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Performance and Carcass Traits of Finishing Pigs Fed Low Phosphorus Containing Diets Based on Normal Hulled or Hulless Barley of a Low-Phytate Hulless Barley With and Without Phytase

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Abstract: The objective of the present experiment was to determine the effects of phytase supplementation on the performance and carcass traits of finishing pigs fed diets containing normal hulled or hulless barley or a newly developed low-phytate hulless barley all formulated without a source of inorganic phosphorus. A total of 72 crossbred pigs weighing an average of 67.9±8.9 kg were assigned on the basis of sex, weight and litter to one of eight dietary treatments in a factorial design experiment. A positive control diet, based on Harrington barley, was formulated to meet the pig's requirements for total phosphorus. Three experimental diets were formulated based on either Harrington barley (0.28% phytate phosphorus) or the hulless barleys CDC Freedom (0.31% phytate phosphorus) and LP 422H (0.16% phytate phosphorus). The experimental diets were deliberately formulated to be below requirements for total phosphorus by removing all of the inorganic phosphorus (i.e. dicalcium phosphate) from the diet so that the diets contained only organic sources of phosphorus. All four diets were fed with and without 1000 FTU/kg phytase (Natuphos 5000). The addition of phytase tended to improve weight gain (p=0.07) and feed intake (p=0.11). Phytase had the greatest effect in the Harrington diet formulated without dicalcium phosphate improving both daily gain (1.01 vs. 1.16 kg/day) and feed conversion (3.07 vs. 2.83). For the barley diets formulated without dicalcium phosphate, daily gain averaged 1.08, 1.11 and 1.14 kg/day while feed conversion averaged 2.95, 2.72 and 2.74 for the Harrington, CDC Freedom and LP 422H diets, respectively. Neither phytase supplementation nor type of barley had any affect on slaughter weight, carcass weight, dressing percentage or carcass value index. Pigs fed the LP 422H diet without phytase had a significantly higher lean yield (p=0.03) and lower loin fat (p=0.07) than pigs fed the LP 422H supplemented with phytase. The overall results of this experiment indicate that the performance of pigs fed low-phosphorus diets containing phytase is generally improved over unsupplemented diets. In addition, the performance of pigs fed hulless barley-based diets formulated without inorganic phosphorus is superior to that of pigs fed hulled barley-based diets formulated without inorganic phosphorus. Finally, the performance of pigs fed low-phytate hulless barley formulated without a source of inorganic phosphorus but supplemented with phytase is at least equal to that of pigs fed diets containing normal-phytate barley supplemented with inorganic phosphorus. Since inorganic phosphorus sources tend to be expensive, a reduction in their use could lower ration costs thereby increasing the potential profitability of swine production.

Key words: Barley, pigs, phytate, phytase, performance

INTRODUCTION

Barley is widely utilized as a feed grain in many parts of the world and forms the foundation of many rations fed to swine[1]. It is primarily placed in the diet as a source of energy, but also provides a substantial proportion of the dietary protein, vitamins and minerals required by the pig[2]. The development of methods to improve the feeding value of barley could have a major impact on the overall profitability of swine production.

The fibrous hull of the barley kernel limits its potential inclusion in rations for young and rapidly growing swine, as the hull lowers the nutrient density of the diet[3]. As well, high levels of fibre tend to increase the rate of passage of digesta and this may limit the amount of time available for digestion of the feed and subsequent nutrient uptake[4]. Hulless barley offers a potential advantage over hulled feed barley due to its lower fibre, higher digestible energy and increased crude protein content[1].

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About 70-75% of the phosphorus found in normal barley is bound as phytate (myo-inositol 1, 2, 3, 4 ,5, 6-hexakis-dihydrogen phosphate)[5]. Pigs are very inefficient in utilizing phytate phosphorus because they do not possess the enzyme phytase required to hydrolyze the phytate molecule[6]. As a result, inorganic sources of phosphorus must be used in ration formulation in order to meet the nutritional requirements of pigs, thereby increasing diet cost. Furthermore, the low digestibility of phytate phosphorus leads to excessive fecal excretion of phosphorus that can potentially pollute the environment[7,8].

