Nutritional value of a genetically improved high-lysine, high-oil corn for young pigs[1,2]

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ABSTRACT: Two experiments were conducted to compare the nutritional adequacy of a genetically improved high-lysine, high-oil corn (HLHOC; .408% lysine, 6.21% fat, as-fed basis) and a high-oil corn (HOC; .289% lysine, 5.97% fat, as-fed basis) for young growing pigs. Experiment 1 used four non-littermate barrows (initially 20.0 kg BW) fitted with ileal T-cannulas in a crossover-designed digestion study. The .75% total lysine diets contained 8.5% casein and an equal amount of lysine (.25%) from the test corn. Apparent ileal digestibilities of amino acids, GE, DM, and CP were similar ($P > .10$) between diets. Apparent ileal lysine digestibilities were 65 and 71% for the HOC and HLHOC, respectively, assuming the lysine in casein to be 100% digestible. Experiment 2 used 100 barrows reared in a segregated early-weaning environment (initially 8.3 kg BW and 27 d of age) to evaluate five corn-soybean meal-based diets in a 2×2 factorial arrangement with main effects being corn type and dietary lysine (.80 or 1.15% digestible lysine). The fifth diet consisted of the .80% digestible lysine HOC diet supplemented with .23% additional L-lysine·HCl (.975% digestible lysine) to verify that lysine was the limiting amino acid in the low-lysine diets. Increasing digestible lysine from .80 to 1.15% increased ($P < .001$) ADG and gain/feed (G/F) regardless of corn variety. Combined ADG and G/F were .347 kg and .641 and .443 kg and .790 for the .80 and 1.15% digestible lysine diets, respectively. Within lysine level, corn type did not affect ADG, ADFI, or G/F ($P > .10$). The results of these studies indicate that the lysine in HLHOC is as available as the lysine in HOC and that HLHOC can be used successfully in swine diets.

Key Words: Digestibility, Growth, Maize Oil, Maize Protein

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Introduction

Advances in plant biotechnology have generated specialty grains that include high-oil corn (**HOC**), which has slightly higher lysine and oil contents than conventional yellow dent corn. It is a suitable replacement for conventional corn (Adeola and Bajjalieh, 1997; Spurlock et al., 1997; DeCamp et al., 1998) and can replace a portion of the oil or fat typically added to swine diets (Bergström et al., 1997; Lohrmann et al., 1998; Kendall et al., 1999). A high-lysine, high-oil corn (**HLHOC**) variety developed recently contains approximately 29% more lysine than typical HOC and 36% more lysine than conventional yellow dent corn (Table 1). The increased lysine results from a transgenic gene insertion, which leads to the expression of a lysine-feedback-insensitive aspartokinase in the corn. Aspartokinase catalyzes the first step in the lysine, methionine, and threonine biosynthetic pathway through phosphorylation of aspartate (Falco et al., 1995). Additionally, this genetic modification leads to the expression of a lysine-feedback-insensitive dihydrodipicolinic acid synthase, which catalyzes the first reaction committed to lysine biosynthesis (Falco et al., 1997).

The HLHOC is currently under development and, to date, has not been evaluated as a feedstuff for swine or other livestock species. The objectives of these studies were to compare the apparent ileal digestibility of the amino acids in diets containing HLHOC and HOC and to compare performance of pigs fed these grains in diets formulated on a digestible amino acid basis.

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Table 1. Analyzed composition of experimental feedstuffs for Exp. 1 and 2 (as-fed basis)[a]

Item, %	Corn variety[b] HOC	HLHOC	Casein	Spray-dried whey	Soybean meal (46.5% CP)
DM	85.60	89.20	89.78	97.20	88.10
CP	8.17	9.72	73.12	11.23	45.89
Crude fat	5.97	6.21	.25	.05	1.05
Amino acid					
Arginine	.419	.447	2.79	.263	3.407
Histidine	.241	.243	2.26	.210	1.240
Isoleucine	.261	.304	3.70	.650	2.192
Leucine	.970	1.247	7.16	1.163	3.772
Lysine	.289	.408	5.92	.927	3.024
Methionine	.163	.196	2.15	.166	.741
Phenylalanine	.387	.471	3.94	.318	2.391
Threonine	.287	.326	3.16	.737	1.871
Tryptophan	.049	.061	1.04	—	—
Valine	.379	.434	4.75	.644	2.330
Alanine	.609	.761	2.34	.603	2.082
Aspartic acid	.609	.629	5.35	1.181	5.637
Cysteine	.182	.205	.38	.285	.720
Glutamic acid	1.527	1.827	16.79	1.996	9.127
Glycine	.339	.351	1.43	.163	1.928
Serine	.391	.464	4.18	.543	2.390
Tyrosine	.303	.373	4.27	.292	1.902

[a]Values are combined means of analyses from DuPont Specialty Grains, a commercial laboratory, and Kansas State University.
[b]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).

