodehutscord[2] and A. Dieckmann

Institut für Ernährungswissenschaften, Universität Halle-Wittenberg, 06099 Halle, Germany

ABSTRACT We studied whether the availability of P is different among poultry species. A basal diet was mixed mainly based on corn, potato protein, and dried egg white. It was calculated according to the recommendations for young turkeys with the exception of P and Ca concentrations, which were deficient. Monobasic calcium phosphate (MCP) was added in graded levels, and analyzed P concentrations in the 7 diets were (in g/kg of dry matter) 2.9, 3.7, 4.5, 5.3, 6.2, 7.2, and 7.7. Four experiments were conducted with 3-wk-old broiler chickens, turkeys, ducks, and quails. Birds were kept in balance crates, and 8 individuals were allocated to each treatment diet. Birds were fed the treatment diets for 10 d, and excreta were quantitatively collected during the last 5 d. P utilization was calculated as the proportion of P intake that was accreted by the birds. The P accretion response of birds to incremental MCP intake was described with sigmoidal functions, and the marginal efficiency of P utilization ($\Delta y/\Delta x$) was calculated. Utilization of P from the unsupplemented basal diet was 58% in broilers, 55% in quails, 46% in ducks, and 39% in turkeys. Supplementation of MCP significantly increased P accretion in all species. Ninety-five percent of the estimated y_{max} in P accretion was achieved with 8.4, 7.3, and 4.8 g P/kg of dietary DM in broilers, ducks, and quails. No plateau in P accretion was achieved in turkeys. These differences correlate well with the differences in the feed/gain ratio, which was 1.3 in turkeys, 1.7 in broilers, 1.9 in ducks, and 3.5 in quails. The maximum in marginal efficiency of supplemented P was 96% in ducks, 81% in turkeys, 74% in broilers, and 77% in quails. These maxima were achieved at different levels of MCP supplementation. We concluded that differences in P availability exist between poultry species for plant and mineral P sources. Quails can be used as model species for broilers in P availability studies, but dietary P levels need special adjustment.

(*Key words*: phosphorus, utilization, efficiency, comparison, bird)

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INTRODUCTION

With respect to the needs of the animals and the environmental load, poultry production systems in many countries aim to optimize the use of dietary P. Diet formulation should, therefore, consider 2 main criteria, namely the species-specific requirement for available P and the availability values for the most common feed ingredients. P availability varies widely, mainly depending on the proportion of phytate P (NRC, 1994). Inorganic phosphate supplements may be different in availability as well, which has been shown in broilers (De Groote and Huyghebaert, 1997; Leske and Coon, 2002), turkeys (Grimbergen et al., 1985; Sullivan et al., 1992), and ducks (Wendt and Rodehutscord, 2004a). To our knowledge, the availability of P sources in different poultry species has not been compared. This information is needed to decide to what extent results from one species can be applied to another.

The objective of the present study was to compare how broilers, turkeys, Japanese quail, and ducks utilize P from a plant-based low-P diet and how they respond to increments in phosphate supplementation. Japanese quail can be regarded as an important model because of their small body size, high rate of reproduction, and relative ease of maintaining the colony (Shim and Vohra, 1984). They have also been used to study P utilization (Dänner and Bessei, 2002). Therefore, a series of 4 experiments were conducted. In order to let birds express their capacities to use P, the focus was on the marginal range of P intake.

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[2]To whom correspondence should be addressed: markus.rodehutscord@landw.uni-halle.de.

Abbreviation Key: BD = basal diet; Eff_M = marginal efficiency of P utilization; MCP = monobasic calcium phosphate; UOM = unexcreted organic matter.

TABLE 1. Ingredient composition of the basal diet and analyzed concentrations

Ingredient (g/kg)	
Corn	610.2
Potato protein	200.0
Dried egg white	120.0
Premix[1]	15.0
NaCl	7.0
Soybean oil	5.0
L-Arginine	3.0
$CaCO_3$	1.6
Beeswax[2]	3.5
Sand[3]	34.7
Analysis (g/kg dry matter)	
Crude protein	361
Crude lipids	42
Lysine[4]	18.7
Methionine + cystine[4]	12.8
Ca	7.0
P	2.9

[1]Premix supplied the following according to the supplier (BASU-Mineralfutter GmbH, Bad Sulza, Germany) (per kg of complete diet): Ca, 4 g; vitamin A, 18,000 IU (retinyl acetate); cholecalciferol, 0.15 mg; vitamin E, 60 IU; vitamin K_3, 3.6 mg; thiamine, 3.2 mg; riboflavin, 10.8 mg; vitamin B_6, 6 mg; vitamin B_{12}, 0.034 mg, niacin, 99 mg; folic acid, 2.3 mg; biotin, 0.26 mg; Ca-D-panthothenate, 20 mg; choline chloride, 1.05 g; Cu, 15 mg; Zn, 90 mg; Fe, 75 mg; Mn, 120 mg; Co, 0.4 mg; I, 1.5 mg; Se, 0.05 mg.

