Effects of Steam Pelleting and Extrusion of Feed on Phytate Phosphorus Utilization in Broiler Chickens[1]

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ABSTRACT Three experiments were conducted to determine the effects of pelleting and extrusion of feeds on the utilization of phytate P by broilers. The first experiment investigated the effects of pelleting the whole corn-soybean meal (SBM) diet, the corn, or SBM separately on phytate P utilization. The P-deficient basal diet contained 0.5% total P and 0.2% phytate P. Steam pelleting the whole diet, the corn, or SBM separately did not decrease the severity of the P deficiency obtained and there were no indications of increased phytate P utilization. In the second experiment, the whole corn-SBM P-deficient diet was extruded. Extrusion of the diet did not influence bone ash and P rickets, both sensitive criteria of P deficiency. Extrusion decreased Ca, P, and phytate P retention and decreased the ME value of the diet. In the third experiment, phytate P retention by chickens fed three commercial pelleted diets was compared to chicks fed the corn-SBM P-deficient diet. Phytate P retention by the chickens fed the commercial diets was much lower than retention by chickens fed the corn-SBM P-deficient diet. These studies gave no indication that pelleting or extrusion of corn-SBM diets would increase phytate P utilization by broiler chickens.

(*Key words*: phytate phosphorus, steam pelleting, extrusion, chicken)

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INTRODUCTION

Feeding broilers a steam pelleted corn-soybean meal (SBM) diet with no added inorganic P resulted in increased growth and bone ash contents as compared to birds fed the same diet that was unprocessed (Bayley *et al*., 1968). In the same experiment, when the corn or SBM was pelleted separately and then mixed in a diet of the same composition as the basal, there was no indication that utilization of phytate P by the broilers was increased. Improved utilization of the phytate P from a corn-SBM diet containing 25% wheat bran, as a result of steam pelleting, has been reported (Summers *et al*., 1967). However, a later study from the same laboratory (Pepper *et al*., 1969) indicated that steam pelleting failed to enhance phytate P availability from a corn-SBM diet when fed to laying hens.

Two other studies (Bayley and Thomson, 1969; Bayley *et al*., 1975) reported small increases in the intestinal absorption of P from corn-SBM diets by swine when the diets were steam pelleted. In one paper, the increase was from 19 to 29% but in the other paper the increase was not statistically significant.

Steam pelleting failed to increase the availability of P in either rice or wheat bran that was added to purified amino acid or corn-SBM diets and fed to chickens (Corley *et al*., 1980). They found the P in rice and wheat bran to be 17.6 and 23.0% available, respectively. Takemasa and Hijikuro (1983) showed that steam pelleting of corn-SBM diets had no effect on the availability of phytate P to chickens.

Because most of the commercial feed fed to broilers is steam pelleted, the question of whether or not pelleting affects phytate P utilization by broilers needs to be answered conclusively. Therefore, in view of the conflicting results obtained in the scientific literature on the use of steam pelleting to increase the availability of natural phytate P, we decided to reinvestigate this effect using phytate disappearance as one of the criteria to obtain more definitive answers to the effect of steam pelleting on natural phytates.

MATERIAL AND METHODS

Experiment 1 was an attempt to repeat the work conducted by Bayley *et al*. (1968). The corn-SBM diet

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Abbreviation Key: dP = dialyzable P; IP4 = inositol tetraphosphate; IP5 = inositol pentaphosphate; IP6 = inositol hexaphosphate; SBM = soybean meal.