Materials and Methods

General

The HOC (Optimum 80) and HLHOC were provided by DuPont Specialty Grains, Des Moines, IA. The latter corn was available in very limited amounts, which precluded using large numbers of pigs for the dietary treatments. Pigs used in Exp. 1 were terminal offspring of PIC L326 or L327 boars × C22 sows, and pigs used in Exp. 2 were PIC C22 barrows (PIC, Franklin, KY). Feedstuffs for both experiments were analyzed prior to the initiation of the experiments (Table 1), and complete diets were analyzed after the completion of both experiments (data not shown). Samples were analyzed using AOAC (1995) procedures. Analyses of the complete mixed diets were within 5% of the targeted formulation values (maximum variation from the expected lysine content was 3.39%). Experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee (Protocol No. 1438 and 1440).

Experiment 1

Four non-littermate barrows were surgically fitted with simple T-cannulas approximately 15 cm anterior to the ileocecal valve. After a 10-d recovery period, the pigs were randomly assigned to treatments in a crossover-designed digestion study to compare the apparent ileal digestibility of nutrients in diets containing HOC and HLHOC. Composition of the experimental diets is given in Table 2. Both diets were fed in meal form and were based on corn and casein. Chromic oxide was added to the diet at .2% as an indigestible marker. These diets were formulated to be isolysinic, isocaloric, and isofibrous. This was accomplished by changing the amounts of cornstarch, corn oil, and cellulose in the HLHOC diet. Both diets contained 8.5% casein and an equal amount of lysine (.25%) from the test corn. Diets were formulated to be marginally deficient in lysine (NRC, 1988), but the amino acid ratios relative to lysine were equal to or exceeded those proposed by Baker (1995). Corns were ground to an average particle size of 650 μm, as analyzed by methods of ASAE (1983).

Each of the two consecutive 7-d periods consisted of 4 d of diet adjustment followed by a day (8.5 h/d) of ileal digesta collection, a day for recovery (to minimize the possibility of dehydration), and a final day of digesta collection. Pigs were fed the same amount each day within each period. Feed intake at the beginning of each period was 4.5% of BW. Each day's ration was divided equally between meals at 0630 and 1730. Daily feed intakes were .907 and 1.089 kg/d for periods 1 and 2, respectively. Water was provided manually at the rate of 2:1 water:feed (wt/wt) twice daily. Mean pig weights at the beginning of period 1 and at the end of period 2 were 20.0 and 26.4 kg, respectively.

Ileal digesta were collected between 0630 and 1500 by attaching a latex balloon to the opened cannula. Digesta were collected every 15 min or more often if needed and stored on ice during the 8.5-h collection period. At the end of each day, a 200-g subsample was frozen. The two subsamples for each pig were combined, freeze-dried, and ground before chemical analyses for Cr (Kimura and Miller, 1957), CP, DM, GE, and individual amino acids (AOAC, 1995) excluding tryptophan, asparagine, glutamine, and proline. All nutrient digestibilities were calculated using chromic oxide as an indigestible marker.

Data from the digestion trial were analyzed initially as a crossover design that included the effects of diet, pig, and period. However, the effects of period and pig were not significant ($P > .10$). Data subsequently were reanalyzed and are reported herein as a completely randomized design. All analyses were performed using the GLM procedures of SAS (1988).

Experiment 2

One hundred barrows were weaned at 17 ± 2 d of age with an initial BW of 5.8 kg. At weaning, pigs were transported approximately 2 h to the segregated early-weaning (**SEW**) nurseries at Kansas State University. Pigs were grouped by weight with four pigs per pen. Prior to the initiation of the experiment, all pigs were fed a complex nutrient-dense diet based on conventional yellow dent corn, 46.5% CP soybean meal, select menhaden fish meal, spray-dried animal plasma, spray-dried blood meal, and spray-dried whey. This diet was formulated to contain 1.60% total lysine, .90% total Ca, and .80% total P. Ten days later, pigs (average BW of 8.3 kg) were allotted randomly by weight to one of five dietary treatments with four pigs per pen and five replicate pens per treatment.