[2]Beeswax was included to determine the recovery of its n-alkanes in excreta (not a subject of this paper).

[3]Sand was gradually replaced to adjust P and Ca contents in 6 other diets as described in the text.

[4]Calculated values.

MATERIALS AND METHODS

Diets

The same diets were used in all experiments. The basal diet (BD; Table 1) was calculated to be deficient in P and Ca but adequate in all other nutrients for 3-wk-old turkeys. Turkeys were taken as the reference because they need the highest nutrient concentrations among the species studied at this age (NRC, 1994). Diets were mainly based on corn. Potato protein and dried egg white were chosen as protein sources because they have a wide CP to P ratio. In 6 other diets, the P concentration was gradually increased by stepwise inclusion of monobasic calcium phosphate [MCP; $Ca(H_2PO_4)_2$] to the BD. A constant Ca:P ratio of 2:1 was intended as suggested by Wendt and Rodehutscord (2004a) in order to avoid any limitation in P accretion through the level of Ca supply. The Ca content was adjusted by variable inclusion of limestone ($CaCO_3$). MCP and limestone inclusions were varied at the expense of sand. All ingredients with the exception of the variable ones (sand, MCP, and limestone) were mixed in one batch to ensure uniformity of the mix. This mix was divided into 7 portions. Sand, MCP, and limestone were then added in the respective amounts. Diets were mixed again in a laboratory mixer and subsequently pelleted without using steam through a 3-mm die. The following supplementary levels of MCP (and limestone in parentheses) were applied in the supplemented diets (g/kg): 3.2 (2.3), 6.4 (4.9), 9.7 (7.5), 12.9 (10.1), 16.1 (12.7), and 19.3 (15.4). Analyzed concentrations (in g/kg of dry matter) for P were 2.9, 3.7, 4.5, 5.3, 6.2, 7.2, and 7.7 and for Ca were 7.0, 8.3, 9.8, 11.6, 14.4, 16.8, and 17.2. The calculated content of phytate P was 1.1 g/kg of diet.

Birds and Experimental Design

Four experiments were run subsequently, one with each species: male broiler chickens (Ross),[3] male White Pekin ducks (Stolle Seddin Vital),[4] male turkeys (British United Turkeys, Big 6),[5] and unsexed Japanese quail. The meat-type quails were from an experimental line that had been selected for 14 generations for high 35-d BW at our research center (Riegel et al., 2004). About 100 hatchlings of turkeys, ducks, and chickens were raised in floor pens with temperature and illumination according to the recommendations given for the respective species. For a pre-experimental period of 2 wk, they were offered ad libitum commercial standard starter feed for the respective species. The quails were raised in cages according to the standard at the research station (Riegel et al., 2004) and were fed a turkey starter feed until 14 d post hatch.

All experiments were conducted in the same way. They were approved by the animal welfare authorities in accordance with the German Animal Welfare Regulations. On d 14 post hatch, birds were selected from the total based on health appearance and average BW. They were moved into balance crates where they were kept individually. On d 16, birds were allocated to treatments (8 per treatment) and received their respective diet ad libitum until d 19. Then feed allowance was restricted to about 90% of the species-specific mean ad libitum intake in order to ensure that differences in P intake originated from the supplemented MCP only. The daily amounts offered in each pen in this period were 65 g for turkeys, 140 g for ducks, 85 g for broilers, and 28 g for quails. In spite of this restriction, voluntary feed intake was incomplete for some individuals occasionally, and these refusals were recorded. Feed was offered in 2 meals per day at about 0900 and 1800 h. From d 21 onward, excreta were quantitatively collected for 5 consecutive days. Excreta were collected from trays underneath the crates before the morning feeding time and bulk-stored at −18°C for each individual separately. Thawed excreta were thoroughly mixed, weighed, and analyzed for dry matter content. Excreta were freeze-dried and ground through a 1-mm screen prior to analysis. Body weights were determined when birds were allocated to the treatments as well as at the beginning and at the end of the excreta collection period. Table 2 depicts a summary of the experiments.

Chemical and Statistical Analyses

The contents of dry matter (105°C), crude nutrients, P, and Ca were determined in diets. Excreta were analyzed

[3]Geflügelhof Möckern, Möckern, Germany.
[4]Seddiner Zucht- und Mastenten GmbH, Westerscheps, Germany.
[5]Moorgut Kartzfehn, Bösel, Germany.