Plant breeders have developed low-phytate genotypes of barley[9,10]. In these genotypes, phytic acid accumulation is blocked by a single gene mutation, resulting in a corresponding increase in free, organic phosphorus in the grain. This change should allow more of the phosphorus in the barley to be utilized by swine resulting in a reduction in phosphorus excretion. In a previous study, we reported a significant improvement in phosphorus digestibility as the phytate content of barley declined[11]. Improvements in phosphorus digestibility have also been reported as a result of inclusion of microbially derived phytase into swine diets[12,13]. The addition of phytase has been shown to further improve the bioavailability of phosphorus in low-phytate barley fed to pigs[14].

Since the development of low-phytate genotypes and phytase supplementation have both been shown to improve the digestibility of phosphorus in barley, it is possible that inorganic phosphorus sources may no longer be required when formulating diets for growing-finishing pigs. The objective of the present experiment was to determine the effects of phytase supplementation on the performance and carcass traits of finishing pigs fed diets containing normal hulled or hulless barley or a newly developed low-phytate hulless barley all formulated without inorganic phosphorus.

MATERIALS AND METHODS

Acquisition of barley samples: The control barley used in this experiment was CDC Harrington, a two-row malting barley[15]. This barley was compared to two hulless varieties of barley including CDC Freedom, a two-rowed hulless barley developed for net blotch and smut resistance and LP 422H, a two-rowed hulless barley developed for reduced phytate content. The LP 422H barley was originally developed from a cross between LP 422 hulled barley (50% phytate reduction) and the hulless barley variety Phoenix. Seed stocks of CDC Harrington, CDC Freedom and LP 422H were increased at the Crop Development Centre, University of Saskatchewan in 2001 and 2002. In 2003, three adjacent five-acre field plots were seeded to these varieties in order to produce sufficient quantities of material to conduct a feeding trial. A chemical analysis of the experimental barleys is shown in Table 1.

Table 1: Chemical analysis of the barleys used in formulating diets to determune the effects of phytase on the performance of finishing pigs fed normal hulled barley or low-phytate hulles barley (% as fed)[1]

	Harrington	CDC freedom	LP 422H
Moisture	12.80	9.83	10.22
Ash	2.48	2.08	1.94
Crude protein	12.10	15.37	16.03
Ether extract	2.75	2.89	3.14
Neutral detergent fibre	15.74	11.64	10.03
Calcium	0.04	0.04	0.03
Total phosphorus	0.39	0.43	0.36
Phytate phosphorus	0.28	0.31	0.16

[1]All chemical composition data are the results of chemical analysis conducted in duplicate

Growth trial: Seventy-two crossbred pigs (Camborough 15 Line female x Canabred sire, Pig Improvement Canada Ltd, Airdrie Alberta) weighing an average of 67.9±8.9 kg were assigned on the basis of sex, weight and litter to one of eight dietary treatments in a factorial design experiment. The main effects tested included diet and sex of pig (barrows and gilts).

A positive control diet, based on Harrington barley, was formulated to meet the National Research Council's[2] recommendations for total phosphorus (Table 2). Three experimental diets were formulated based on either Harrington barley (0.28% phytate phosphorus) or the hulless barleys CDC Freedom (0.31% phytate phosphorus) and LP 422H (0.16% phytate phosphorus). The experimental diets were deliberately formulated to be below NRC[2] requirements for total phosphorus by removing all of the inorganic phosphorus provided by dicalcium phosphate (Dical) from the diet so that the diets contained only organic sources of phosphorus. All four diets were fed with and without 1000 FTU/kg phytase (Natuphos 5000, BASF, Ludwigshafen, Germany). The enzyme was obtained from Aspergillus niger fermentation and the final product contained 5000 FTU/g of phytase activity. One unit of phytase activity (FTU) has been defined as the amount of enzyme that liberates one μmole of inorganic phosphorus per minute from an excess of sodium phytate at 37°C and pH 5.5 (manufacturer's specifications).

