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Amino acid digestibility and nitrogen utilization of high oil, high lysine, and waxy maize fed to growing pigs

J.L. Snow [a,1], H.H. Stein [b], P.K. Ku [a], N.L. Trottier [a,*]

[a] *Department of Animal Sciences, Michigan State University, East Lansing, MI 48824, USA*
[b] *Department of Animal and Range Sciences, South Dakota State University, Brookings, SD 57007, USA*

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Abstract

Two experiments were conducted to determine the amino acid (AA) digestibility and nitrogen (N) utilization of three maize hybrids, i.e. high oil (HO), waxy (WX), and high lysine (HL) as compared to isogenic high oil (IHO), isogenic waxy (IWX), and a yellow dent (YD1) maize variety near-isogenic to HL. One yellow dent maize of unrelated genetics (YD2) was included as an additional control and to serve as a common treatment for cross-square comparison. In exp. 1, four castrates (initial BW: 52.8 ± 1.7 kg) were equipped with T-cannulas in the distal ileum and used in two consecutive 4×4 Latin squares to determine AA digestibility. In exp. 2, eight castrates (initial BW: 19.11 ± 0.49 kg) were arranged in two 4×4 Latin squares and used in a N balance experiment. Diets consisted of 966.2 g test maize/kg and 33.8 g vitamins, minerals, and salt/kg. In exp.1, apparent ileal digestibility coefficients (CAID) for HO and WX were not different ($P > 0.05$) compared to their respective isogenic maize or YD2. High lysine maize had lower ($P < 0.05$) CAID for isoleucine, leucine, methionine, phenylalanine, threonine, and valine when compared to YD1, its near-isogenic maize, and lower ($P < 0.05$) CAID for isoleucine, leucine, and phenylalanine when compared to YD2. Mean CAID for HO, WX, HL, and YD2 were 0.65 ± 0.05, 0.70 ± 0.05, 0.53 ± 0.05, and 0.60 ± 0.03, respectively. True ileal digestibility coefficients (CTID) for the indispensable AA did not differ when HO and WX maize were compared to their respective isogenic maize, but HL maize had lower ($P < 0.05$) CTID for the majority of indispensable AA except for arginine and histidine than YD1. Mean CTID for HO, WX, HL, and YD2 were 0.78 ± 0.04, 0.84 ± 0.04, 0.67 ± 0.04, and 0.77 ± 0.03, respectively. Nitrogen retained, urinary N, fecal N, N digestibility, and N utilization for HO, WX, and HL were not different ($P > 0.05$) compared to their genetically similar maize. Nitrogen absorbed and DM digestibility were higher ($P < 0.05$) for HO than for IHO. Nitrogen digestibility was similar ($P > 0.05$) for WX compared to YD 2 and greater ($P > 0.05$) for HO and HL compared to YD 2. In conclusion, AA CAID and CTID, were similar for HO and

* Corresponding author. Tel.: +1-517-432-5140; fax: +1-517-432-0190.
E-mail address: trottier@msu.edu (N.L. Trottier).
[1] Present address: 286 ASL, 1207 W. Gregory, University of Illinois, Urbana, IL 61801, USA.

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WX maize compared to their isogenic maize, however, AA CAID and CTID for HL maize was lower than its near-isogenic maize. Nitrogen utilization for HO, WX, and HL were similar to that of their respective genetically similar maize.

Keywords: Pigs; Amino acids; Digestibility; Nitrogen utilization; High oil maize; High lysine maize; Waxy maize

