Some Factors Affecting the Biological Availability of Phosphorus in Wheat By-Products[1]

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ABSTRACT

Two experiments, one *in vitro* and one *in vivo,* were made to investigate various treatment effects on the availability of the phosphorus in wheat by-products. Autoclaving wheat bran, shorts, middlings, and germ resulted in marked decreases in their content of phytin phosphorus. The phosphorus requirement of chicks for maximum growth, efficiency of feed utilization, and bone ash formation was found lower when complete diets or only the wheat bran portion thereof were steam-pelleted. These findings suggest that a significant proportion of the phytin phosphorus of wheat bran can be made available to the chick for growth formation by steam-pelleting.

It is generally assumed that only about 30% of the phosphorus of plant origin is available to the growing chicken for normal bone development, the remainder being tied up in phytic acid complexes which cannot be broken down in the intestinal tract of the bird. A large proportion of the phosphorus in wheat is found in the outer layers of the kernel. Wheat shorts contains approximately 0.70% and wheat bran contains around 1.20% of total phosphorus. The feeding value of such products would be enhanced if a large percentage of this phosphorus could be made available to poultry through inexpensive processing.

Hart *et al.* (1) observed that soaking wheat bran overnight allowed the enzyme phytase to act, with the result that some of the phytin phosphorus in the bran was reduced to inositol and inorganic phosphorus. Anderson (2) and Boutwell (3) showed that wheat bran is very rich in phytase and confirmed the work of Hart and co-workers that phytase will hydrolyze phytin *in vitro.* Singsen (4) demonstrated that autoclaving wheat bran made more of its phosphorus available to the growing chicken for bone development.

O'Dell (5) found a marked increase in the inorganic phosphorus content of isolated soybean meal after autoclaving for various lengths of time. Lease (6) reported a similar but less dramatic change in the inorganic phosphorus content of sesame meal with autoclaving. McCance and Widdowson (7) demonstrated that wet heat quickly destroyed phytase, whereas dry heat did not. Thus the increase in inorganic or available phosphorus demonstrated by the above workers would appear to have been due to the hydrolysis of phytin by the autoclaving treatment and not to the action of the enzyme phytase.

The present work was carried out to study potential means of enhancing phosphorus availability in wheat by-products to the chicken.

MATERIALS AND METHODS

In experiment 1, four different wheat by-products, described by Cave

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et al. (8)—bran, shorts, middlings, and wheat germ meal—were subjected to autoclaving at 15 p.s.i. for 0, 1, 2, 3, or 4 hr. At the end of the desired autoclaving period the samples were dried in an oven at 75°F. for 2 hr., at which time a constant weight was obtained. All samples were then finely ground and three replicate aliquots of each by-product were taken for total and phytin phosphorus analysis, duplicate determinations being made on each aliquot. Total phosphorus was determined by the AOAC (9) procedure and phytin phosphorus by the method of Early and DeTurk (10).

Experiment 2 was designed to study the effects of commercial steam-pelleting on the ability of the chick to utilize the phosphorus of wheat bran. The temperature in the conditioning chamber of the pellet machine was 190°–200°F., the moisture content was raised to 18–20%, and the feed was in the chamber for 5–6 sec. The basal diet employed is shown in Table I

TABLE I
COMPOSITION OF BASAL DIETS

Ingredient	Basal Diet 1	Basal Diet 2	Ingredient	Basal Diet 1	Basal Diet 2
	%	%		%	%
Ground yellow corn	.....	35.63	Calcium carbonate	1.75	1.75
Carbohydrate mix[a]	29.63	.....	Micro mineral mix[b]	0.4	0.4
Soybean meal (50%)	38.0	32.0	Vitamin mix[c]	0.2	0.2
Corn oil	3.0	3.0	DL-methionine	0.2	0.1
Wheat bran	25.0	25.0			
Sodium chloride	0.3	0.3	Analysis (determined)		
Kaolin	1.32	1.32	Calcium	0.78	0.80
Choline chloride	0.2	0.2	Total phosphorus	0.56	0.59

[a] An equal-parts mixture of corn starch and dextrose.

[b] Micro mineral mix (mg./kg. of diet): $CoCl_2 \cdot 6H_2O$, 2; $MgSO_4$, 2,500; $FeSO_4 \cdot 2H_2O$, 100; $MnSO_4 \cdot H_2O$, 200; KI, 6; $CuSo_4$, 12; $ZnCO_3$, 200; $Na_2MoO_4 \cdot 2H_2O$, 10.

[c] Vitamin mix (mg./kg. of diet): alpha tocopherol (250 I.U./g.), 20; vitamin D_3 (1,650 I.C.U./g.), 360; vitamin A (250,000 I.U./g.), 20; riboflavin, 12; calcium-d-pantothenate, 20; pyridoxine HCl, 6; biotin, 0.3; menadione sodium bisulfite, 3; vitamin B_{12} (0.1%), 20; ascorbic acid, 150; niacin, 60; folic acid, 3; thiamine HCl, 20.

