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Nutrient retention and growth performance of chicks given low-phytate conventional or hull-less barleys

M. SALARMOINI, G.L. CAMPBELL[1], B.G. ROSSNAGEL[2] AND V. RABOY[3]

Department of Animal Science, Shahid Bahonar University of Kerman, Iran, [1]Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, Canada, [2]Crop Development Centre, University of Saskatchewan, Saskatoon, Canada, and [3]USDA-ARS, Aberdeen, ID 83210, USA

Abstract 1. The experimental barley samples included 4 hulled and one hull-less low-phytate barley cultivars and two commercial barley varieties as controls.

2. The diets were provided in meal form, with the experimental barley samples constituting the cereal source. Two additional treatments were added for each of the control varieties in which intermediate and recommended levels of phosphorus were provided.

3. A completely randomised design was used with 5 replicates of 5 chicks per treatment. The chicks were grown from 2 to 14 d of age with excreta collected over the subsequent 3 d.

4. Although total phosphorus levels were similar for all barley samples, there were large differences in their phytate content, which ranged from less than 0·5 to 13·8 g/kg. M2 955 hulled barley exhibited the lowest phytate and the highest phosphorus solubility.

5. There was a negative linear relationship between grain phytate and weight gain and with bone ash. The low-phytate hulled barleys M2 955 and the low-phytate hull-less barley (*lpa*1-III) gave better feed conversion (8%) than controls. The hull-less low-phytate barley gave significantly higher total phosphorus (18%) and soluble phosphorus retention (23%) than the hull-less control. The low-phytate samples tended to give lower excreta phosphorus levels (total and soluble), but the effect was significant only for the hull-less samples. Amino acid retention was significantly higher for the low-phytate hull-less barley than the control (4%).

6. Overall, the results suggest that using low-phytate barley can result in similar growth while using less supplemental phosphorus, reducing waste phosphorus by more than 50%.

INTRODUCTION

Growing concern of the impact of animal waste on the environment has accompanied expansion and concentration of the animal industry. Manure phosphorus is a major pollutant because of the need to overformulate feeds to compensate for the low availability of phytate phosphorus in plant ingredients, which, in the case of barley is 57 to 70% of total phosphorus (Ravindran *et al.*, 1995). Phosphorus availability is typically less than 0·50 (NRC, 1994) in monogastric species. The poor digestibility of phytate-P increases the cost of production since additional sources of available phosphorus are needed in ration formulation to meet the nutritional requirements of the animal. Further, undigested phytate has a negative impact on mineral (Torre *et al.*, 1991; Davidsson *et al.*, 1994, 1995; Han *et al.*, 1994; Saha *et al.*, 1994; Linares *et al.*, 2007) and possibly protein digestibility (Cheryan, 1980; Chitra *et al.*, 1995; Zyla *et al.*, 1995; Storebakken *et al.*, 1998) *via* protein–mineral–phytate interactions (Gifford and Clydesdale, 1990; Honig and Wolf, 1991; Torre *et al.*, 1991) and an inhibitory effect on proteolytic enzymes (Caldwell, 1992).

The benefit of naturally occurring phytase in feed ingredients in phytate hydrolysis and alleviation of the negative effects has long

Correspondence to: M. Salarmoini, Department of Animal Science, Shahid Bahonar University of Kerman, Iran. Fax: +98-3413222043. E-mail: salarmoini@mail.uk.ac.ir

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been recognised. In recent years, this has led to widespread adoption of microbial phytase addition to monogastric feeds, which degrades phytate during gastric residency. This approach is not entirely satisfactory because of the added cost of the enzyme additive, the limited hydrolysis achieved and the sensitivity of phytase to high temperatures encountered in feed processing. An alternative approach would be to develop feeds with reduced levels of phytate. Low-phytate mutants (*lpa*) have been isolated in feedstuffs including maize (Raboy *et al.*, 2000), barley (Larson *et al.*, 1998; Rasmussen and Hatzack, 1998; Dorsch *et al.*, 2003) and soybean (Wilcox *et al.*, 2000; Raboy, 2002).