Table 2. Percentage composition of diets used in Exp. 1 (as-fed basis)[a]

Item	Dietary treatment[b] HOC	HLHOC
HOC	86.96	—
HLHOC	—	61.60
Cornstarch	—	23.29
Casein	8.50	8.50
Monocalcium phosphate	1.60	1.94
Corn oil	—	1.37
Antibiotic[c]	1.00	1.00
Limestone	.99	.84
Cellulose[d]	—	.51
Salt	.35	.35
Vitamin premix[e]	.25	.25
Chromic oxide	.20	.20
Trace mineral premix[f]	.15	.15

[a]Diets were formulated to be isolysinic (.75% total lysine) and contained .75% total Ca and .65% total P. Calorie and fiber contents also were balanced across treatments by adding corn oil and cellulose to the HLHOC diet.

[b]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).

[c]Provided 55 mg carbadox/kg of complete diet.

[d]Solka Floc 300 powdered cellulose, Fiber Sales and Development Corp., Urbana, OH.

[e]Provided per kg of complete diet: vitamin A, 11,023 IU; vitamin D_3, 1,653 IU; vitamin E, 44 IU; menadione (menadione dimethylpyrimidinol bisulphite), 4.4 mg; vitamin B_{12}, .04 mg; riboflavin, 9.9 mg; pantothenic acid, 33 mg; and niacin, 55 mg.

[f]Provided per kg of complete diet: Zn, 165 mg; Fe, 165 mg; Mn, 40 mg; Cu, 17 mg; I, .3 mg; and Se, .3 mg.

Five diets were evaluated (Table 3) during the test period. Four diets were arranged in a 2 × 2 factorial with corn source and dietary lysine level as the main effects. Lysine levels were chosen to be either deficient (.80% apparent ileal digestible lysine (.985% total lysine)) or adequate (1.15% apparent ileal digestible lysine (1.39% total lysine)) for pigs of this weight (Owen et al., 1995). Within each lysine level, diets contained equal amounts of corn and all other ingredients, except L-lysine·HCl, which was added to the HOC diets at the expense of cornstarch. Crystalline lysine was assumed to be 100% digestible (Chung and Baker, 1992). From the results of Exp. 1, HOC and HLHOC were estimated to have apparent ileal lysine digestibilities of 65 and 71%, respectively. Digestibility coefficients from the NRC (1998) for soybean meal and dried whey were used in diet formulation to calculate dietary apparent ileally digestible lysine contents. Crystalline methionine, tryptophan, and threonine were added to diets to ensure their adequacy and to maintain at least the minimum amino acid ratios relative to lysine as set forth by the NRC (1998). Thus, within lysine level, any differences in pig performance should have been attributable to differences in bioavailability of lysine. The fifth diet consisted of the .80% lysine HOC diet supplemented with .23% additional L-lysine·HCl (.975% digestible lysine) to verify that lysine was the limiting amino acid in the low-lysine diets. Corns were ground to an average particle size of 725 μm (ASAE, 1983), and all diets were fed in meal form.

Pigs were housed in an environmentally controlled nursery in 1.33- × 1.33-m pens with tri-bar flooring and allowed ad libitum access to feed through a five-hole self-feeder and water through a single-nipple waterer. Weight gains and feed intakes were measured at d 10 of the experiment and used to determine ADG, ADFI, and gain/feed (**G/F**).

The data were analyzed as a randomized complete block with treatments arranged as a 2 × 2 factorial plus a control. Treatment sums of squares were divided into main effects, interactions of the main effects, and a comparison of the .975% apparent digestible lysine diet to the HOC diet containing .80% apparent digestible lysine using single degree of freedom contrasts. Pen was the experimental unit in all analyses. Data were analyzed using the GLM procedures of SAS (1988).

Results

Experiment 1

Apparent ileal digestibility of individual amino acids, DM, CP, and GE were similar ($P > .10$; Table 4) for the HLHOC and HOC diets. Digestibility values are for diets containing 8.5% casein. Casein was assigned a

Table 3. Percentage composition of diets used in Exp. 2 (as-fed basis)[ab]

	Digestible lysine, %				
	.80		1.15		.975
Item	HOC	HLHOC	HOC	HLHOC	Control
HOC	64.48	—	49.34	—	64.47
HLHOC	—	64.48	—	49.34	—
Soybean meal (46.5% CP)	20.92	20.92	36.50	36.50	20.92
Spray-dried whey	10.00	10.00	10.00	10.00	10.00
Antibiotic[c]	1.00	1.00	1.00	1.00	1.00
Monocalcium phosphate	1.47	1.47	1.20	1.20	1.47
Limestone	.84	.84	.87	.87	.84
Vitamin premix[d]	.25	.25	.25	.25	.25
Trace mineral premix[d]	.15	.15	.15	.15	.15
Salt	.35	.35	.35	.35	.35
L-Lysine·HCl	.08	—	.06	—	.31
DL-Methionine	.08	.08	.02	.02	.08
L-Tryptophan	.04	.04	—	—	.04
L-Threonine	.11	.11	.01	.01	.11
Cornstarch	.23	.31	.25	.31	.01
Calculated value					
ME, Mcal/kg	3.40	3.42	3.40	3.43	3.40
Total Ca, %	.75	.75	.75	.75	.75
Total P, %	.70	.70	.70	.70	.70
Analyzed value					
Total lysine, %	.97	.99	1.39	1.40	1.15
CP, %	17.0	18.0	24.7	23.3	16.8