All diets contained soybean meal as the sole source of supplementary protein. During the finishing period (67.9-114.7 kg), the diets were formulated to supply 0.75% lysine, 0.57% threonine as well as 0.66% methionine and cystine (Table 3). All diets were supplemented with

Table 2: Ingredient composition and chemical analysis of finisher diets (67.9-114.7 kg) formulated using normal hulled and hulless barley or low-phytate hulless barley supplemented and unsupplemented with phytase

	Harrington barley		Harrington barley		CDC freedom barley		LP 422H barley	
	- Phytase + Dical	+ Phytase + Dical	- Phytase - Dical	+ Phytase - Dical	- Phytase - Dical	+ Phytase -Dical	- Phytase - Dical	+ Phytase - Dical
Diet formulation (% as fed)								
Barley	78.64	78.62	79.17	79.15	81.32	81.30	81.61	81.59
Soybean meal	14.49	14.49	14.42	14.42	11.92	11.92	11.59	11.59
Tallow	3.68	3.68	3.50	3.50	3.83	3.83	3.87	3.87
Vitamin mineral premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium phosphate	0.68	0.68	0.00	0.00	0.00	0.00	0.00	0.00
Limestone	1.01	1.01	1.41	1.41	1.43	1.43	1.43	1.43
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Phytase[2]	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02
Chemical composition (% as fed) [3]								
Moisture	11.46	11.30	11.65	11.25	10.14	9.83	10.41	10.06
Ash	4.08	4.12	3.94	3.76	4.05	4.02	3.67	3.78
Crude protein	15.91	15.62	15.96	15.93	17.23	17.29	17.68	18.14
Ether extract	4.50	4.75	4.97	4.55	5.26	5.15	5.41	5.80
Neutral detergent fibre	15.19	15.07	15.76	15.69	10.98	10.12	10.37	11.39
Calcium	0.70	0.66	0.69	0.72	0.72	0.72	0.69	0.70
Total phosphorus	0.49	0.49	0.40	0.39	0.43	0.42	0.36	0.38
Phytate phosphorus	0.28	0.28	0.27	0.27	0.29	0.32	0.21	0.19

[1]Supplied per kilogram of diet: 8250 IU vitamin A; 825 IU vitamin D_3; 40 IU vitamin E; 4 mg vitamin K; 1 mg thiamine; 5 mg riboflavin; 35 mg niacin; 15 mg pantothenic acid; 2 mg folic acid; 12.5 μg vitamin B_{12}; 0.2 mg biotin; 80 mg iron: 25 mg manganese; 100 mg zinc; 50 mg Cu; 0.5 mg I; 0.1 mg selenium.
[2]Natuphos 5000, BASF, Ludwigshafen, Germany (5000 FTU/g)
[3]All chemical composition data are the results of chemical analysis conducted in duplicate

Table 3: Essential amino acid composition (% as fed) of finisher diets (67.9-114.7 kg) formulated using normal hulled and hulless barley or low-phytate hulless barley supplemented and unsupplemented with phytase

	Harrington barley		Harrington barley		CDC freedom barley		LP 422H barley	
	- Phytase + Dical	+ Phytase + Dical	- Phytase - Dical	+ Phytase - Dical	- Phytase - Dical	+ Phytase -Dical	- Phytase - Dical	+ Phytase - Dical
Arginine	0.87	0.87	0.89	0.86	0.86	0.84	0.87	0.92
Histidine	0.40	0.40	0.41	0.39	0.41	0.40	0.41	0.43
Isoleucine	0.62	0.62	0.63	0.61	0.64	0.62	0.59	0.63
Leucine	1.12	1.13	1.15	1.11	1.17	1.14	1.15	1.20
Lysine	0.76	0.77	0.78	0.76	0.74	0.74	0.75	0.78
Methionine + Cystine	0.66	0.66	0.66	0.65	0.67	0.70	0.68	0.70
Phenylalanine	0.81	0.83	0.43	0.82	0.89	0.87	0.86	0.91
Threonine	0.57	0.58	0.58	0.57	0.58	0.58	0.57	0.60
Valine	0.81	0.82	0.83	0.81	0.84	0.82	0.81	0.85

[1]Natuphos 5000, BASF, Ludwigshafen, Germany (5000 FTU/g)
[2]All amino acid composition data are the results of analysis conducted in duplicate

sufficient vitamins and minerals to meet or exceed the levels recommended by NRC[2]. The diets were pelleted using low-pressure steam at approximately 60°C.