There are a number of studies that have evaluated low-phytate feedstuffs and the results have consistently shown improved phosphorus availability compared to the normal types for maize (Ertl *et al.*, 1998; Huff *et al.*, 1998; Spencer *et al.*, 2000), barley (Sugiura *et al.*, 1999; Jang *et al.*, 2003; Thacker *et al.*, 2003; Linares *et al.*, 2007) and soybean meal (Sands *et al.*, 2003; Dilger and Adeola, 2006).

A major problem with barley in general is its high fibre level, attributed to the hull which remains attached to the harvested grain. Removal of the hull through the development of hull-less barley, in which the hull is lost during harvesting, has resulted in a cereal which is more compatible with nutrient dense feeds preferred by the animal industry (Campbell *et al.*, 1993). The hull constitutes 12 to 15% of normal barley weight and is a major contributor to faecal bulk in barley-fed animals. Elimination of the hull through hull-less cultivars in conjunction with incorporation of the *lpa* trait may yield improved barley from both nutritional and environmental perspectives. The objective of the current study was to examine the effects of normal and hull-less low-phytate barley samples on growth performance and nutrient retention in broiler chickens which provide a sensitive model suitable for small samples generated during initial plant breeding efforts.

MATERIALS AND METHODS

Barley samples

The low-phytate barley germplasm was originally obtained from V. Raboy (USDA-ARS, Aberdeen, ID, USA). The experimental barley samples included 4 hulled and one hull-less low-phytate barley cultivar grown at Saskatoon, SK (1999; Crop Development field plots). The specific barley cultivars used in the experiment were as follows (Dorsch *et al.*, 2003): *lpa*1-1 (M2 422)—hulled barley exhibiting approximately 40 to 50% reduction in phytate compared to normal barley; *lpa*2-1 (M2 1070)—hulled barley with 50 to 70% reduction in phytate, but arising from a mutation in which inositol phosphates with 5 or fewer phosphate moieties accumulate; *lpa*3-1 (M2 635)—hulled barley with approximately 75% reduction in phytate; M2 955—hulled barley with more than 95% phytate reduction and *lpa*1-1H (M2 H422)—a hull-less low-phytate genotype developed using *lpa*1-1 as the *lpa* donor (anticipated to have comparable phytate reduction). These mutants were first referred to using the original M2 plant they were discovered in. However, once it was determined that the variants were governed by single gene differences and those genes were mapped, the variants were given gene symbols. This has been the case for *lpa*1, *lpa*2 and *lpa*3 but not for M2 955. Two commercial barley varieties were grown as controls; CDC Dolly (hulled barley) and CDC McGwire (hull-less barley). Both commercial barley varieties were from a somewhat different genetic background than the original germplasm used for the introduction of the hull-less trait in *lpa*1-1H.

Chick management

Male broiler chicks were given a commercial broiler starter diet for 2 d prior to random assignment to experimental treatments. Cockerels were housed 5 per pen in thermostatically controlled battery brooders, with 5 pens per treatment. Both feed (as mash) and water were provided *ad libitum*. Weighed amounts of feed were given as required, and at 14 d both the chick and residual feed weights were recorded for performance calculations. Nutrient retention determinations were based on the subsequent 3-d period during which excreta were collected (total collection) and corresponding feed intake recorded (Bourdillon *et al.*, 1990). The collected excreta were frozen each day and stored frozen until drying at the end of the trial. Feed was removed overnight at the start and end of the excreta collection period. At the end of the trial, two chicks per replication were killed by cervical dislocation, and the left tibia was taken from each bird.

Experimental diets

The experimental diets (Table 1) were formulated to meet or exceed the requirements for broiler chickens as established by the NRC (1994), with the exception of phosphorus which was intended to be limiting but not completely deficient. Inorganic phosphorus was provided as dicalcium phosphate (0·2%). The diets were provided in meal form, with the experimental barleys constituting the cereal source.