1. Introduction

Using conventional plant breeding methods, maize hybrids containing higher concentrations of nutrients than yellow dent varieties have been successfully developed. In the past, commercial production of these maize hybrids was not feasible because of low yields and poor agronomic traits, but research and field tests have led to maize hybrids with yields similar to the yellow dent maize varieties. Because of differences in nutrient density and (or) composition, these so-called "value added" or "specialty maize" such as high oil (HO), high lysine (opaque-2) (HL), and waxy (WX) maize may offer nutritional advantages over conventional yellow dent maize varieties. High oil maize is characterized by a higher germ to endosperm ratio and oil concentration than conventional yellow dent maize varieties (Lambert, 1994). Oil concentration in HO maize hybrids is greater than 60 g/kg, while oil concentration in yellow dent maize varieties usually ranges from 35 to 50 g/kg (Lambert, 1994). Because of the higher germ to endosperm ratio, the increase in oil concentration is associated with an increase in protein quality (Lambert, 1994). High lysine maize contains a lower prolamine and higher albumin, globulin, and glutelin protein fractions than yellow dent maize (Wilson, 1992), consequently increasing its lysine concentration (Boyer, 1994). For instance HL maize fed to pigs is adequate as the only source of protein for the finishing period (Burgoon et al., 1992). The WX gene is epistatic to all known endosperm mutants, causing the absence of amylose and an abundance of amylopectin (White, 1994). Thus, WX maize is heavily produced for paper, textile, corrugating, and adhesive industries. Very little information exists on the nutritional value of WX maize and its use in animal feeds.

There is, to date, a dearth of information on the protein digestibility and utilization of these specialty maize hybrids, and whether or not they offer superior nutritional value than yellow dent maize varieties. Amino acid (AA) and protein digestibility of the yellow dent maize varieties have been extensively investigated and summarized (NRC, 1998), and are widely used in the formulation of diets to meet true digestible AA requirements of the pig. In light of continued interest in the use of HO and HL maize hybrids, and the potential inclusion of WX maize hybrid in commercial animal feeds and (or) feeding trials, we conducted two studies to determine their AA digestibility and protein utilization in growing pigs.

The objectives of the current study were first to determine apparent ileal (CAID) and standardized ileal (CTID) AA digestibility coefficients of HO, WX, and HL maize hybrids fed to growing pigs; second, to assess whether the CAID and CTID for HO, WX, and HL are superior to those obtained in yellow dent maize varieties; third, to determine whether the utilization of protein from these specialty maize is superior to that of yellow dent maize varieties.

2. Materials and methods

2.1. Specialty maize

High oil (Cargill 5990 TC), isogenic high oil (IHO; Cargill 5990), waxy (WX; Pioneer 3528E), isogenic waxy (IWX; Pioneer 3527), high lysine (Crows), and yellow dent 1 (YD1; Crows) were obtained. Three seed companies provided both a specialty hybrid and its respective isogenic yellow dent maize. High oil and WX had corresponding isogenic yellow dent varieties, but an isogenic maize was not available for HL, therefore, a yellow dent maize that was near-isogenic to HL maize was provided. These maize varieties were planted at Michigan State University farms in adjacent plots of approximately 110 m^2. Plots were monitored throughout the growing season for maize DM content, ear density, and plot density (data not reported). Plots were harvested individually when the maize contained at least 75% DM. Buffer rows between plots were used to maintain identity of the hybrids. All hybrids were commercially dried. All test maize were ground using a Raymond Mill (No. 82; Chicago, IL). Particle size of each maize, as measured by geometric mean diameter, was determined using weight distribution over standard US sieves according to Ensor et al. (1970). In addition, a yellow dent maize (YD2) of unrelated genetics to the previously mentioned maize was purchased to serve as an additional control and as a common treatment for comparison across Latin squares.

2.2. Diets, animals, experimental design, and sampling procedures

Amino acid digestibility and protein utilization of the test maize varieties were determined in two separate experiments. Each experiment was approved by the Michigan State University, All University Committee for the Use and Care of Animals.

Diets were formulated by mixing approximately 97% of test maize with limestone, dicalcium phosphate, salt, microminerals, and vitamins to meet or exceed NRC (1988) nutrient requirements. For diets used in exp. 1, 0.25% chromium oxide was included (Table 1) as an indigestible marker to estimate AA digestibility (see Eq. (1)). Maize-based diets were deficient in isoleucine, lysine, methionine, threonine, and tryptophan. To meet the requirements for growth for all indispensable AA (NRC, 1988), pigs were provided an AA mixture of isoleucine, lysine, methionine, threonine, and tryptophan supplemented to their daily feed allotments during the dietary adjustment period of exp. 1. Composition of the AA mixtures is reported in Table 2. The AA mixtures were removed 1 day prior to sampling of ileal digesta or excreta, and during the sampling period.