TABLE 1. Composition of the basal diet

Ingredients	Amount
	(%)
Ground yellow corn	53.24
Soybean meal (dehulled)	38.09
Poultry fat (stabilized)	5.00
Limestone	1.99
Iodized sodium chloride	0.45
Dicalcium phosphate (feed grade)	0.61
DL-methionine (98%)	0.19
Vitamin premix[1]	0.25
Trace mineral premix[2]	0.08
Chromic oxide	0.10
Calculated composition[3]	
Crude protein	23.10
ME, kcal/kg	3,130
Ca	1.0
P, total	0.5
Analyzed composition	
Experiment 1	
Ca	1.10
P	0.50
Phytate P	0.25
Experiment 2	
Ca	1.07
P	0.53
Phytate P	0.25
Experiment 3	
Ca	0.98
P	0.48
Phytate P	0.26

[1]Vitamin premix provided in milligrams per kilogram diet (except as noted): vitamin A (as all-*trans*-retinyl acetate), 1.9; cholecalciferol, 27.5 μg; vitamin E (all-*rac*-α-tocopheryl acetate), 11; riboflavin, 4.4; calcium pantothenate, 12; nicotinic acid, 44; choline Cl, 220; vitamin B_{12}, 9 μg; vitamin B_6, 3.0; menadione (as menadione sodium bisulfite), 1.1; thiamin (as thiamin mononitrate), 2.2; folic acid, 3; biotin, 0.3; and ethoxyquin, 125.

[2]Trace mineral premix provided in milligrams per kilogram diet: MnO_2, 222; ZnO, 150; $FeSO_4 \cdot 7H_2O$, 200; $FeCO_3$, 83; $CuSO_4 \cdot 5H_2O$, 29; and $Ca(IO_3)_2$ 15.

[3]See Table 4 for proximate analysis and gross energy content of diets used in Experiment 3.

shown in Table 1 was fed either as a mixed mash, mixed mash steam pelleted and ground, and mixed mash containing either corn or SBM that was steam pelleted and then reground. The mixed mash, corn, or SBM were pelleted using a pellet mill at a pressure of 0.34 MPa (50 psi) and temperature of 65 to 70 C. Each of the four diets was fed to six pens of 10 d-old Ross × Ross cockerels obtained from a local hatchery.[3]

Experiment 2 was conducted to determine whether extrusion of the whole corn-SBM diet shown in Table 1 would influence the utilization of the natural phytates it contained. The basal diet was either untreated or extruded with an MPF-30 twin screw extruder[4] at a screw speed of 397 rpm, barrel temperature of 130 C in the last two zones to induce a product temperature entering the die of 116 C at 3.03 MPa (440 psi) pressure. The screw configuration and speed provided a specific mechanical energy input during extrusion of 162 kJ/kg feed. The conversion is not correct here, this is mechanical energy. The feed at 12.4% moisture was continuously metered into the extruder at 0.987 kg/min and water was continuously injected into the liquid feed port of the extruder at 39.7 mL/min, which raised the feed moisture content to 15.8% during extrusion. The feed was in the extruder barrel for 35 s before exiting the die. The extruded feed was ground in a Wiley Mill[5] using a 2-mm screen. The two diets were each fed to four pens of 10 1-d-old straight run Peterson × Hubbard chicks obtained from a local hatchery.[6] Experiment 3 was conducted to determine the amount of phytate P utilized by chicks from three commercial broiler starter rations steam pelleted at the commercial feed mills of three different integrated poultry companies located in northern Georgia. The feeds in crumble form were collected at the point of delivery into the bulk delivery trucks. They were ground in a communitive machine[7] and 0.1% Cr_2O_3 mixed into the three commercial diets. The P-deficient corn-SBM diet shown in Table 1 was fed as a control diet. The four diets were each fed to six pens of 10 Ross × Ross 1-d-old cockerels obtained from a local hatchery.[3]

In all three experiments, the 1-d-old chickens were wing-banded and randomly placed in electrically heated Petersime[8] wire floored battery brooders. The chicks were raised on a continuous illumination schedule and feed and water provided for *ad libitum* consumption. Plastic tubes[9] were placed over the fluorescent lights in the room and battery to prevent exposure to light wavelengths in the ultraviolet range.