(diet 1); this diet contained 25% of wheat bran and was calculated to contain 0.18% inorganic phosphorus for the chick.[3] To this diet, graded levels of KH_2PO_4 were added, at the expense of kaolin, to give added phosphorus levels of 0.1, 0.2, and 0.3%. The rations were then fed in the form of mash or steam pellets (crumbles), or with only the bran portion pelleted and reground, and the diets then fed as mash. Four replicate lots of 20 White Leghorn male chicks were randomly assigned to each treatment at 1 day of age. Four additional treatments, with a diet of a more practical type (diet 2, Table I), were included. To this basal, which was calculated to contain 0.20% inorganic phosphorus, 0.28% phosphorus from KH_2PO_4 was added at the expense of kaolin. The diets were then fed in mash and steam-pelleted (crumbled) form to two replicate pens of 20 birds.

[3] Inorganic phosphorus for the chick is defined by the National Research Council as all the phosphorus of nonplant origin plus 30% of the phosphorus of plant products (Nutrient requirements of poultry. National Academy of Science-National Research Council, Washington, D. C., 1960).

The feeding experiment was carried out in battery brooders. At the end of 26 days, body weight and feed:gain ratios were recorded, and the left tibia of each bird was saved for bone ash determination. Bone ash was determined according to the AOAC (9) method. Two milliliters of blood was obtained from each bird by cardiac puncture. The replicates were pooled and plasma inorganic phosphorus was determined; a Technicon Auto-Analyzer was used as outlined by the manufacturer (Technicon, Chauncey, N. Y.).

All data were analyzed statistically according to the method of analysis of variance. Tests of significance of treatment effects were made by means of multiple comparison tests as indicated by Robinson (11).

RESULTS AND DISCUSSION

The effect of autoclaving the wheat by-products is shown in Fig. 1. It will be noted that the phytin phosphorus content of the wheat by-products

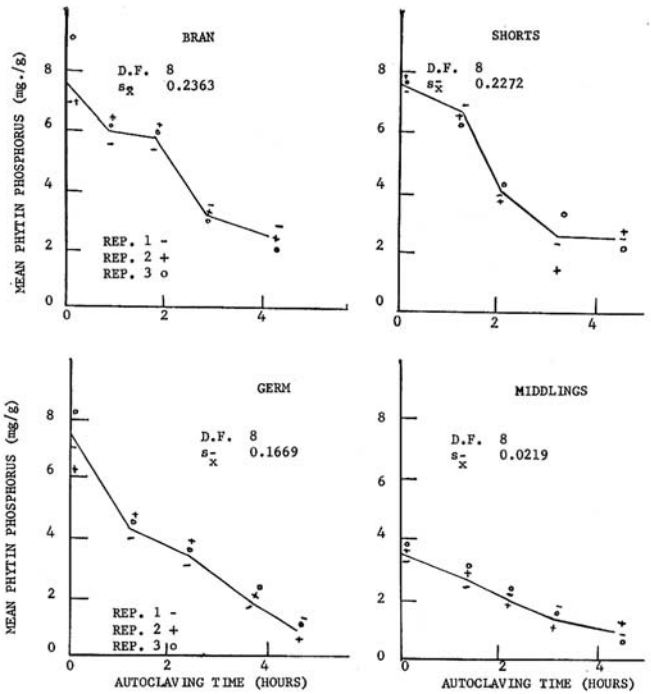

Fig. 1. Effect of autoclaving on the phytin phosphorus content of wheat by-products.

decreased with autoclaving time. The results agree with the work of O'Dell (5) and Lease (6) in demonstrating that autoclaving results in decreased levels of phytin phosphorus in some plant materials.

The results of experiment 2 (Tables II and III) would indicate that steam-pelleting does enhance phosphorus utilization by the chick. Comparing

TABLE II

EFFECT OF STEAM-PELLETING ON ABILITY OF CHICKS TO UTILIZE THE PHOSPHORUS IN WHEAT BRAN[a]