TABLE 2. Summary of details from the 4 experiments with growing birds

	Experiment (species)			
Item	Broilers	Ducks	Turkeys	Quails
Number of treatments	7	7	7	7
Number of replicates per treatment	8	8	8	8
Daily feed allowance, g/bird	85	140	65	28
BW at start of excreta collection on d 21, g/bird	838	1,309	608	194
BW gain during the collection period, g/d	49	73	49	8
Feed intake per BW gain	1.70	1.93	1.29	3.48

for dry matter, ash, P, and Ca. Total N (macro-Kjeldahl), crude ash, crude fat (petroleum ether extract), and crude fiber were determined according to official methods (Naumann and Bassler, 1976). Crude protein was calculated as N × 6.25. Organic matter was calculated as the difference between DM and crude ash. Dry samples of feeds and excreta were incinerated for 10 h at 550°C, following a pre-incineration at 250°C for 4 h. Ashes were weighed, and then minerals were solubilized with 10 mL of 6 *N* HCl. The solution was taken to dryness by heating in a sand bath, and this procedure was repeated with another 10 mL of 6 *N* HCl. Samples were subsequently heated for 5 min in a sand bath after addition of 10 mL of diluted HNO_3 and then filtered. Concentrations of P and Ca were determined with an inductively coupled plasma spectrometer[6] as the averages of measures made at wavelengths of 213.6 and 214.9 nm (P) and 393.4 and 396.9 nm (Ca). Diluted standard solutions[7] were used for calibration.

Accretions by birds of P and Ca (mg/d) were calculated as the difference between intake (mg/d) and the amount recovered in the excreta (mg/d). Utilization is the accretion as a percentage of intake. Unexcreted organic matter (UOM) is expressed as percentage of organic matter intake. Results were subjected to routine ANOVA procedures using the SPSS software package for Windows.[8] Responses in P accretion were described where possible with the following four-parameter logistic equation (Gahl et al., 1994):

$$y = \frac{y_{max} + [b \times (1 + c) - y_{max}]\, e^{-kx}}{1 + c \times e^{-kx}} \qquad [1]$$

where x = P content in the diet (g/kg of DM) or P intake (mg/d), y = P accretion (mg/d), y_{max} = asymptotic maximum response at infinite x, b = y-intercept or response to zero intake, c = parameter related to the inflection point or shape, and k = parameter related to the scale of the data.

In order to evaluate and compare the utilization of supplemented MCP depending on varying intake, the marginal efficiency of P utilization (Eff_M) was calculated. As suggested by Rodehutscord et al. (2003), this is defined as the increment in P accretion caused by each increment in P intake ($\Delta y/\Delta x$). It is reflected by the slope of the response curve for P accretion depending on P intake. This response was described by use of equation 1 and Eff_M was calculated based upon estimated parameters and the first derivative of equation 1, which is as follows (Gahl et al., 1996):

$$\frac{\Delta y}{\Delta x} = \frac{k\, e^{-kx}}{(1 + c\, e^{-kx})^2} \times (y_{max} - b) \times (1 + c). \qquad [2]$$

Regressions were calculated using GraphPad Prism 4.02.[9]

RESULTS

From the total of 280 birds, 2 broilers and 2 ducks had to be removed during the excreta collection periods and could not be considered in the data evaluation. In no case was the number of replicates per treatment less than 7. Turkeys that were fed the unsupplemented BD had increasing problems over time in standing and moving. Consequently, the collection period was finished after 3 d for 2 individuals and after 4 d for 5 individuals from this treatment. Apart from this, all trials were run as planned.

Data for accretion and efficiency of utilization of P and Ca are given for broiler chickens, ducks, turkeys, and quails in Tables 3, 4, 5, and 6. Utilization of P from the BD without any P supplementation was 58% (SE 3.2) for broilers, 46% (SE 1.6) for ducks, 39% (SE 1.7) for turkeys, and 55% (SE 2.2) for quails. The supplementation of MCP significantly increased P accretion in all experiments (Figure 1). Although within the range of supplementation a plateau in P accretion was not achieved with turkeys, a plateau became obvious for the other species. Ninety-five percent of the estimated y_{max} in P accretion was achieved with 8.4, 7.3, and 4.8 g P/kg of dietary DM in the studies with broilers, ducks, and quails. Among the MCP-containing diets, maximum utilization values for total P were determined between 61 and 66% (Tables 3 to 6). When P accretion (y) was plotted against quantitative P intake (x), equation 1 could be fitted for all species. Estimated parameters and goodness of fit are shown in Table 7. Based on these functions Eff_M was calculated with equation 2, and results are shown in Figure 2. Because feed intake was so different between species, the x-axis in Figure 2 is scaled to multiples of basal P intake. For broil-

[6]JY 24, Jobin Yvon GmbH, Grassbrunn, Germany.
[7]Certipur, Merck KG, Darmstadt, Germany.
[8]Version 11.0, SPSS Inc., Chicago, IL.
[9]GraphPad Software Inc., San Diego, CA.