The pigs were housed in groups of four in 2.7x3.6 m concrete floored pens and were provided water ad libitum. The pens were equipped with four individual feeders. Each pig was allowed access to its own individual feeder for 30-min twice daily (08:00 and 15:00 hrs). Individual body weight, feed consumption and feed conversion were recorded weekly. Five castrates and four gilts were fed each diet. Pigs were assigned to feeders in such a way as to minimize the potential for treatment effects to be confounded with environmental effects.

Carcass measurements: All pigs were slaughtered at a commercial abattoir at an average weight of 114.7 kg. Carcass weight was recorded and dressing percentage calculated. Carcass fat and lean measurements were obtained with a Destron PG 100 probe placed over the 3rd and 4th last ribs, 70 mm off the midline. These values were then used in calculating Carcass Value Indices according to the Table of differentials in effect at the time of the experiment[16].

Chemical analysis: Samples of barley as well as the finisher rations were chemically analysed according to the methods of the Association of Official Analytical Chemists[17]. Analyses were conducted for moisture (AOAC method 930.15), crude protein (AOAC method 984.13), ash (AOAC method 942.05) and ether extract (AOAC method 920.39). Neutral detergent fibre was analysed using the method of Van Soest *et al.*[18]. The

Table 4: Effect of phytase on the performance of finisher pigs (67.9-114.7 kg) fed diets formulated using normal hulled and hulless barley or low-phytate hulless barley

	Harrington barley		Harrington barley		CDC freedom barley		LP 422H barley		Sex of pig				P values		
	- Phytase	+ Phytase	- Phytase	+ Phytase	- Phytase	+ Phytase	- Phytase	+ Phytase							
	+ Dical	+ Dical	- Dical	- Dical	- Dical	- Dical	- Dical	- Dical	SEM	Gilts	Barrows	SEM	Treat	Sex	TxS
Daily gain (kg)[a,b]	1.20	1.23	1.01	1.16	1.10	1.13	1.06	1.22	0.054	1.08	1.21	0.027	0.07	0.01	0.16
Daily intake (kg)[a,c,d,h]	3.29	3.47	3.10	3.25	2.95	3.13	2.88	3.35	0.132	2.97	3.40	0.066	0.11	0.01	0.24
Feed conversion[e,f,h]	.76	85	3.07	2.83	2.68	2.76	2.73	2.75	0.088	2.74	2.85	0.044	0.08	0.09	0.40

[a]Orthogonal contrast for phytase diets vs. non-phytase diets at $p<0.05$
[b]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. Harrington diets without dicalcium phosphate at $p<0.05$
[c]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. CDC Freedom diets without dicalcium phosphate at $p<0.05$
[d]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. LP422H diets without dicalcium phosphate at $p<0.05$
[e]Orthogonal contrast for Harrington diets without dicalcium phosphate vs. CDC Freedom diets without dicalcium phosphate at $p<0.05$
[f]Orthogonal contrast for Harrington diets without dicalcium phosphate vs. LP422H diets without dicalcium phosphate at $p<0.05$
[g]Orthogonal contrast for CDC Freedom diets without dicalcium phosphate vs. LP 422H diets without dicalcium phosphate at $p<0.05$
[h]Orthogonal contrast for hulled barley-based diets vs. hulless barley-based diets at $p<0.05$

Table 5: Effect of phytase on carcass traits of finisher pigs fed normal hulled and hulless barley or low-phytate hulless barley

	Harrington barley		Harrington barley		CDC freedom barley		LP 422H barley		Sex of pig				P values		
	- Phytase	+ Phytase	- Phytase	+ Phytase	- Phytase	+ Phytase	- Phytase	+ Phytase							
	+ Dical	+ Dical	- Dical	- Dical	- Dical	- Dical	- Dical	- Dical	SEM	Gilts	Barrows	SEM	Treat	Sex	TxS
Slaughter weight (kg)	114.8	114.2	112.9	113.3	114.0	117.7	115.1	115.2	1.482	113.8	115.4	0.741	0.44	0.15	0.04
Carcass weight (kg)[f]	89.4	89.1	87.7	88.0	88.6	91.3	91.2	89.8	1.239	89.5	89.1	0.619	0.35	0.58	0.02
Dressing percent (%)[f]	77.9	77.8	77.6	77.6	77.7	77.6	79.2	77.9	0.493	78.7	77.3	0.246	0.45	0.01	0.05
Carcass value index[d]	113.4	112.4	111.6	111.0	110.3	113.1	111.4	107.7	1.699	112.2	110.7	0.849	0.34	0.25	0.24
Lean yield[a]	60.5	60.0	60.1	60.2	59.8	60.0	61.0	58.5	0.445	60.6	59.5	0.222	0.03	0.01	0.01
Loin fat (mm)	18.5	19.0	18.7	19.1	19.7	18.4	17.4	22.5	1.049	17.9	20.3	0.524	0.07	0.01	0.02
Loin lean (mm)[a]	60.1	53.3	53.4	57.8	55.9	51.4	59.4	52.6	2.239	56.0	54.9	1.199	0.09	0.63	0.21