[a]All diets were formulated to be isolysinic within each lysine level based on determined apparent ileal lysine digestibility values from Exp. 1.
[b]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).
[c]Provided 55 mg carbadox/kg of complete diet.
[d]Refer to Table 2 for content.

digestibility value of 100% (Chung and Baker, 1992). Thus, digestibility values for the individual amino acids for each corn type can be calculated by difference using the analyzed compositions of the corns and casein (Table 1), percentage composition of the diets (Table 2), and dietary digestibility values (Table 4). The apparent ileal digestibilities of lysine in the HOC and HLHOC diets were calculated by this method to be 65 and 71%, respectively (Table 5). With the exception of histidine, apparent ileal digestibility of all other amino acids favored HLHOC, but the differences were small, ranging from .2 (phenylalanine and valine) to 3.2 (glycine) percentage units. Because of experimental design, the content of all amino acids, other than lysine, was less in the HLHOC diets than in the HOC diet. However, these data clearly show that amino acids in HLHOC are at least as digestible as those in HOC.

Experiment 2

The interaction of dietary apparent ileally digestible lysine level and corn type was not significant ($P > .40$) for ADG, ADFI, and G/F (Table 6). Increasing dietary digestible lysine from .80 to 1.15% increased ($P = .001$) ADG and G/F; ADFI was not affected ($P = .42$) by lysine level. Performance of pigs fed diets containing HOC or HLHOC was not different ($P > .35$), indicating similar nutritional values for both corns.

Discussion

The similarity in apparent ileal digestibility values for DM, CP, GE, and individual amino acids in diets containing either HOC or HLHOC indicates a similar nutritional value for the two corn types. The apparent ileal digestibilities of lysine of 65 and 71% for the HOC and HLHOC, respectively, are in general agreement with studies determining the lysine digestibility of quality protein maize for swine (Sullivan et al., 1989; Burgoon et al., 1992).

A few studies have evaluated the digestibility of HOC varieties for growing swine (Adeola and Bajjalieh, 1997; DeCamp et al., 1998; Snow et al., 1998). In most cases, the feeding value of the HOC was at least equal to that of conventional yellow dent corn. Interpretation of existing data is made difficult by lack of amino acid profiles (DeCamp et al., 1998; Snow et al., 1998) or differences in types of high-oil corns evaluated (Adeola and Bajjalieh, 1997).

In precision-fed cecectomized roosters, Parsons et al. (1998) determined that the digestibility of amino acids and bioavailability of lysine in HOC were equal to or greater than those in conventional yellow dent corn. They attributed potential increases in lysine bioavailability from HOC to an increased proportion of germ protein and(or) higher oil content in HOC. Parsons et al. (1998) also postulated that the germ protein in HOC

Table 4. Apparent ileal digestibility (%) of nutrients in diets containing high-oil and high-lysine, high-oil corns (Exp. 1)[ab]

Item	Corn variety[cd]		
	HOC	HLHOC	SEM
DM	82.5	84.7	1.90
CP	84.3	85.5	1.27
Ash	40.0	41.3	2.82
GE	83.8	85.8	1.82
Amino acid			
Arginine	88.6	90.3	.92
Histidine	89.9	91.3	1.04
Isoleucine	88.4	90.2	.86
Leucine	92.8	93.4	.75
Lysine	88.4	90.4	1.00
Methionine	93.5	94.6	.60
Phenylalanine	90.6	91.4	.89
Threonine	81.4	83.8	1.16
Valine	88.2	89.6	.88
Alanine	87.1	89.3	1.40
Aspartic acid	85.8	88.4	1.10
Cysteine	76.8	78.7	1.88
Glutamic acid	91.4	93.0	.94
Glycine	60.8	66.6	2.57
Serine	84.7	87.1	.95
Tyrosine	87.5	89.2	1.21

[a]Values are means of four barrows used in a crossover design.
[b]All diets contained 8.5% casein.
[c]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).
[d]Diets did not differ ($P > .10$).

may be more highly digestible, and that the higher oil content may slow transit time through the intestine enough to allow for more complete digestion of nonlipid dietary components.