TABLE 3. Means for intake, accretion, and utilization of P and Ca by broiler chickens 21 to 25 d of age fed increasing dietary P concentrations and percentage of unexcreted organic matter

	Dietary P concentration (g/kg of DM)								
Item	2.9	3.7	4.5	5.3	6.2	7.2	7.7	Pooled SEM	*P* (ANOVA)
Replicates, n	8	7	8	8	7	8	8		
Dry matter intake, g/d	69	76	77	77	77	74	77	0.8	0.022
P									
Intake, mg/d	203	281	352	409	479	540	598	18.3	<0.001
Accretion, mg/d	115	171	221	254	283	315	309	9.9	<0.001
Accretion/intake × 100	57.6	61.0	62.7	62.1	59.0	58.4	51.8	0.85	0.005
Ca									
Intake, mg/d	489	634	767	906	1,113	1,260	1,340	41.6	<0.001
Accretion, mg/d	151	244	313	370	386	446	449	16.1	<0.001
Accretion/intake × 100	32.7	38.5	40.8	40.8	34.7	35.7	33.5	1.08	0.196
UOM,[1] % of OM intake	77.6	77.7	78.2	78.9	79.7	81.2	80.3	0.26	<0.001

[1]UOM = unexcreted organic matter; OM = organic matter.

ers, ducks, turkeys, and quails, Eff_M showed maxima of 74, 96, 81, and 77%, respectively. According to the almost linear accretion response of turkeys over the entire range of supplementation, the maximum for turkeys was less pronounced than the maxima for the other species. Maxima were achieved at different levels of intake above the basal level.

According to the experimental design, Ca intake was increased together with P intake. Ca accretion was significantly improved with increasing intake in all species (Tables 3 to 6). In general, and as a consequence of the chosen Ca level in the diets, the level of Ca utilization was moderately low. It was highest in ducks, followed by quails, broilers, and turkeys. A quadratic response in Ca utilization to increasing intake is indicated by the data for broilers, ducks, and quails. Ca utilization continuously increased with intake in turkeys. Increments in Ca accretion were closely linked to increments in P accretion and constant within species, as indicated by strong linear relationships (Figure 3). The slopes were, however, significantly different among species, meaning that Ca and P were retained in different ratios.

Percentage UOM slightly (about 2 percentage units) but significantly ($P < 0.05$) depended on P intakes by broilers, ducks, and quails (Tables 3, 4, and 7) but not by turkeys ($P > 0.05$; Table 6). The average percentage UOM was highest in ducks (84%), followed by turkeys (81%), broilers (79%), and quails (78%).

DISCUSSION

The P content in the BD was made deficient for all species. The significant response in P accretion of all species to supplemented P confirms that this deficiency was achieved. About two-thirds of the P contained in the BD originated from corn. Of this, again about two-thirds are present as phytate (Eeckhout and De Paepe, 1994). The remaining P was provided by phytate-free potato protein and dried egg white. Hence, in comparison with corn-soybean meal-based diets that were often used as BD in P availability studies, the proportion of P contained as phytate was lower. This finding may be an explanation for the relatively high level of P utilization that we observed for the BD (49% on average). However, species were able to utilize P from the BD to a different extent. Broilers showed the highest P utilization (58%), followed by quails (55%), ducks (46%), and turkeys (39%). The following aspects may be relevant to explain these differences:

1. Different limitations in P absorption from the intestines between species. This appears unlikely, because with MCP supplementation all species still increased

TABLE 4. Means for intake, accretion, and utilization of P and Ca by Pekin ducks 21 to 25 d of age fed increasing dietary P concentrations and percentage of unexcreted organic matter

	Dietary P concentration (g/kg of DM)								
Item	2.9	3.7	4.5	5.3	6.2	7.2	7.7	Pooled SEM	*P* (ANOVA)
Replicates, n	8	7	8	8	8	7	8		
Dry matter intake, g/d	129	130	130	130	130	130	130	0.01	0.030
P									
Intake, mg/d	376	475	586	679	802	934	993	29.3	<0.001
Accretion, mg/d	172	266	361	441	525	583	574	20.5	<0.001
Accretion/intake × 100	45.7	56.0	61.6	65.0	65.5	62.4	57.8	1.05	<0.001
Ca									
Intake, mg/d	904	1,070	1,275	1,505	1,862	2,178	2,226	66.7	<0.001
Accretion, mg/d	371	567	720	868	1,022	1,088	1,068	36.6	<0.001
Accretion/intake × 100	40.9	53.0	56.5	57.6	54.9	49.9	48.0	0.99	<0.001
UOM,[1] % of OM intake	82.4	84.6	83.9	84.7	85.1	84.7	84.8	0.24	0.037

[1]UOM = unexcreted organic matter; OM = organic matter.