[a]Orthogonal contrast for phytase diets vs. non-phytase diets at $p<0.05$
[b]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. Harrington diets without dicalcium phosphate at $p<0.05$
[c]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. CDC Freedom diets without dicalcium phosphate at $p<0.05$
[d]Orthogonal contrast for Harrington diets with dicalcium phosphate vs. LP422H diets without dicalcium phosphate at $p<0.05$
[e]Orthogonal contrast for Harrington diets without dicalcium phosphate vs. CDC Freedom diets without dicalcium phosphate at $p<0.05$
[f]Orthogonal contrast for Harrington diets without dicalcium phosphate vs. LP422H diets without dicalcium phosphate at $p<0.05$
[g]Orthogonal contrast for CDC Freedom diets without dicalcium phosphate vs. LP 422H diets without dicalcium phosphate at $p<0.05$
[h]Orthogonal contrast for hulled barley-based diets vs. hulless barley-based diets at $p<0.05$

calcium and total phosphorus contents were determined using the nitric-perchloric acid digestion method of Zasoski and Burau[19] with calcium determined on a Perkin-Elmer Model 4000 Atomic Absorption Spectrophotometer (AOAC method 968.08) and total phosphorus determined colorimetrically (Pharmacia LKB Ultrospec III) using a molybdovanadate reagent (AOAC method 965.17). The ferric precipitation method was used to extract and precipitate the phytic acid phosphorus[20]. The colorimetric assay of Chen *et al.*[21] was used to measure phytic acid in the digested samples.

The amino acid content of the diets was determined by High Performance Liquid Chromatography (Hitachi L-8800 Amino Acid Analyzer, Tokyo, Japan). All samples were hydrolyzed for 24 hrs at phosphate 110°C with 6N HCL prior to analysis.

Statistical analysis: The performance and carcass data were analysed as a 2x8 factorial using the General Linear Models procedure of the SAS Institute, Inc.[22] with the factors in the model consisting of diet, sex of pig (barrows and gilts) and their interaction. Treatment means were compared using single degree of freedom orthogonal contrasts. Contrasts tested included (1) all diets supplemented with phytase compared with diets without phytase (2) Harrington diets supplemented with dicalcium phosphate compared with Harrington diets without dicalcium phosphate (3) Harrington diets supplemented with dicalcium phosphate compared with CDC Freedom diets without dicalcium phosphate (4) Harrington diets supplemented with dicalcium phosphate compared with LP 422H diets without dicalcium phosphate (5) Harrington diets without dicalcium compared with CDC Freedom diets without dicalcium phosphate (6) Harrington diets without dicalcium phosphate compared with LP 422H diets without dicalcium phosphate (7) CDC Freedom diets without dicalcium phosphate compared with LP 422H diets without dicalcium phosphate and (8) all hulless barley-based diets compared with all hulled-barley based diets.

RESULTS AND DISCUSSION

The results of the chemical analyses (Table 1) conducted for moisture, ash, crude protein, ether extract and neutral detergent fibre are within the range of those previously reported for barley from standard industry sources such as the United States-Canadian Tables of Feed Composition[23], Feedstuffs Ingredient Analysis Table[24], as well as the National Research Council's Nutrient Requirements of Swine[2]. As expected, the hulless varieties of barley had a lower neutral detergent fibre and higher crude protein content than the hulled Harrington variety. The phytate analyses conducted on the barley samples confirm our earlier findings that the selection program was successful in reducing the phytate content of barley[11,14]. The Harrington barley contained 0.28% phytate phosphorus while CDC Freedom barley contained 0.31% phytate and the LP 422H barley contained 0.16% phytate.