TREATMENT	AVERAGE WEIGHT	FEED/GAIN	PLASMA INORGANIC PHOSPHORUS	BONE ASH	
	g.		*mg. %*	*%*	*Probit*
			Mash		
Basal	162 a	2.46 a	2.01	26.2	4.36 a
Basal + 0.1% inorg. P	213 bc	2.12 bcd	4.35 ab	35.5	4.62 b
Basal + 0.2% inorg. P	200 b	2.16 bc	4.87 bcd	36.4	4.65 bc
Basal + 0.3% inorg. P	167 a	2.46 a	4.64 abc	32.0	4.53 a
			Steam pellets (crumbles)		
Basal	228 cde	2.16 bc	4.38 ab	37.9	4.70 cd
Basal + 0.1% inorg. P	220 cd	2.08 bcde	4.76 bcd	35.4	4.63 b
Basal + 0.2% inorg. P	219 cd	2.21 b	5.00 bcde	35.8	4.64 b
Basal + 0.3% inorg. P	212 bc	2.16 bc	5.30 cde	35.5	4.64 b
			Bran portion of diet steam-pelleted and then reground; diets fed as mash		
Basal	236 de	1.94 e	3.97 a	35.9	4.64 b
Basal + 0.1% inorg. P	226 cde	1.97 de	5.67 e	39.1	4.73 d
Basal + 0.2% inorg. P	226 cde	2.02 cde	5.35 de	39.0	4.72 d
Basal + 0.3% inorg. P	243 e	1.94 e	5.12 cde	39.1	4.72 d
St. dev. of individual values	1.91	0.02	0.08		0.006
Degrees of freedom	33	33	33		33

[a] Means followed by the same letter or letters are not significantly different.

the results (Table II) of the three unsupplemented basal diets one with the other, a significant improvement in all criteria resulted from steam-pelleting the complete diet or only the bran portion thereof. The pelleting process improved the performance of the birds to an extent at least equivalent to that of the basal diet supplemented with 0.1% added inorganic phosphorus. Since the basal diet contained 0.56% total phosphorus, of which 0.18% was calculated as inorganic, steam-pelleting appeared to render more than 25% of the remaining phosphorus available to the chick.

That the phosphorus in wheat bran was rendered more readily available by pelleting is indicated by the fact that plasma inorganic phosphorus and bone ash were improved as much when only the bran portion of the basal diet was pelleted and then reground and fed in a mash diet, as when the whole diet was pelleted (compare the results of the unsupplemented basal diet fed in three physical forms).

As the amount of phosphorus added was increased beyond the 0.1% level in the mash diet, weight, feed efficiency, and percent bone ash were depressed significantly. This may well have resulted from the fact that the level of calcium in the basal diet was border-line (0.78%), so that the added phosphorus was tying up calcium and causing a deficiency of this element. In the series of diets which were fed as pellets (crumbles), results were optimum with the basal diet, and any increase in phosphorus tended to depress weight gain and percent bone ash; this suggests that phosphorus was being made available by the pelleting process. The fact that results were

generally superior with the diets in which only the bran portion was pelleted and then reground, as compared with the series in which the total diets were pelleted, suggests that less phosphorus was being made available in the former series so that the limited calcium supply was more readily available. That a level of 0.8% calcium was too low for optimum performance with this diet was shown by recent unpublished experiments made in our laboratory. The deficiency of calcium probably accounts for the somewhat lower than maximum bone ash values in the present experiments.

TABLE III

EFFECT OF STEAM-PELLETING ON PHOSPHORUS UTILIZATION[a]

TREATMENT	AVERAGE WEIGHT	FEED/GAIN	PLASMA INORGANIC PHOSPHORUS	BONE ASH	
	g.		*mg. %*	*%*	*Probit*
Mash					
Basal	157	2.51	1.73	30.2	4.48
Basal + 0.28% inorganic P	172 a	2.39 a	4.38 a	40.4	4.76 a
Steam pellets (crumbles)					
Basal	205 b	2.26 b	4.26 a	38.8	4.72 b
Basal + 0.28% inorganic P	206 b	2.33 c	4.73 a	42.5	4.81 c
St. dev. of individual values	2.62	0.01	0.16		0.006
Degrees of freedom	3	3	3		3

[a] Means followed by the same letter are not significantly different.

The results in Table III give further evidence that steam-pelleting enhanced phosphorus availability. Supplementing the diet fed as mash with 0.28% inorganic phosphorus resulted in significant improvements in weight, feed efficiency, plasma inorganic phosphorus, and percent bone ash. On the other hand, when the diets were fed as pellets the inclusion of the phosphorus supplement caused no significant increase in weight, feed efficiency, or plasma inorganic phosphorus, and caused a much smaller increase in bone ash. It would thus appear that the level of phosphorus in the basal diet was adequate to support normal growth when the diet was pelleted but was distinctly inadequate when fed as mash. Since this was a mixed diet we have no way of knowing how much of the phosphorus was released from bran phytin and how much from the phytin of the remaining ingredients.

Evidence has been obtained in our laboratories indicating that when wheat bran is pelleted without the use of steam (or with insufficient steam to effect hydrolysis) and the pellets are reground and fed in mash diets, chick weight, feed efficiency, and bone ash values are no greater than with corresponding diets made with untreated bran. Comparing these results with those presented above constitutes further evidence that steam-pelleting releases phosphorus from the phytin complex, making it available to the chick for growth and bone formation.

Further experiments are contemplated to define more precisely the conditions necessary for treatment of wheat by-products for maximum phosphorus availability.

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