At the end of the 16-d experimental period, the birds were weighed by pen and feed intake was recorded for feed efficiency computation. One bird was randomly selected from each pen and a blood sample was removed by cardiac puncture for subsequent determination of plasma Ca[10] and plasma dialyzable P (dP).[11] All birds were then killed by asphyxiation with carbon dioxide and randomly inspected for the presence and severity of rickets (Long *et al*., 1984). The left tibia was removed for bone ash determination on a dry fat-free basis (AOAC, 1995). Pen excreta were collected between 14 and 16 d of age. All feed and excreta were analyzed for Ca (Hill, 1955), total P (O'Neill and Webb, 1970), and phytate P (Latta and Eskin, 1980). Excreta samples were also analyzed for chromic oxide (Brisson, 1956) to calculate retention. The percentage retention of Ca, P,

[3]Seaboard Farms, Athens, GA 30606.
[4]A.P.V. Baker, Grand Rapids, MI 49501.
[5]Model No. 2, Arthur H. Thomas Co., Philadelphia, PA 19101.
[6]Harrison Feed and Poultry, Bethlehem, GA 30620.
[7]The Fitzpatrick Co., Elmhurst, IL 60126.
[8]Petersime Incubator Co., Gettysburg, OH 54328.
[9]Arm-a-lite® Thermoplastic Processes, Stirling, NJ 07980.
[10]Section N-31, Technicon Autoanalyzer Methodology, Technicon Corp., Tarrytown, NY 10591.
[11]Section N-46, Technicon Autoanalyzer Methodology, Technicon Corp., Tarrytown, NY 10591.

TABLE 2. Effects of steam pelleting on 16-d BW, gain:feed ratio, bone ash, rickets incidence, plasma Ca, and dialyzable P levels and retention of Ca, P, and phytate P in broiler chicks, Experiment 1

Treatments	16-d BW	Gain:feed	Bone ash	Rickets	Plasma minerals		Retention		
					Ca	dP[1]	Ca	P	Phytate P
	(g)	(g:g)	(%)		(mg/100 mL)		(%)		
Basal	301	0.636	26.4	69	12.9	1.6	56.5[c]	42.2	33.6
Basal-pelleted and ground	290	0.628	25.2	86	13.0	1.8	61.1[b]	42.7	33.9
Basal-with corn pelleted and ground	307	0.669	26.5	83	12.7	1.6	63.3[ab]	46.5	32.6
Basal-with SBM pelleted and ground	311	0.663	26.7	77	13.5	1.8	66.2[a]	42.8	40.7
SEM(n)	17 (6)	0.026 (6)	0.5 (6)	9 (6)	0.6 (6)	0.1 (6)	1.6 (6)	2.2 (6)	4.0 (6)
ANOVA									
Source of variation	df	Probability							
Treatment	3	0.776	0.448	0.086	0.401	0.714	0.431	<0.001	0.309	0.294

[a–c]Values of the same variable with no common superscript differ significantly ($P \leq 0.05$); results of Duncan's new multiple range test.
[1]Plasma dialyzable P.

and phytate P were calculated according to the methods of Edwards and Gillis (1959). The diets fed in Experiment 3 were also analyzed for moisture, ash, ether extract, crude fiber (AOAC, 1995), nitrogen,[12] and gross energy.[13]

The diets fed in all three experiments were also analyzed for inositol hexaphosphate (IP6), inositol pentaphosphate (IP5), and inositol tetraphosphate (IP4) using the methods described by Sooncharernying and Edwards (1993) to determine whether there was any indication of breakdown of IP6 as a result of physical treatment of the diets.

Analysis of variance were computed using General Linear Models procedure of SAS® (SAS Institute, 1990). When appropriate, mean differences were separated by Duncan's new multiple range test.