In exp. 1, four Yorkshire pigs, with an initial body weight of approximately 40 kg, were equipped with T-cannulas at the terminal ileum using surgical procedures adapted from Stein et al. (1998). Following surgery, pigs were moved to individual pens (1.5 m × 2.75 m) in a mechanically ventilated room with a mean ambient temperature of 21 °C. Pigs were allowed 14 days for recuperation. During this period, pigs were provided ad libitum access to a standard grower diet, and feed intake, body temperature and integrity of the cannula were monitored daily. All pigs were provided free access to water. Ampicillin (Fort Dodge Laboratories Inc., Fort Dodge, IA) was administered intramuscularly in the neck, during the first 3 days post surgery. Following surgical recuperation, the four littermate castrates

Table 1
Ingredient composition of experimental diets (as-fed basis)

Ingredients	g/kg
Maize[a]	966.2
Dicalcium phosphate	12.5
Limestone	8.8
Vitamin mix[b]	5.0
Trace mineral mix[c]	2.5
Salt	2.5
Chromic oxide[d]	2.5

[a] Maize varieties used were yellow dent 1, yellow dent 2, high oil, isogenic high oil, waxy, isogenic waxy, and high lysine.

[b] Provided the following per kilogram of diet: retinyl acetate, 4.6 mg; cholecalciferol, 11.5 μg; α-tocopherol, 36.7 mg; menadione, 3.7 mg; Vitamin B_{12}, 27.5 μg; riboflavin, 3.7 mg, D-pantothenic acid, 14.7 mg; niacin, 22.0 mg; thiamine, 0.9 mg; pyridoxine, 0.8 mg.

[c] Provided the following per kilogram of diet: Fe, 50 mg; Zn, 50 mg; Cu, 5 mg; Mn, 5 mg; Se, 0.15 mg and I, 0.075 mg.

[d] Chromium oxide was included as an indigestible marker in exp. 1. In exp. 2, no chromic oxide was added, therefore, the maize was increased from 966.2 to 968.7 g/kg.

(52.8 ± 1.7 kg) were arranged in two consecutive 4×4 Latin squares. Pigs were fed HO, HL, YD1 and YD2 diets in square 1 and IHO, WX, IWX, and YD2 diets in square 2. The YD2 diet was included in both squares to allow comparisons of maizes across the two squares. Pigs were allowed 5 days to adjust to diets. Diets were offered in three equal daily meals and daily feed intake was restricted to 90% of ad libitum intake. On days 6 and 7, digesta were collected for 12 h each day as previously described (Stein et al., 1998, 1999a). Digesta from each pig were pooled over the 2-day collection period and stored at −20 °C. Pigs were weighed weekly to monitor growth and health.

In exp. 2, eight Yorkshire castrates with an initial body weight of 19.1 ± 0.49 kg were randomly assigned to the seven test maize diets and arranged in two 4×4 Latin squares. Pigs within each square were littermates. As in exp. 1, the YD2 diet was included in both squares to allow comparisons of maizes across the two squares. Pigs were individually housed in stainless steel metabolism cages (1.2 m × 0.75 m) containing low-pressure nipple waterers that provided free access to water. The metabolism cages allowed for separate collection of urine and feces. The metabolism room was mechanically ventilated and the average room temperature was 21 °C.

Table 2
Amino acid mixture composition (g/kg of diet)

Amino acid	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	Yellow dent 2
Ile	0.53	0.93	1.23	0.92	0.77	1.23	1.27
Lys	3.96	4.07	4.50	4.24	4.35	3.38	4.97
Met	0.60	1.22	0.98	0.65	0.69	0.74	1.02
Thr	1.79	2.15	2.29	2.12	2.16	2.21	2.40
Trp	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Pigs were allowed 5 days to adjust to the diets followed by a 5-day separate urinary and fecal collection. Five grams of ferric oxide was mixed with 100 g of diet and used as an indigestible marker to mark the beginning and end of fecal collection. Feces and urine were collected once daily, with weights and volumes recorded. Sulfuric acid (20%) was added (100 ml) prior to each daily urine collection to reduce NH_3 volatilization and preserve nitrogen. Daily fecal samples were pooled and frozen at −20 °C, and 20% of the daily total urinary volume was pooled and frozen at −20 °C until analyses were performed.