Table 1. *Composition of experimental diets (g/kg as fed)*

Ingredient	Phosphorus concentration (g/kg)		
	20[1]	31[2]	42[2]
Barley (hulled or hull-less)	717	717	717
Soybean meal (480 g/kg)	190	190	190
Canola (rapeseed) oil	51	51	51
Dicalcium phosphate	2	7·8	13·6
Limestone	22	18	15·1
DL-Methionine	1·3	1·3	1·3
L-Lysine	2·6	2·6	2·6
Salt (iodised)	2·9	2·9	2·9
Vitamin–mineral premix[3]	7·4	7·4	7·4
Grit	3·7	1·9	0·0
Enzyme[4]	1	1	1

[1]Calculated analyses of the basal diet was as follows: ME (MJ/kg) 12·55, crude protein (g/kg) 180, calcium (g/kg) 9, available phosphorus (g/kg) 4, methionine (g/kg) 3·8, lysine (g/kg) 10. Seven barley samples are indicated in Table 2.

[2]Intermediate and normal phosphorus supplementation; barleys used were hulled, normal phytate barley (CDC Dolly) and hull-less, normal phytate barley (CDC McGwire).

[3]The vitamin–mineral premix provided the following per kg of diet: retinol 3·78 mg, cholecalciferol 0·055 mg, tocopherol 30 mg, menadione 2 mg, riboflavin 6 mg, pantothenic acid 10 mg, nicotinic acid 60 mg, folic acid 0·6 mg, biotin 0·15 mg, cobalamin 0·02 mg, choline 400 mg, Zn 80 mg, Cu 10 mg, Mn 80 mg, Se 0·3 mg.

[4]Enzyme supplementation (*Aspergillus niger*; GNC Bioferm Inc., Saskatoon, SK, Canada) was 1 g/kg, providing 1000 β-glucanase units/kg (manufacturer's specification; unit is mg total reducing sugar (glucose equivalent) released per 10 min at 30°C and pH 4·0).

The treatments (11 totals) included the low-phytate barleys (5), and the normal (control) hulled and hull-less barley (2). Two additional treatments were added for each of the control barleys (4 totals) in which an intermediate (0·78% dicalcium phosphate) and recommended phosphorus (1·36% dicalcium phosphate) were provided. The calcium content was the same for all diets.

Chemical analyses

The excreta samples were dried (24 h at 60°C) using a forced-air oven, weighed and sampled. Both the dried excreta and diet samples were ground (1 mm screen) prior to analysis for moisture, ash, ether extract and acid detergent fibre (ADF) according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 1995). Nitrogen was determined by the combustion method using a LECO FP-528 Analyser (Leco Corp., St Joseph, MI, USA). Total phosphorus was determined following wet ashing with nitric and perchloric acids (AOAC, 1995). Acid soluble phosphorus was extracted from 0·5 g of the ground barley samples using 0·5 M HCl, with vortexing (5 s), followed by incubation (22°C) with shaking (3 h), centrifugation and phosphorus determination using the supernatant. Gross energy was determined using a Parr Adiabatic Calorimeter (Parr Instrument Co. Ltd, Moline, IL, USA). Amino acids were determined following acid hydrolysis (24 h with 6 M HCl at 110°C) using a Biochrome 20 Amino Acid Analyser (Pharmacia Biotech (Biochrome) Ltd, Cambridge, UK). Phytate was determined according to Rounds and Nielsen (1993). Bone ash was determined using whole tibia, which were cleaned following parboiling to facilitate flesh removal, prior to drying (60°C), and fat extraction by refluxing for 8 h in petroleum ether and ashing (12 h, 600°C). Bone ash% was calculated as the ash expressed as a percentage of the dry defatted sample.

Statistical analyses

The results were analysed as a completely randomised design, using pen as the replication unit. The statistical analysis was performed using the general linear method (GLM) of SAS (SAS Institute, 1999). Student–Newman–Keuls (SNK) test was used to detect ($P<0·05$) differences among treatment means.