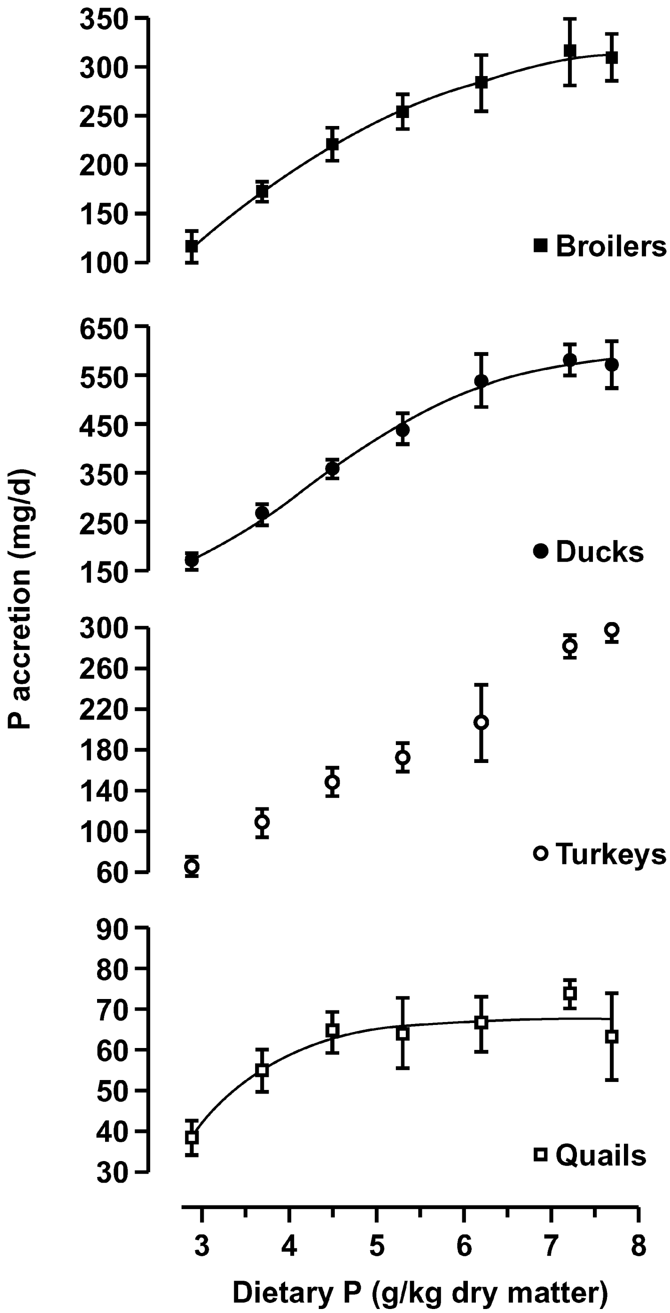


FIGURE 1. Phosphorus accretion responses of birds between d 21 and 25 of age to increasing dietary P concentrations (means and SD; n = 8). Note that the y-axis is scaled differently for each species. Equation 1 was fitted to the data, except turkeys, and the following parameters were estimated. Broilers: y_{max} = 340, b = –95.41, c = 3.212, k = 0.5516, r^2 = 0.92, and $s_{y.x}$ 21.7; ducks: y_{max} = 606, b = 67.41, c = 56.91, k = 0.9438, r^2 = 0.95, and $s_{y.x}$ 34.6; and quails: y_{max} = 67.5, b = –140.6, c = 3.641, k = 1.165, r^2 = 0.67, and $s_{y.x}$ 7.2.