2.3. Sample analysis

Digesta samples were thawed, freeze-dried, and finely ground through a 1 mm screen using a cyclone mill (Cyclotec Sample Mill 1093, Sweden). Fecal samples were thawed and homogenized in a Hobart mixer for 10 min and sub-sampled. The sub-samples were freeze-dried and ground as described for digesta samples. Dry matter of maizes, diets, digesta, and fecal samples was determined using a vacuum oven at 60 °C for 12 h. A Hach–Kjeldahl was used to determine crude protein (CP) (Hach et al., 1987). Gross energy was determined via adiabatic bomb calorimetry (Parr Instrument Co., Moline, IL).

Amino acids were measured by the Pico •Tag® method (Waters Co., Milford, MA) using a Waters high-pressure liquid chromatograph (Waters, Co., Milford, MA) fitted with a 15-cm hydrolysate column. Samples were hydrolyzed for 24 h at 110 °C with 6N HCl prior to AA analysis. Cysteine and tryptophan concentrations were not determined. Chromium concentration in diets and digesta samples was determined according to AOAC (No. 975.03B, 1990).

2.4. Calculations and statistical analysis

Apparent ileal digestibility coefficients were calculated according to the following equation (Stein et al., 1999a):

$$\mathrm{CAID} = 1 - \left[\left(\frac{\mathrm{AA_d}}{\mathrm{AA_f}}\right) \times \left(\frac{\mathrm{Cr_f}}{\mathrm{Cr_d}}\right)\right], \tag{1}$$

where CAID is the coefficient for apparent ileal digestibility; AA_d the concentration of an amino acid or protein in the digesta (g/(kg DM)); AA_f the concentration of an amino acid or protein in the feed (g/(kg DM)); Cr_f the concentration of chromium in the feed (g/(kg DM)) and Cr_d is the concentration of chromium in the digesta (g/(kg DM)).

True ileal digestibility coefficients were calculated by correcting CAID for non-specific (basal) endogenous losses of protein and AA using the following equation (Rademacher et al., 1999):

$$\mathrm{CTID} = \mathrm{CAID} + \left(\frac{\mathrm{EAL}}{\mathrm{AA_f}}\right), \tag{2}$$

where CTID is the coefficient for true ileal digestibility; EAL the non-specific endogenous loss of protein or an AA (g/(kg DMI)) and AA_f is the dietary concentration of protein or the amino acid in the feed (g/(kg DM)). The non-specific endogenous losses used in these calculations were adapted from Rademacher et al. (1999). True ileal digestibility was calculated only for the indispensable AA.

Data were analyzed using MIXED procedure of SAS (SAS Stat Inc., Cary, NC). Basic assumptions of ANOVA were satisfied based on residual plots. In exp. 1, a linear model with main effects of square, collection nested within square, diet, and pig as a random variable were used in the following statistical model:

$$y_{ijkl} = \mu + \rho_i + \delta_j + \alpha_k + \beta_l + e_{ijkl},$$

where μ is the overall mean; ρ_i the fixed effect of the *i*th collection period within each Latin square; δ_j the random effect of pig; α_k the fixed effect of maize hybrid; β_l the fixed effect of square; e_{ijkl} the residual error and y_{ijkl} is the response for the *i*th period, *j*th pig, *k*th maize hybrid, and *l*th Latin square. Any non-significant effects were removed from the model and least-squares means were determined from the reduced model. Latin square effect in both experiments was not significant ($P > 0.05$), hence data from both squares were pooled. In exp. 2, the linear model included main fixed classification effects of square, collection nested within square, and diets; pig nested within square was included as a random effect. Missing data were analyzed as missing values in SAS. Differences between all pair-wise least-squares mean comparisons were evaluated using Tukey–Kramer test (Younger, 1998). Statistical significance was based on an experiment wise type I error rate of 0.05. Correlation was determined between feed intake and mean CAID and CTID using CORR procedures of SAS.