RESULTS

Barley composition

The low-phytate barley cultivars (Table 2) were comparable to their conventional counterparts with respect to crude protein, ADF, ether extract and total phosphorus. There was one exception; *lpa*1-1 had approximately 13% less total phosphorus (3·5 *vs* 4 g/kg) than the commercial variety. Acid detergent fibre was considerably lower for the two hull-less lines. There were striking differences in phytate content, ranging from 44% to less than 4% in comparison with the commercial varieties (CDC Dolly or CDC McGwire). Phytate declined progressively, with *lpa*1-1 > *lpa*3-1>M2 955. Normal barley varieties contained much less soluble phosphorus (75 to 114 g/kg) than the low-phytate lines (205 to 564 g/kg). Soluble phosphorus corresponded to the initial projections based on phytate reduction; *lpa*1-1 (323 g/kg) was less than *lpa*3-1 (429 g/kg), which in turn was less than M2 955 (564 g/kg). The lowest phosphorus solubility of the low-phytate lines was exhibited by *lpa*2-1. The hull-less, low-phytate cultivar *lpa*1-1H had similar soluble phosphorus *vs* its hulled low-phytate parent *lpa*1-1 (29 *vs* 32%).

Chick growth performance and tibia ash

Feed intake was not significantly greater than for the control variety CDC Dolly for all low-phytate barley samples. M2 955, *lpa*2-1 and *lpa*1-1H had approximately 8% poorer feed conversion than

the controls ($P<0.01$, Table 3). Chicks given M2 955 gained 20% more weight than chicks receiving control CDC Dolly. The linear relationship relating weight gain (Y) to phytate content (X) for all barley samples was: $Y=22.57-0.26X$ ($r^2=0.41$; $P<0.01$). Tibia ash is an important measure of phosphorus accumulation and bone health. Chicks given M2 955 and *lpa*3-1 had 25 and 18% more tibia ash, respectively, than chicks receiving control CDC Dolly. In this experiment there was a negative linear relationship between tibia ash (Y) and phytate content (X): $Y=398-5.9X$ ($r^2=0.58$; $P<0.01$).

Comparison of *lpa*1-1H with the control treatments supplemented with inorganic phosphorus indicated that tibia ash was significantly below the lowest level of supplementation, although weight gain was comparable and feed conversion better than either supplementation levels. Comparison of the *lpa*1-1 with *lpa*1-1H indicated that all performance parameters (feed intake ($P>0.05$), weight gain ($P>0.05$) and feed conversion ($P<0.05$)) were better for the low-phytate hull-less barley compared to the low-phytate hulled barley. Tibia ash tending to be lower ($P>0.05$) for the low-phytate hulled barley.

Phosphorus balance

The coefficient of phosphorus retention among hulled barley samples exhibiting reduced phytate did not differ significantly among the low-phytate cultivars, or from the hulled barley control CDC Dolly diet (Table 4). Overall phosphorus digestibility was subdivided into insoluble and soluble phosphorus retention, which indicated that the soluble fraction (reflecting non-phytate phosphorus) was highly digestible compared to the insoluble phosphorus fraction. Growth performance for chicks receiving M2 955 and *lpa*1-1H was the same as controls with standard level of phosphorus (control plus 1.36% dicalcium phosphate), but total excreta phosphorus was 52 and 65% lower, respectively. For the hull-less low-phytate barley total phosphorus retention and soluble phosphorus retention were 18 and 23% higher than the hull-less control.

Table 2. *Composition of the experimental barleys (g/kg DM)*

Barley	Barley specifications	Dry matter	Crude protein	Ether extract	ADF	Total phosphorus	Phytate[1]	Soluble phosphorus	(Soluble phosphorus/total phosphorus)*100
*lpa*1-1	Hulled, low phytate	875	136	25.8	55	3.5	5.5 (43.6)	1.1	32.3
*lpa*3-1	Hulled, low phytate	876	132	21.3	53.9	4	3.3 (26.4)	1.7	42.9
M2 955	Hulled, low phytate	908	156	23.1	50.2	4.3	ND[2]	2.2	56.4
*lpa*2-1	Hulled, low phytate	906	157	25.9	45.2	4.3	5.2 (41.2)	0.9	20.5
CDC Dolly	Hulled, normal phytate	870	138	22.4	43.4	4	12.6 (100.0)	0.5	11.4
*lpa*1-1H	Hull-less, low phytate	880	156	28.5	13.2	3.8	6.1 (44.2)	1.1	29.4
CDC McGwire	Hull-less, normal phytate	868	128	26.7	14.3	4.6	13.8 (100.0)	0.3	7.5