RESULTS

Experiment 1

The basal diet (Table 2) was severely deficient in P, as evidenced by the poor growth, high incidence of rickets, low plasma dP, and low bone ash observed in the chickens. Numerous studies from this laboratory have shown that broilers fed the corn-SBM diet supplemented with adequate P have 16-d BW of 400 to 500 g, incidence of rickets 0 to 10%, plasma dP 7 to 9 mg/100 mL, and bone ash 38 to 42% (Edwards, 1993; Edwards *et al.*, 1994; and Mitchell and Edwards, 1996a). Similar values for chickens fed diets adequate in P may be seen in Table 4 of this paper. Steam pelleting the whole diet, the corn separately, or SBM separately did not decrease the severity of these criteria that indicate P deficiency. Retention of P and phytate P was not significantly affected by the treatments; however, retention of Ca was significantly increased by all the pelleting treatments.

Experiment 2

The basal diet (Table 3) was severely deficient in P, as evidenced by poor growth, high incidence of rickets, low plasma P, and low bone ash observed in the chickens. The chickens fed the extruded feed had significantly lower Ca, P, and phytate P retention. The ME of the extruded feed was significantly lower than the basal diet. The plasma dP level was significantly higher in chicks fed the extruded diet; however, the plasma dP values were very low for both treatments. Bone ash and rickets, both sensitive criteria of P deficiency, were not influenced by feeding the chickens the extruded feed.

Experiment 3

The analysis of the feed and excreta from this experiment are presented in Table 4. It appears that the three commercial diets differed in protein, ether extract, and P. The P-deficient diet was very similar to the commercial diets in most components, but contained more Ca and less P. The excreta from the birds fed the P-deficient diet was lower in Ca, P, and phytate P than the excreta from the birds fed the commercial diets.

The chickens fed the commercial diets grew faster, had greater gain:feed ratios, lower plasma Ca, higher plasma dP, higher bone ash, and a lower incidence of rickets than those birds fed the P-deficient diet. There were no differences in Ca or P retention among birds fed the various diets, but the birds fed the commercial diets had lower phytate P retentions than the birds fed the P-deficient diet. There were significant differences in growth rate, gain:feed, and bone ash among the commercial feeds. There was no difference between the commercial feeds in the ability of the chickens to utilize the phytate P. The

[12]CNS 2000, Instrument Manual, method adopted by Poultry Research Laboratory, 1994 Leco Corp., St. Joseph, MI 49085.
[13]Instructions for 1241 and 1242 Adiabatic colorimeter. Parr Instruments Corp., Moline, IL 21265.

TABLE 3. Effect of extrusion on 16-d BW, gain:feed ratio, bone ash, rickets incidence, plasma Ca and dialyzable P levels and retention of Ca, P, and phytate P in broiler chicks, Experiment 2

Treatment	16-d BW	Gain:feed	Bone ash	Rickets	Plasma minerals		Mineral retention			
					Ca	dP[1]	Ca	P	Phytate P	Metabolizable energy[2]
	(g)	(g:g)	(%)		(mg/100 mL)		(%)			(kcal/kg)
Basal	285	0.656	26.7	88	12.9	1.5[b]	55.9[a]	53.6[a]	48.2[a]	3,725[a]
Extruded	277	0.698	25.2	93	10.2	2.2[a]	48.4[b]	47.5[b]	41.9[b]	3,535[b]
SEM(n)	10 (4)	0.006 (4)	0.61 (4)	3 (4)	1.0 (4)	0.2 (4)	1.47 (4)	1.01 (4)	1.65 (4)	24 (4)
ANOVA										
Source of variation	df	Probability								
Treatment	1	0.577	0.137	0.142	0.234	0.100	0.030	0.012	0.005	0.037	0.001

[a,b]Values of the same variable with no common superscript differ significantly ($P \leq 0.05$); results of Duncan's new multiple range test.

[1]Plasma dialyzable P.

[2]Dry matter basis.

birds fed the commercial diet (Diet 3) that contained the lowest level of P had the lowest bone ash, the highest incidence of rickets, and the greatest retention of phytate P.