3. Results and discussion

3.1. Chemical composition

Geometric mean diameters were similar among the test maizes with 0.92, 0.93, 0.95, 0.92, 0.81, 0.93, and 0.85 mm for HO, IHO, WX, IWX, HL, YD1, and YD2, respectively. The coefficient of variation was 5.8%. Nutrient composition of the seven test maizes is presented in Table 3. The major differences in nutrient concentrations were observed for crude protein and ether extracts. Crude protein ranged from 83.6 to 108.1 g/kg in the hybrids with YD1 and HO having the highest CP concentrations. High oil also had the highest value for ether extract, i.e. 79.3 g/kg while all of the other maize samples ranged from 39.7 to 54.4 g/kg. These values are in agreement with Adeola and Bajjalieh (1997) who reported ether extract concentration ranging from 54.1 to 97.3 g/kg in three lines of high oil maize.

Amino acid concentrations of the test maizes were similar to reported values for other varieties of high oil, waxy, high lysine, and yellow dent maize with the largest variation occurring with leucine concentrations (Burgoon et al., 1992; Adeola and Bajjalieh, 1997). As expected, the highest lysine concentration was found in the HL maize. These results are in agreement with data reported by Burgoon et al. (1992).

Amino acid concentrations are reported in Table 4. Glutamic acid and leucine were the most abundant AA comprising approximately 170 and 100 g/(kg protein), across hybrids. High lysine maize had a higher proportion of lysine (41.4 g lysine/(kg protein)) than the

Table 3
Component and nutrient composition of maize hybrids (dry matter basis)

Items	Maize hybrids						
	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	Yellow dent 2
Crude protein (g/kg)	101	88.2	87.0	88.0	87.0	108.1	83.6
Ether extract (g/kg)	79.3	54.4	44.9	44.9	39.7	49.6	42.3
Gross energy (MJ/kg)	19.46	18.83	18.87	18.41	18.62	19.04	19.20
Ash (g/kg)	19.0	20.6	16.4	19.0	16.5	20.8	16.3
Amino acid (g/kg)							
Indispensable							
Arg	4.8	4.5	4.7	4.6	6.1	5.6	4.8
His	3.3	3.0	3.2	3.2	3.4	3.7	3.0
Ile	3.7	3.3	3.0	3.2	3.0	4.0	3.4
Leu	11.5	9.6	8.8	9.4	6.3	12.7	8.5
Lys	2.6	2.4	2.6	2.5	3.6	2.9	2.7
Met	2.4	2.1	2.1	2.2	2.0	2.4	1.9
Phe	4.9	4.2	4.0	4.2	3.3	5.4	4.0
Thr	3.3	3.0	3.0	3.0	3.2	3.6	2.6
Val	4.9	4.3	4.3	4.4	4.5	5.4	4.4
Dispensable							
Ala	7.4	6.1	5.8	6.2	5.0	7.8	6.7
Asp	6.5	5.7	6.6	4.9	8.2	7.3	3.0
Glu	18.1	15.1	14.9	14.9	12.7	19.9	14.2
Gly	3.7	3.3	3.5	3.4	4.0	4.0	3.5
Pro	8.6	7.3	7.5	7.7	6.8	9.5	6.6
Ser	4.8	4.3	4.3	4.3	4.0	5.3	4.3
Tyr	3.4	3.1	3.1	2.9	3.0	3.7	3.0

other maizes (32.3–25.7 g lysine/(kg protein)), as reported by Pond and Maner (1984) for HL and YD2. Data on the AA profile in the HL protein also show increases in arginine, aspartic acid, and glycine, but decreases in alanine and leucine that are similar to those reported by Pond and Maner (1984).

The other indispensable AA as a proportion of CP were similar across hybrids. Inclusion of the different maize samples in the diets resulted in CP concentration ranging from 82.7 to 109.3 g/kg (Table 5). In agreement with Adeola and Bajjalieh (1997), gross energy was highest in the HO diet with a value of 18.87 MJ/kg whereas all the other diets contained approximately 18.2 MJ/kg.