Although direct comparisons were not made, the data cited above suggest that HLHOC should be as digestible as conventional yellow dent corn, because HLHOC was as digestible as HOC, which in turn is as digestible as conventional corn.

Within each digestible lysine level of Exp. 2, both corn varieties yielded similar growth performance responses, indicating similar nutritional values for HOC and HLHOC. The majority of research evaluating HOC for pigs has been with growing-finishing pigs because of the increased energy value of HOC (Spurlock et al., 1997; Lohrmann et al., 1998; Snow et al., 1998). Nursery pigs have a limited capacity to utilize supplemental dietary fat, but this capacity increases sharply with age (Tokach et al., 1995). Bergström et al. (1997) and DeCamp et al. (1998) have conducted feeding trials using HOC for nursery pigs. In both cases, feeding HOC produced growth performance similar to that resulting from feeding conventional yellow dent corn, indicating that HOC can replace the conventional yellow dent corn and a portion of the soybean meal. Thus, HLHOC also should be an adequate replacement for conventional yellow dent corn and a larger portion of the soybean meal in typical swine diets because of the increased lysine content.

Care must be taken in formulating diets containing HLHOC. This is because the lysine level in the protein has been increased substantially, but content of other amino acids has not been increased in proportion to lysine. Thus, tryptophan or threonine is more likely to be deficient when HLHOC is used, because less soybean meal will be included in diets. However, when properly used, HLHOC can be an excellent grain source for swine. Crop yields are presently unavailable for HLHOC. However, because HLHOC is a cross product of the TOPCross hybrid system from HOC, it is logical to assume that yields between the two HOC varieties would be similar. Bitney et al. (1999) concluded that growing or feeding HOC to swine was not economically feasible, primarily because of yield and identity preservation issues. However, if effective identity preservation systems can be used, the added lysine in HLHOC may make its economic profile more favorable than that of HOC.

Implications

The amino acids in high-lysine, high-oil corn are as digestible as those in high-oil corn. In addition, the amino acids and energy in high-lysine, high-oil corn are well digested by pigs. Thus, high-lysine, high-oil corn can be used in nutritionally balanced swine diets without reducing growth performance. High-lysine, high-oil corn offers the potential to reduce the amount of supplemental protein and energy needed in swine diets.

Table 5. Apparent ileal digestibility (%) of amino acids in high-oil and high-lysine, high-oil corns, calculated by difference[a]

Amino acid	Corn variety[b]	
	HOC	HLHOC
Arginine	81.2	81.7
Histidine	80.6	80.1
Isoleucine	72.3	73.7
Leucine	87.6	88.2
Lysine	65.2	71.2
Methionine	85.1	86.4
Phenylalanine	81.3	81.5
Threonine	61.4	62.1
Valine	73.7	73.9
Alanine	82.3	84.8
Aspartic acid	73.6	74.8
Cysteine	72.1	73.4
Glutamic acid	82.2	84.2
Glycine	44.6	47.8
Serine	68.7	71.1
Tyrosine	70.3	72.1

[a]Values calculated from mean digestibilities given in Table 4 and assuming 100% digestibility for amino acids in casein.
[b]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).

Table 6. Performance of pigs fed diets containing high-oil and high-lysine, high-oil corns (Exp. 2)[abc]

	Digestible lysine, %						Probability values (P =)			
	.80		1.15							
Item	HOC	HLHOC	HOC	HLHOC	.975 Control	SEM	Lys	Corn	Lys × Corn	Contrast[d]
ADG, kg	.361	.333	.442	.443	.385	.016	.001	.39	.44	.45
ADFI, kg	.552	.531	.548	.565	.564	.023	.42	.77	.56	.79
Gain/feed	.654	.627	.800	.780	.681	.021	.001	.43	.61	.42

[a]Corn varieties were high-oil corn (HOC) and high-lysine, high-oil corn (HLHOC).
[b]Values are means of four pigs per pen and five replicate pens per treatment. Pigs averaged 8.3 kg BW initially (d 10 after weaning) and 12.23 kg BW at the conclusion of the 10-d trial.
[c]Within each lysine level, diets are identical except that L-lysine·HCl was added to the HOC diets to make them isolysinic. The .975% digestible lysine diet was identical to the .80% digestible lysine HOC diet except that L-lysine·HCl was added.
[d]Contrast refers to the comparison of the .975% digestible lysine diet to the HOC diet containing .80% digestible lysine.

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