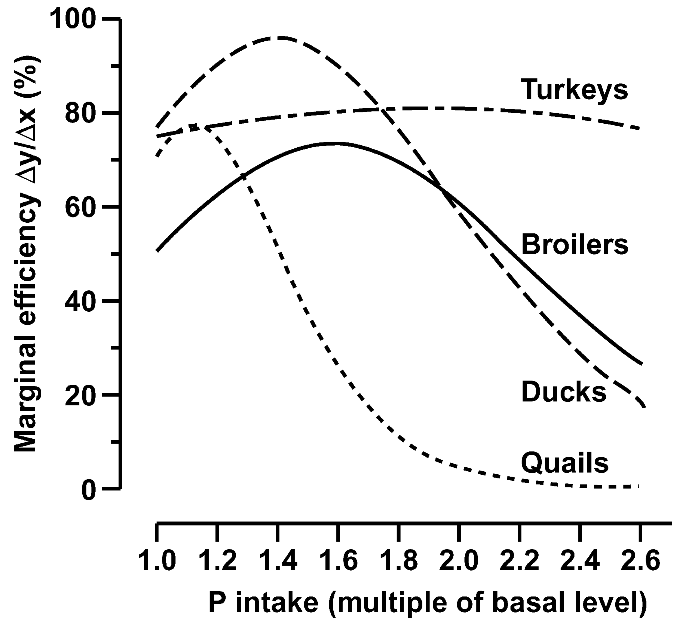


FIGURE 2. Marginal efficiency of P utilization (Eff_M) determined with birds 21 to 25 d of age. The curves show the first derivative (equation 2) of the functions for P accretion depending on P intake as given in Table 7. Because intake was different among species, intake is expressed here as a multiple of baseline intake in order to make data easier to compare. Baseline intakes were (in mg/d): 203 (broilers), 376 (ducks), 170 (turkeys), and 70 (quails) (Tables 3 to 6).

their percentage of P utilization. Furthermore, species with the lowest utilization of P from the BD were not the lowest in marginal efficiency of supplemented MCP.

2. Differences in the unavoidable P loss between species. The higher the unavoidable loss via faeces and urine at a given level of P intake is, the lower the value for P utilization is. Potential differences between species in unavoidable losses become more obvious as the dietary P level decreases. At present, the literature does not provide the data needed for a comparison of species with regard to unavoidable losses.
3. Differences in the ability to hydrolyze phytate, caused by 3 potential sources of phytase. First, even when corn has no detectable intrinsic phytase activity, very low activity may be contained (Eeckhout and De Paepe, 1994) that could be active in the gastrointestinal tract. Differences in the pH development along the tract, and in passage rate, may affect the efficacy of such plant phytase in the gut. In vitro studies have shown the dependency of different phytases upon pH and time of exposure to proteolytic enzymes (Simon and Igbasan, 2002). Second, the intestinal microflora may produce some phytase as indicated by comparative studies with chicken raised under conventional or gnotobiotic conditions (Kerr et al., 2000). Third, endogenous phytase activity was determined in small intestinal brush border membrane vesicles of broilers and laying hens (Maenz and Classen, 1998). In 1 out of 3 broiler experiments conducted by Applegate et al. (2003a), intestinal phytate hydrolysis has been correlated with intestinal phytase activity. We are not aware of studies on endogenous phytase activity in turkeys, ducks, or quails.

The range of data found in the literature for P utilization in 3-to-4-wk-old broilers is high (40 to 73%), even when only diets <5 g of P/kg of diet are considered (Van Der Klis et al., 1993; Broz et al., 1994; Mitchell and Edwards, 1996; Yi et al., 1996; Denbow et al., 1998; Li et al., 2000; Paik et al., 2000; Viveros et al., 2002). Diets in these studies

TABLE 5. Means for intake, accretion, and utilization of P and Ca by turkeys 21 to 25 d of age fed increasing dietary P concentrations and percentage of unexcreted organic matter[1]

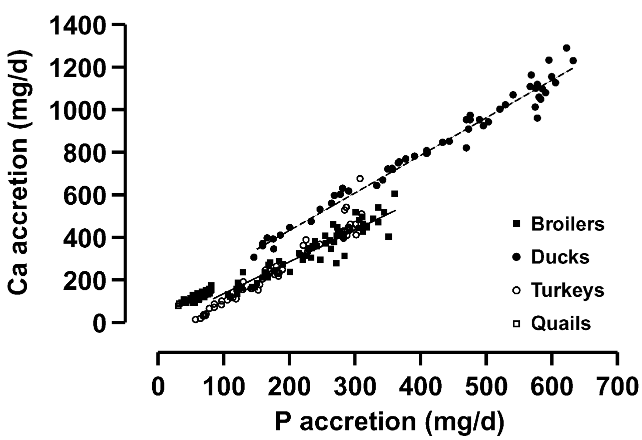
Item	Dietary P concentration (g/kg of DM)							Pooled SEM	*P* (ANOVA)
	2.9	3.7	4.5	5.3	6.2	7.2	7.7		
Dry matter intake, g/d	58	59	59	59	56	60	60	0.4	0.251
P									
Intake, mg/d	170	218	265	306	349	431	463	13.6	<0.001
Accretion, mg/d	66	109	148	173	206	282	297	10.9	<0.001
Accretion/intake × 100	38.9	49.9	55.7	56.3	58.8	65.4	64.2	1.24	<0.001
Ca									
Intake, mg/d	408	490	577	679	810	1,005	1,038	31.1	<0.001
Accretion, mg/d	66	116	164	218	298	434	465	10.9	<0.001
Accretion/intake × 100	6.1	23.6	28.2	31.9	36.1	43.2	44.9	1.79	<0.001
UOM,[2] % of OM intake	80.9	81.4	80.1	79.2	79.6	82.0	80.4	0.27	0.058

[1]n = 8 turkeys per treatment.