3.2. Amino acid digestibility

Apparent ileal AA digestibility coefficients for the maize samples are presented in Table 6. Indispensable AA CAID for IHO, IWX, and YD2 were somewhat lower than values reported by NRC (1998), but similar to values reported by Stein et al. (1999a). Feed intake was not correlated with AA CAID. The differences among current values and those reported by NRC (1998) may be due to the methods used to determine AA digestibility. Lower AA

Table 4
Protein amino acid concentration of maize hybrids (g/(kg protein), dry matter basis)

Amino acid	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	Yellow dent 2
Indispensable							
Arg	47.5	51.0	54.0	52.3	70.1	51.8	57.4
His	32.7	34.0	36.8	36.4	39.1	34.2	35.9
Ile	36.6	37.4	34.5	36.4	34.5	37.0	40.7
Leu	113.9	108.8	101.1	106.8	72.4	117.5	101.7
Lys	25.7	27.2	29.9	28.4	41.4	26.8	32.3
Met	23.8	23.8	24.1	25.0	23.0	22.2	22.7
Phe	48.5	47.6	46.0	47.7	37.9	50.0	47.8
Thr	32.7	34.0	34.5	34.1	36.8	33.3	31.1
Val	48.5	48.8	49.4	50.0	51.7	50.0	52.6
Dispensable							
Ala	73.3	69.2	66.7	70.5	57.5	72.2	80.1
Asp	64.4	64.6	75.9	55.7	94.3	67.5	35.9
Glu	179.2	171.2	171.3	169.3	146.0	184.1	169.9
Gly	36.6	37.4	40.2	38.6	46.0	37.0	41.9
Pro	85.1	82.8	86.2	87.5	78.2	87.9	78.9
Ser	47.5	48.8	49.4	48.9	46.0	49.0	51.4
Tyr	33.7	35.1	35.6	33.0	34.5	34.2	35.9

CAID values in cereal grains have been reported with the direct method compared to those obtained with the difference method (Fan and Sauer, 1995). In the present study as well as in the study by Stein et al. (1999a), the direct method was used to estimate CAID. The numerically greater CAID observed in YD1 and IHO in comparison to the other yellow dent maize varieties tested herein was unexpected, but similar to other reported studies (NRC, 1998; Stein et al., 1999a).

For HO and WX, AA CAID were not different ($P > 0.05$) from those obtained for IHO or YD2. Compared to IWX and YD2, WX maize had similar ($P > 0.05$) CAID for all AA. Although there is a paucity of published data for these maize hybrids, CAID data from the current study for IHO, WX and YD1 fall within published AA CAID ranges (Southern, 1991). High lysine maize had lower ($P < 0.05$) CAID than its near-isogenic maize for the majority of AA. However, except for isoleucine, leucine, methionine, alanine, and glutamic acid, no differences ($P > 0.05$) in CAID between HL and unrelated YD2 were observed. Results for HL are lower than those of Burgoon et al. (1992) who reported indispensable CAID for opaque-2 (another high lysine hybrid) and yellow dent maize ranging from 0.65 to 0.86, and 0.63 to 0.85, respectively, but YD1 coefficients were similar to those reported by Burgoon et al. (1992). In the maize varieties, low CAID for glycine and proline were observed because endogenous losses at the distal ileum of pigs are very high for proline and glycine (Stein et al., 1999b). Mean CAID for HO, WX, and HL were 0.64, 0.70, and 0.53, respectively.

Coefficients for true ileal digestibility were calculated for the indispensable AA (Table 7). Since AA CTID were calculated from AA CAID and the same basal endogenous AA contributions, AA digestibility patterns across treatments are similar. Amino acid CTID for

Table 5
Component and nutrient composition of experimental diets (dry matter basis)

Items	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	Yellow dent 2
Calculated							
Crude protein (g/kg)	100.6	85.4	85.6	85.6	79.3	103.6	77.5
Gross energy (MJ/kg)	18.79	18.20	18.24	17.78	17.99	18.41	18.54
Calcium (g/kg)	7.0	6.9	7.0	7.0	6.9	6.9	7.0
Phosphorus (g/kg)	5.7	5.7	5.7	5.7	5.7	5.7	5.7
ADFI (kg per day)	2.37	2.51	2.63	2.82	2.35	2.51	2.55
Analyzed							
Crude protein (g/kg)	96.4	95.1	84.3	85.5	86.5	109.3	82.7
Gross energy (MJ/kg)	18.87	18.24	18.37	18.24	18.12	18.33	17.99
Amino acid (g/kg)							
Indispensable							
Arg	4.7	4.2	4.2	3.9	6.4	5.0	4.0
His	3.6	3.1	3.0	2.9	3.8	3.8	2.7
Ile	3.8	3.2	2.9	3.1	2.8	3.9	2.6
Leu	10.9	9.8	8.6	8.7	6.2	13.0	7.4
Lys	2.5	2.2	2.5	2.3	3.4	2.6	2.3
Met	2.3	2.1	2.0	2.1	2.1	2.5	1.6
Phe	4.6	4.2	3.8	3.8	3.4	5.4	3.4
Thr	3.2	2.9	3.0	3.0	3.2	3.5	2.6
Val	4.7	4.3	4.0	4.0	4.5	5.1	3.6
Dispensable							
Ala	7.0	6.3	5.8	5.7	5.1	8.0	5.1
Asp	6.2	5.6	5.8	5.8	8.0	6.9	4.9
Glu	16.9	14.6	13.5	14.4	12.6	18.9	11.6
Gly	3.4	3.1	3.2	3.1	3.9	3.8	3.0
Pro	8.0	7.6	7.3	7.2	6.8	9.5	6.0
Ser	4.8	4.2	4.2	4.0	4.1	5.3	3.7
Tyr	3.3	3.0	2.9	2.7	3.1	3.6	2.6