Analysis of Diets

The results of the analysis of the diets used in all three experiments for various forms of inositol phosphates are presented in Table 5. All four diets used in Experiment 1 contained approximately 90% of the inositol phosphates as IP6 and approximately 10% as IP5. The diet shown in Table 1 containing 53% corn and 38% SBM was calculated to contain 91.1% IP6, 8.3% IP5, and 0.6% IP4 (Kasim and Edwards, 1998a). There is certainly no indication that steam pelleting of the whole diet, corn or the SBM caused any breakdown of the IP6 to IP5 or IP4 in the diets used in Experiment 1. The analyses of the extruded diet used in Experiment 2 also does not indicate any significant breakdown of IP6 by the extrusion process. The three steam pelleted commercial diets also had approximately 90% of the phytate as IP6 and 10% as IP5.

TABLE 4. Results of feeding the P-deficient diet and three commercial broiler starter diets on 16-d BW, gain:feed ratio, bone ash, rickets incidence, plasma Ca and dialyzable P levels, retention of Ca, P, and phytate P, and analysis of feed and excreta samples for proximate analysis and Ca, P, and phytate P, Experiment 3

Treatments	16-d BW	Gain:feed	Bone ash	Rickets	Plasma minerals		Retention		
					Ca	dP[1]	Ca	P	Phytate P
	(g)	(g:g)	(%)		(mg/100 mL)		(%)		
P-deficient control	312[c]	0.700[c]	27.6[b]	95.0[a]	12.9[a]	2.2[b]	59.3	46.7	50.6[a]
1 Commercial feed[2]	417[b]	0.760[ab]	40.1[a]	3.5[b]	11.3[b]	5.3[a]	61.3	43.8	31.5[b]
2 Commercial feed[2]	447[ab]	0.749[b]	40.1[a]	5.0[b]	10.6[b]	4.8[a]	59.0	44.9	30.5[b]
3 Commercial feed[2]	478[a]	0.810[a]	39.3[a]	10.2[b]	10.6[b]	4.5[a]	60.0	46.9	32.6[b]
SEM(n)	18 (6)	0.017 (6)	0.4 (6)	3.2 (6)	0.4 (6)	0.5 (6)	2.0 (6)	2.1 (6)	2.2 (6)
ANOVA					Probability				
Source of variation	df								
Treatments	3	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.857	0.672	<0.001

Analysis of feed and excreta:	Feed									Excreta		
	Moisture	Ash	Protein	Ether extract	Crude fiber	Gross energy	Ca	P	Phytate P	Ca	P	Phytate P
	(%)					(kcal/g)	(%)					
P-deficient control	11.9	5.1	21.5	8.0	2.3	4.2	0.98	0.48	0.255	1.27	0.86	0.43
1 Commercial feed	12.3	5.5	20.7	11.7	2.0	4.4	0.88	0.65	0.217	1.36	1.42	0.62
2 Commercial feed	12.2	5.5	23.0	4.9	2.1	4.1	0.92	0.67	0.213	1.56	1.45	0.60
3 Commercial feed	12.0	5.3	20.7	7.4	2.0	4.3	0.88	0.61	0.227	1.38	1.32	0.62

[a–c]Values of the same variable with no common superscript differ significantly ($P \leq 0.05$); results of Duncan's new multiple range test.

[1]Plasma dialyzable P.

[2]The three commercial feeds were collected at the mills in crumble form, then were ground and the Cr_2O_3 added before they were fed in a mash form.