[2]UOM = unexcreted organic matter; OM = organic matter.

contained small amounts of P from nonplant sources. They were based mainly on corn and soybean meal and had no detectable intrinsic phytase activity. In face of this restriction, the range appears high. It may be caused by differences in diet composition, feeding regimen, age and breed of broilers, and other methodological details. The value measured herein for the BD with broilers (58%) falls within this range. As discussed earlier, it may be assumed that P contained in potato protein and egg albumen has high availability. With corn as the only dietary P source (1.7 g of P/kg of diet), Leske and Coon (1999) determined a P utilization of 34%. In the BD of our study, about two-thirds of total P originated from corn, and the rest was mainly from the protein sources.

In turkeys, the utilization of P from the BD was 39%. For turkeys that are about 3 wk old, P utilization efficiencies between 46 and 63% have been reported for low-P diets (lowest P level in each study; Qian et al., 1996; Juin et al., 2001; Li et al., 2001; Applegate et al., 2003b). Qian et al. (1996) recorded increased P utilization from 44 to 56% with a decreased Ca to P ratio from 2.0:1 to 1.1:1. P utilization efficiencies were 43 and 49% in 7- and 14-d-old turkeys in a study by Sanders et al. (1992). A P digestibility of 45% was measured by Grimbergen et al. (1985) at the terminal ileum of 6-wk-old turkeys. Although all these diets were deficient in P content, different dietary ingredients were used in these studies, and the methods of determination also were not the same (some based on different markers and only short sampling intervals). In contrast to the present study, all diets contained small amounts of P from inorganic sources or fish meal. This may be considered the reason why P utilization by turkeys in the present study was lower than reported in all other turkey studies.



$y_{Broilers}$ = −23.9 (±19.8) + 1.52 (±0.08) x; r^2: 0.88; $s_{y.x}$: 42.0

y_{Ducks} = 77.9 (±17.5) + 1.77 (±0.04) x; r^2: 0.98; $s_{y.x}$: 43.4

$y_{Turkeys}$ = −111 (±13.8) + 1.95 (±0.07) x; r^2: 0.94; $s_{y.x}$: 39.0

y_{Quails} = 29.6 (±4.73) + 1.35 (±0.08) x; r^2: 0.85; $s_{y.x}$: 6.96

FIGURE 3. Relationships between accretion of Ca and P in birds 21 to 25 d of age fed increments of monobasic calcium phosphate at a dietary Ca:P ratio of about 2.2:1. The slopes of the regression lines are significantly different ($P < 0.001$).

In 6 experiments, 3-to-5-wk-old growing Pekin ducks utilized the P from plant-based diets without supplementation of P and phytase in a range between 28 and 49% (Rodehutscord et al., 2003; Wendt et al., 2003; Wendt and Rodehutscord, 2004a,b). This range is much lower than those described above for broilers and turkeys. All reported duck data were measured with the same breed with ducks from the same laboratory, which may have reduced between-study variation. Again, the mentioned range contains the value determined for the BD with ducks in this study (46%).

There are different options that can be considered in comparison of species. With regard to diet, we decided to conduct this comparison with identical sources and levels of P, meaning that the ingredient composition had to be the same for all species. One consequence of this approach is that the nutrient content of the diet does not exactly match the requirements for all species. Nutrient contents (except P and Ca) were calculated to be sufficient for 3-wk-old turkeys, because they need higher dietary concentrations of amino acids and other nutrients at that age than the other species (NRC, 1994; Gesellschaft für Ernährungsphysiologie, 1999, 2004). Consequently, the other species were supplied with excess nutrients. We are not aware of any study that has shown effects of such

TABLE 6. Means for intake, accretion and utilization of P and Ca by quails 21 to 25 d of age fed increasing dietary P concentrations and percentage of unexcreted organic matter[1]

Item	Dietary P concentration (g/kg of DM)							Pooled SEM	*P* (ANOVA)
	2.9	3.7	4.5	5.3	6.2	7.2	7.7		
Dry matter intake, g/d	24	25	25	24	25	25	25	0.1	0.412
P									
Intake, mg/d	70	90	112	127	154	180	189	5.6	<0.001
Accretion, mg/d	38	55	64	64	66	74	63	1.6	<0.001
Accretion/intake × 100	54.5	60.7	57.0	49.9	42.9	40.9	33.4	1.37	<0.001
Ca									
Intake, mg/d	169	204	245	282	357	419	423	12.8	<0.001
Accretion, mg/d	81	107	121	119	119	125	106	2.4	<0.001
Accretion/intake × 100	47.9	52.5	49.4	42.2	33.3	29.8	25.1	1.41	<0.001
UOM,[2] % of OM intake	76.7	77.7	77.9	77.3	78.3	78.6	77.9	0.16	0.049

[1]n = 8 quails per treatment.