HO were not different ($P > 0.05$) from AA CTID for IHO and YD2. Similarly, AA CTID for WX were similar ($P > 0.05$) to those obtained for IWX or YD2. Amino acid CTID for HL were lower ($P < 0.05$) than that of YD1, except for arginine and histidine. Also, HL AA CTID were similar to that of YD2 for arginine, histidine, lysine, and methionine but all other AA CTID were lower ($P < 0.05$).

Mean CTID for HO and WX were not different from their isogenic maize or YD2, but HL had lower CTID than YD1 and similar CTID to YD2. However, it should be pointed out that some hybrids had notably higher digestibility values and due to the large variance, statistical significance was not attained.

3.3. Nitrogen balance

Nitrogen utilization and dry matter digestibility of the seven test maize samples are reported in Table 8. Initial (19.2–20.4 kg) and final BW (33.3–33.4 kg) of the pigs were

Table 6
Apparent amino acid digestibility coefficients of high oil, waxy, and high lysine maize hybrids, their yellow dent isogenic maize and yellow dent maize varieties of related and unrelated genetics[a]

	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	S.E.M.[b]	Yellow dent 2 ± S.E.M.
n	4	4	4	4	4	4		8
Feed intake (kg per day)	2.37	2.51	2.63	2.82	2.35	2.51		2.55
Indispensable								
Arg	0.71 ab	0.73 ab	0.72 ab	0.63 b	0.75 a	0.78 a	0.04	0.68 ± 0.03 ab
His	0.72 ab	0.78 a	0.77 ab	0.66 b	0.68 ab	0.78 a	0.04	0.68 ± 0.03 b
Ile	0.73 a	0.77 a	0.74 a	0.66 a	0.51 b	0.76 a	0.04	0.65 ± 0.03 a
Leu	0.80 a	0.84 a	0.83 a	0.75 a	0.60 b	0.84 a	0.04	0.76 ± 0.03 a
Lys	0.58	0.66	0.64	0.55	0.52	0.66	0.05	0.55 ± 0.04
Met	0.74 ab	0.78 a	0.76 ab	0.68 abc	0.62 c	0.78 a	0.04	0.66 ± 0.03 bc
Phe	0.76 a	0.82 a	0.81 a	0.71 a	0.59 b	0.82 a	0.04	0.73 ± 0.03 a
Thr	0.51 ab	0.65 a	0.62 ab	0.50 abc	0.32 c	0.65 a	0.06	0.48 ± 0.05 bc
Val	0.65 ab	0.74 a	0.71 ab	0.60 abc	0.51 c	0.73 ab	0.05	0.61 ± 0.03 bc
Dispensable								
Ala	0.69 ab	0.80 a	0.73 ab	0.69 ab	0.48 c	0.77 a	0.04	0.65 ± 0.03 b
Asp	0.73	0.77	0.81	0.71	0.69	0.83	0.05	0.79 ± 0.04
Glu	0.76 ab	0.82 a	0.80 a	0.75 ab	0.66 b	0.85 a	0.04	0.79 ± 0.03 a
Gly	0.30	0.37	0.49	0.34	0.23	0.48	0.10	0.25 ± 0.07
Pro	0.49 a	0.44 a	0.28 ab	0.28 ab	0.26 ab	0.54 a	0.14	0.02 ± 0.1 b
Ser	0.70 ab	0.75 ab	0.73 ab	0.62 bc	0.57 c	0.78 a	0.05	0.67 ± 0.03 abc
Tyr	0.61 bc	0.73 a	0.68 ab	0.56 bc	0.51 c	0.71 a	0.05	0.61 ± 0.03 bc
Mean	0.65 abc	0.72 a	0.70 ab	0.61 abc	0.53 c	0.73 a	0.05	0.60 ± 0.03 bc