[1]Phytate expressed as % of the normal phytate barley (hulled CDC Dolly or hull-less CDC McGwire) shown in parentheses.
[2]Not detected, below the level of sensitivity of the method used (<0.5 g/kg).

Table 3. *Production parameters and tibia ash for broiler chickens fed diets based on barley lines with varying phytate*

Barley	Barley specifications	Feed intake (g/bird/d)	Weight gain (g/bird/d)	Feed conversion (F/G)	Tibia ash (g/kg)
*lpa*1-1	Hulled, low phytate	30.5^{ab}	19.6^{bc}	1.57^{a}	358^{bc}
*lpa*3-1	Hulled, low phytate	32.4^{ab}	21.5^{abc}	1.54^{abc}	387^{ab}
M2 955	Hulled, low phytate	32.4^{ab}	22.9^{ab}	1.42^{d}	409^{a}
*lpa*2-1	Hulled, low phytate	30.8^{ab}	21.5^{abc}	1.43^{cd}	367^{abc}
CDC Dolly[1]	Hulled, normal phytate	34.5^{a}	23.3^{a}	1.50^{abcd}	407^{a}
CDC Dolly[2]	Hulled, normal phytate	33.1^{ab}	21.7^{abc}	1.54^{abc}	379^{ab}
CDC Dolly	Hulled, normal phytate	29.6^{b}	19.1^{c}	1.55^{ab}	327^{c}
*lpa*1-1H	Hull-less, low phytate	31.0^{ab}	22.0^{abc}	1.44^{bcd}	335^{c}
CDC McGwire[1]	Hull-less, normal phytate	33.6^{ab}	22.8^{ab}	1.48^{abcd}	407^{a}
CDC McGwire[2]	Hull-less, normal phytate	33.6^{ab}	22.5^{abc}	1.51^{abcd}	400^{a}
CDC McGwire	Hull-less, normal phytate	30.0^{b}	19.2^{c}	1.57^{a}	326^{c}
SE		0.86	0.79	0.002	10.4

[a–d]Values within a column with no common superscript differ significantly ($P<0.05$).
[1]Normal barley with added 13.6 g/kg dicalcium phosphate (standard level of phosphorus).
[2]Normal barley with added 7.8 g/kg dicalcium phosphate.

Excreta phosphorus was correspondingly lower at 31% ($P<0.01$, Table 4).

The low-phytate samples tended to give lower excreta phosphorus, but the effect was significant only for the hull-less samples (Table 4). Phosphorus supplementation as dicalcium phosphate decreased the phosphorus retention coefficient and increased excreta phosphorus.

Digestibility

Retention of the major non-mineral fractions (dry matter, fat, protein, amino acids) did not differ significantly among the barley lines varying in phytate content in either normal or hull-less lines (Table 5). An exception was amino acid retention in the case of the hull-less barley, which was higher ($P<0.01$) for the low-phytate hull-less barley than its conventional counterpart.

Inorganic phosphorus supplementation had no effect on nutrient retention in either hulled or hull-less types. Overall, the hull-less barley had higher dry matter retention than the hulled barley types, although the retention of other nutrients was similar.