[2]UOM = unexcreted organic matter; OM = organic matter.

an excess on P absorption and metabolism. We, therefore, gave highest priority to achieve the same P supply in all species and decided to use identical diets. Furthermore, we used birds of the same age (21 to 25 d post hatch). This may have caused differences in the stage of development and associated body composition, which becomes obvious for example from the feed/gain ratio. It ranged from 1.29 (turkeys) to 3.48 (quails), causing a corresponding difference in P intake per kilogram of BW gain. This finding explains why 4.8 g of P/kg of DM were sufficient for high-P accretion in quails, whereas even the highest P level was not sufficient to achieve a plateau in P accretion of turkeys (Figure 1). However, for all species, the basal P level was sufficiently low to cause a deficiency and to allow for a response to supplemented MCP.

Nevertheless, the response to supplemented MCP was different between species. The maximum in Eff_M with increasing P supplementation was reached earliest in quails, followed by ducks, broilers, and turkeys (Figure 2). This ranking can be attributed to the interrelation between the range in MCP supplementation and the P requirement of the respective species. However, the species also differed in the maximum of Eff_M. It was highest in ducks (96%), followed by turkeys (81%), quails (77%), and broilers (74%). This is an indication that species can differ in their abilities to absorb or utilize inorganic P. Values for Eff_M in the range of 86 to 92% were reported in earlier studies with MCP and ducks (Rodehutscord et al., 2003; Wendt and Rodehutscord, 2004a), but no comparable data are to be found for the other species. Chickens and ducks showed a distinctly different development in the activity of different digestive enzymes over time after hatch (Jamroz et al., 2002). Under the assumption that the intestinal pH may be different, it appears possible that MCP solubility is affected as well. This hypothesis still needs to be studied in order to explain the differences observed in this study. Also, the question whether phosphate transport mechanisms in the intestinal tissues may be different in efficiency and its regulation remains to be answered.

Quails were similar to broilers in the utilization of P from the BD and in the Eff_M maximum. They may be considered, therefore, as model species for broilers in P availability studies. Results from this experiment show that, at the chosen basal P level in conjunction with the age of quails (3 wk), the response range to supplemented MCP was low. Dänner and Bessei (2002) compared a very low P diet (0.8 g P/kg of feed) and a standard diet in 3-to-6-wk-old quails. Intake and growth were lower by only 17 and 37% in the low P diet. This surprisingly good adjustment to the extremely low P content likewise was a consequence of the high feed/gain ratio (Table 2) found in the quails of this age and the resulting low dietary P requirements. In consequence, if quails are used as a model species in P availability studies, it may be better to use younger quails (with a lower feed/gain ratio) or to apply a lower basal P level than the one of the present study.

Similar comparative studies with growing poultry are hard to find in the literature. Broilers and mallard ducks responded, with adequate P supply, differently in tibia

TABLE 7. Results of parameter estimate (± SE) for P accretion (y, mg/d) depending on P intake (x, mg/d)[1]

Bird	Estimated parameter y_{max}	b	c	k	r^2	$s_{y.x}$
Broilers	328.8 ± 13.45	63.85 ± 30.56	29.75 ± 32.38	0.01074 ± 0.002680	0.92	21.3
Ducks	614.2 ± 25.70	30.16 ± 84.45	29.27 ± 34.42	0.006358 ± 0.001607	0.96	31.4
Turkeys	640.0 ± 667.3	–45.86 ± 52.24	3.163 ± 5.286	0.003580 ± 0.005379	0.98	11.2
Quails	67.35 ± 1.523	22.70 ± 25.54	223.5 ± 993.4	0.06882 ± 0.03756	0.68	7.1

[1]Equation 1 was used: $y = (y_{max} + (b \times (1 + c) - y_{max})e^{-kx}) / (1 + c \times e^{-kx})$.

growth, tibia ash, and tibia P to different aluminium supply or acidification of the diet (Capdevielle et al., 1998). The chosen levels of aluminium and acid were extreme in this study and cannot be considered representative. However, they give an indication that 1,25-dihydroxycolecaliferol metabolism and plasma phosphate levels may respond differently to certain dietary factors in broilers and ducks.

We conclude that broilers, turkeys, and ducks have a different capacity to utilize plant P and mineral P. It can be hypothesized with care that differences in phytate hydrolysis in the gut caused the observed differences in utilization of P from the BD. Inorganic P sources can be expected to be different in their availability to different poultry species. Among the species studied, ducks are most efficient in utilizing inorganic P. With regard to feed compounding, availabilities for inorganic P sources determined with broilers can be applied for turkey and duck feeds without a risk of overestimating availabilities. Quails can be used as model species for broilers in P availability studies, but the dietary P levels need special adjustment.

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