The results of the chemical (Table 2) and amino acid analysis (Table 3) conducted on the experimental diets indicate that the diets met the specifications called for in the diet formulation. The two Harrington barley-based diets supplemented with dicalcium phosphate had higher total phosphorus contents than the remaining diets. All diets formulated without dicalcium phosphate were deficient in total phosphorus according to NRC [2]. Supplementation with phytase did not appreciably alter the chemical composition of the diets.

The effects of phytase supplementation on the performance of pigs fed diets containing low phytate barley are shown in Table 4. The addition of phytase improved weight gain and feed intake ($p<0.05$). Phytase had the greatest effect in the Harrington diet formulated without dicalcium phosphate improving both daily gain (1.01 vs. 1.16 kg/day) and feed conversion (3.07 vs.2.83). Sands *et al.*[13] reported a significant improvement in weight gain for pigs fed corn-based diets supplemented with phytase while intake and feed conversion were unaffected. In contrast, Gagne *et al.*[25] and Shelton *et al.*[26] reported no improvement in pig performance due to phytase supplementation of corn-based diets, while Grandhi[27] reported no improvement in pig performance due to phytase supplementation of barley-based diets.

Barley variety also had significant ($p<0.05$) effects on pig performance (Table 4). For the barley diets formulated without dicalcium phosphate, daily gain averaged 1.08, 1.11 and 1.14 kg/day while feed conversion averaged 2.95, 2.72 and 2.74 for the Harrington, CDC Freedom and LP 422H diets, respectively. The improved performance of pigs fed hulless vs. hulled barley varieties supports the work of Gill *et al.*[28] who reported higher gains and improved feed conversion with hulless vs. hulled barley. In contrast, Mitchall *et al.*[29] and Thacker[1] reported no improvement in the performance of pigs fed hulless barley.

The finding that the weight gain of pigs fed the low-phytate LP422H hulless barley-based diets was modestly improved over that of pigs fed the normal-phytate CDC Freedom hulless barley-based diets supports earlier work. Veum *et al.*[30] reported improvements in pig performance as the level of phytate in the barley decreased. In addition, previous reports with low-phytate corn have also reported improvements in pig performance as the level of phytate in corn decreased[31,13].

The effects of phytase supplementation on carcass traits of pigs fed diets formulated based on low-phytate barleys is shown in Table 5. Neither phytase supplementation nor type of barley had any affect on slaughter weight, carcass weight, dressing percentage or carcass value index. Grandhi[27] and O'Quinn *et al.*[32] also reported no effect of phytase inclusion on the carcass traits of pigs fed barley and sorghum-based diets, respectively. Pigs fed the LP 422H diet supplemented without phytase had a significantly higher lean yield ($p=0.03$) and lower loin fat ($p=0.07$) than pigs fed the LP 422H supplemented with phytase. Shelton *et al.*[26] reported an increase in tenth rib fat in pigs fed corn-based diets supplemented with phytase although no difference was reported when tenth rib fat was measured with ultrasound as opposed to total-body electrical conductivity. They speculated that the increase in fat content could be attributed to an increase in energy availability as a result of phytase activity.

Over the entire experiment, barrows gained weight faster ($p=0.01$) and consumed more feed ($p=0.01$) than gilts (Table 4). Feed conversion tended to be better ($p=0.09$) for gilts than barrows. Gilts also had significantly a higher dressing percentage ($p=0.01$) and lean yield ($p=0.01$) but lower loin fat ($p=0.01$) than barrows (Table 5).

The overall results of this experiment indicate that the performance of pigs fed low phosphorus diets containing phytase is generally improved over unsupplemented diets. In addition, the performance of pigs fed hulless barley-based diets formulated without inorganic phosphorus is superior to that of pigs fed hulled barley-based diets formulated without inorganic phosphorus. Finally, the performance of pigs fed low-phytate hulless barley formulated without inorganic phosphorus but supplemented with phytase is at least equal to that of pigs fed diets containing normal-phytate barley and inorganic phosphorus. Since inorganic phosphorus sources tend to be expensive, a reduction in their use could lower ration costs thereby increasing the potential profitability of swine production.

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