DISCUSSION

Low-phytate feed ingredients offer the economic benefit of reducing the costs incurred by inorganic phosphorus supplementation or dietary supplementation with phytase, while reducing environmental impact due to phosphorus in manure. The benefit of low-phytate maize in terms of phosphorus nutrition has previously been shown with pigs (Spencer *et al.*, 2000), chickens (Huff *et al.*, 1998) and fish (Sugiura *et al.*, 1999). Introduction of the low-phytate trait into barley offers the potential to achieve similar

Table 4. *Phosphorus retention and concentration of total and soluble phosphorus in excreta for chicks fed low and normal phytate barleys*

Barley	Barley specifications	Phosphorus retention coefficient	Soluble phosphorus retention (g/kg)	Excreta phosphorus (total, g/kg)	Excreta phosphorus (soluble, g/kg)
*lpa*1-1	Hulled, low phytate	0·697[a]	841[a]	4·6[e]	0·7[d]
*lpa*3-1	Hulled, low phytate	0·711[a]	815[ab]	4·9[e]	1·1[d]
M2 955	Hulled, low phytate	0·717[a]	860[a]	5·1[e]	1·1[d]
*lpa*2-1	Hulled, low phytate	0·696[a]	727[bc]	5·3[e]	1·0[d]
CDC Dolly[1]	Hulled, normal phytate	0·553[c]	606[d]	10·6[b]	3·4[b]
CDC Dolly[2]	Hulled, normal phytate	0·612[b]	731[bc]	8·8[c]	1·7[c]
CDC Dolly	Hulled, normal phytate	0·682[a]	573[d]	6·1[de]	1·2[d]
*lpa*1-1H	Hull-less, low phytate	0·733[a]	848[a]	4·9[e]	0·8[d]
CDC McGwire[1]	Hull-less, normal phytate	0·526[c]	635[dc]	14·1[a]	3·8[a]
CDC McGwire[2]	Hull-less, normal phytate	0·595[b]	712[c]	10·3[b]	2·1[c]
CDC McGwire	Hull-less, normal phytate	0·622[b]	380[e]	7·1[d]	1·7[c]
SE		0·021	25·97	0·43	0·13

[a–d]Values within a column with no common superscript differ significantly ($P<0.05$).
[1]Normal barley with added 13·6 g/kg dicalcium phosphate (standard level of phosphorus).
[2]Normal barley with added 7·8 g/kg dicalcium phosphate.

Table 5. *Dry matter, fat, protein and amino acid retention coefficient for chicks fed low and normal phytate barleys*

Barley	Barley specifications	Dry matter retention coefficient	Ether extract retention coefficient	Protein retention coefficient	Amino acid retention coefficient
*lpa*1-1	Hulled, low phytate	0·700[d]	0·838[abc]	0·594[b]	0·838[a]
*lpa*3-1	Hulled, low phytate	0·711[cd]	0·870[a]	0·614[ab]	
M2 955	Hulled, low phytate	0·719[cd]	0·846[ab]	0·603[b]	0·853[a]
*lpa*2-1	Hulled, low phytate	0·709[cd]	0·840[abc]	0·610[ab]	
CDC Dolly[1]	Hulled, normal phytate	0·727[bc]	0·854[ab]	0·619[ab]	
CDC Dolly[2]	Hulled, normal phytate	0·726[bc]	0·856[ab]	0·615[ab]	
CDC Dolly	Hulled, normal phytate	0·736[abc]	0·870[a]	0·613[ab]	0·846[a]
*lpa*1-1H	Hull-less, low phytate	0·745[ab]	0·820[bc]	0·606[b]	0·850[a]
CDC McGwire[1]	Hull-less, normal phytate	0·755[a]	0·816[bc]	0·648[a]	0·852[a]
CDC McGwire[2]	Hull-less, normal phytate	0·752[ab]	0·814[bc]	0·632[ab]	
CDC McGwire	Hull-less, normal phytate	0·731[abc]	0·800[c]	0·608[ab]	0·821[b]
SE		0·006	0·01	0·009	0·005

[a–d]Values within a column with no common superscript differ significantly ($P<0.05$).
[1]Normal barley with added 13·6 g/kg dicalcium phosphate (standard level of phosphorus).
[2]Normal barley with added 7·8 g/kg dicalcium phosphate.

benefits with possibly greater benefit due to its higher protein level requiring less protein supplementation as phytate-rich oilseed meal to meet dietary needs. The introduction of the low phytate into hull-less barley offers the additional advantage of reducing the fibre level in comparison with conventional barley.