TABLE 5. Amounts of tetra-(IP4), penta-(IP5), and hexa-(IP6) inositol phosphate present in the diets used in Experiments 1, 2, and 3, expressed as phytate P

Diet	Spectrophotometric method-total[1]	HPLC method[1]			
		IP4	IP5	IP6	Sum of IP4+IP5+IP6
	(g/kg)				
Experiment 1					
Basal	2.51	0.00	0.26	2.47	2.73
Basal-pelleted and ground	2.88	0.00	0.26	2.51	2.77
Basal-corn pelleted and ground	2.73	0.00	0.27	2.74	3.01
Basal-soybean meal pelleted and ground	2.88	0.00	0.21	2.33	2.54
Experiment 2					
Basal	2.52	0.02	0.14	2.66	2.82
Basal-extruded	2.61	0.05	0.29	2.54	2.89
Experiment 3					
Basal	2.55	0.00	0.26	2.97	3.23
1 Commercial feed	2.17	0.00	0.23	2.16	2.39
2 Commercial feed	2.13	0.00	0.23	2.33	2.56
3 Commercial feed	2.27	0.00	0.26	2.46	2.72

[1]Average of two replicates per sample.

DISCUSSION

There is practically no evidence from the present experiments that would indicate that steam pelleting or extruding a corn-SBM diet will increase the availability of the natural phytate P in a P-deficient diet to broilers. It is important to remember that in all cases in this experiment, and in those of Bayley *et al.* (1968), all the diets that were steam pelleted were also reground. Therefore, the experiments do not really have adequate controls for particle size. This difference may be important, as recent studies from our laboratory (Kasim and Edwards, 1998b) have shown that the particle size to which corn is ground can influence phytate P utilization. The increased retention of Ca by all the chickens that received the pelleted complete diet, pelleted corn, or pelleted SBM in Experiment 1 cannot be ignored and it is difficult to imagine more Ca being retained in these fast-growing young birds without also increasing P retention. Increasing the particle size of corn resulted in increased utilization of phytate P by broilers. However, the effects of possible interaction between pelleting and particle size have not been reported. Treatment with the highest Ca retention (SBM pelleted) also had the highest phytate P retention, although this difference was not significant.

Whole corn-SBM diets fed before and after extrusion in two experiments by Haque *et al.* (1991) resulted in significantly improved 3-wk BW of chicks in one experiment, but not the other, with no differences in the amount of feed required for BW gain. In the present study, most of the effects of extrusion indicated poorer utilization of nutrients. Further research on extrusion of poultry diets is warranted to study both extrusion methods and conditions, effects on individual ingredients, and the effect of particle size.

Work in our laboratory (Kasim and Edwards, 1998a) indicated that processed plant feed ingredients have more of their total phytate as the IP4 and IP5 form. Data had been obtained in two previous studies (Edwards, 1993; Sooncharernying and Edwards, 1993) that indicate that a key to the amount of phytate utilization is the amount initially broken down to IP5. It is reasonable to think that processing such as steam pelleting or extrusion might increase IP6 utilization by breaking it down before the ingredient is fed to the chickens. However, the analysis of the diets fed in all three experiments for the various forms of inositol phosphate present (Table 5) does not indicate that the steam pelleting or extruding resulted in a breakdown of IP6 to IP5 or IP4. Pelleting of pig diets high and low in Ca did not cause a breakdown of IP6 to the other forms in the work reported by Skoglund *et al.* (1997). Phytase activity of the diets was also not reduced by steam pelleting in these studies, and pelleting did not appear to influence the utilization of phytate by the young growing pig.

In the present report, approximately 30% of the phytate P in steam pelleted commercial diets was digested by the young broiler chicken. This value is higher than the values of approximately 10% digestibility for corn phytate by broilers (Nelson, 1976), but it is in the range of digestibilities reported by Edwards and Veltmann (1983) and Mitchell and Edwards (1996a,b) for the digestion of phytate from a corn-SBM diet.

Chemical analyses, as well as the data from the chick experiments, indicated that neither steam pelleting nor extruding had any significant effect on the utilization of natural phytate by the chickens. All of these observations confirm the majority of the data in the literature that also indicate no effect of steam pelleting on phytate utilization by chickens.

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