In the current study, several barley genotypes exhibiting various levels of phytate reduction were examined. The observed level of phytate reduction for the barley cultivars examined fall within the range previously reported for the low-phytate lines (Dorsch *et al.*, 2003). When introduced into the hull-less line, the level of phytate reduction was similar to the low-phytate, hulled parent (*lpa*1-1). Phosphorus utilisation generally corresponded to the extent of phytate reduction, with similar reduction in excreta phosphorus. This was also evident as highly digestible acid-soluble phosphorus was markedly higher in the low-phytate lines. These results confirm the findings of other studies that feeding low-phytate barley can dramatically decrease the release of phosphorus excretion in to the environment (Jang *et al.*, 2003; Leytem *et al.*, 2007; see also Sugiura *et al.*, 1999 in fish and Thacker *et al.*, 2003 in pig).

While complete or near complete elimination of phytate from the barley would be a laudable objective for plant breeders from an animal nutrition perspective, full realisation is unlikely without seriously reducing agronomic performance. Further improvement in phosphorus utilisation would presumably be achievable with phytase supplementation. Examination of the low-phytate barley incubated with phytase *in vitro* indicated similar phosphate release, implying no change in phytase susceptibility among the *lpa* germplasms. Raboy *et al.* (1991) observed phytate phosphorus was positively correlated with total phosphorus and protein, so searched for single genes that block phytate synthesis or accumulation. By simply manipulating seed phosphorus chemistry, the genes do not have a substantial effect on seed total phosphorus or total nitrogen. In this experiment, components such as crude protein, ether extract and ADF were not obviously affected, indicating that the *lpa* genes have no major impact on the gross composition of the barley.

Phytate may have a negative impact on digestibility because of its capacity to bind both feed protein and digestive enzymes (Ravindran *et al.*, 1995); however, retention of the non-mineral fractions was not affected with the exception of amino acid retention, where the low-phytate hull-less barley gave higher results than the conventional hull-less barley. Numerous reports (Chitra *et al.*, 1995; Storebakken *et al.*, 1998; Peter and Baker, 2001) have indicated similar ambiguity in utilisation, particularly with protein utilisation, in response to phytate. It may be related to the fact that the phytate in oilseed meals (which would constitute a major fraction in the diet) is intimately associated with the protein, unlike cereals where phytate is concentrated in the aleurone underlying the bran. Low dietary phosphorus apparently did not affect non-mineral retention, which implicates any difference in retention observed being attributable to the phytate. The hull-less trait did improve dry matter digestibility because of lower fibre content, although this did not result in higher digestibility of other nutrients. Dilution of digesta with fibre arising from hull content would be anticipated to have some detrimental effect on digestibility. It may be important to note, however, that classic digestibility measurements are static; they do not take into account metabolic effort or time to accomplish equivalent digestion (Ankrah *et al.*, 1999) which may be greater in the presence of hull or phytate.

Chick performance results were consistent with overall improved phosphorus nutrition for the *lpa* germplasm for both hulled and hull-less barley, although inorganic phosphorus supplementation was necessary for all diets. Hull-less barley outperformed conventional barley at comparable phosphorus levels, and the low-phytate hull-less barley (*lpa*1-1H) gave significantly better feed conversion than the corresponding hulled barley treatment (*lpa*1-1). The exceptional feed conversion exhibited by chicks fed the very low-phytate barley (M2 955), suggests that more phytate removal may rival hull-lessness as a means of improving feed barley. According to Linares *et al.* (2007), feeding low-phytate barley had no significant effect on feed conversion and tibia ash, but feed intake and body weight gain and zinc concentration in tibia were significantly improved. In another experiment (Jang *et al.*, 2003), growth and bone ash were improved by low-phytate grain (maize and barley) compared to wild type maize and barley diets and the improvements were contributed to fewer minerals in a phytate mineral complex, increased starch digestibility or increased protein availability.

Overall results are consistent with low-phytate barley cultivars have improved nutritional value and reduced phosphorus effluent losses.

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