a–c: means in rows without common letters differ ($P < 0.05$).
[a] Values are least-squares means.
[b] Standard error of the mean.

Table 7
True amino acid digestibility coefficients of high oil, waxy, and high lysine maize hybrids, their yellow dent isogenics and yellow dent maize varieties of related and unrelated genetics[a]

Amino acid	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	S.E.M.[b]	Yellow dent 2 ± S.E.M.
Arg	0.79 ab	0.83 ab	0.81 ab	0.73 b	0.81 ab	0.85 a	0.04	0.78 ± 0.03 ab
His	0.78 ab	0.84 a	0.83 ab	0.72 b	0.73 b	0.83 ab	0.04	0.75 ± 0.03 ab
Ile	0.83 a	0.88 a	0.87 a	0.78 a	0.64 b	0.86 a	0.04	0.80 ± 0.03 a
Leu	0.84 a	0.89 a	0.88 a	0.80 a	0.68 b	0.88 a	0.04	0.82 ± 0.03 a
Lys	0.74 ab	0.84 a	0.81 a	0.72 ab	0.64 b	0.81 a	0.05	0.73 ± 0.04 ab
Met	0.79 ab	0.83 a	0.81 a	0.73 ab	0.67 b	0.83 a	0.04	0.73 ± 0.03 ab
Phe	0.83 a	0.91 a	0.89 a	0.80 a	0.69 b	0.89 a	0.04	0.83 ± 0.03 a
Thr	0.70 a	0.86 a	0.83 a	0.71 a	0.51 b	0.83 a	0.06	0.71 ± 0.05 a
Val	0.76 ab	0.86 a	0.85 a	0.73 ab	0.63 b	0.84 a	0.05	0.76 ± 0.03 a
Mean	0.78 ab	0.86 a	0.84 a	0.75 ab	0.67 b	0.85 a	0.04	0.77 ± 0.03 ab

a–c: means in rows without common letters differ ($P < 0.05$).
[a] Values are least-squares means.
[b] Standard error of the mean.

Table 8
Nitrogen utilization and dry matter digestibility of high oil, waxy, and high lysine maize hybrids, their yellow dent isogenic maizes and yellow dent maize varieties of related and unrelated genetics[a]

Item	High oil	Isogenic high oil	Waxy	Isogenic waxy	High lysine	Yellow dent 1	S.E.M.[b]	Yellow dent 2 ± S.E.M.
n	4	4	4	4	4	4		7
g per day								
DM intake	1066.5 b	1052.0 b	1118.3 ab	1068.9 b	1275.0 a	1076.0 b	54.9	1002.3 ± 39.6 b
Fecal DM	110.1 b	126.0 b	162.1 a	134.4 b	179.6 a	122.2 b	13.6	136.0 ± 10.8 b
N intake	16.3 bc	15.1 cd	14.8 cd	14.3 cd	17.7 ab	18.2 a	0.8	13.3 ± 0.6 d
N in feces	2.8	3.1	3.8	3.1	3.5	3.2	0.4	3.4 ± 0.3
N in urine	5.9 a	4.9 ab	4.1 ab	4.9 ab	4.5 ab	4.1 b	0.7	4.6 ± 0.5 ab
N absorbed[c]	13.8 b	11.7 c	10.7 cd	10.9 c	14.6 ab	15.4 a	0.7	9.6 ± 0.6 d
N retained[d]	7.9 bc	6.8 bcd	6.6 bcd	6.0 cd	10.1 ab	11.3 a	1.0	5.0 ± 0.6 d
Coefficient								
DM digestibility	0.90 a	0.88 bc	0.85 d	0.87 bc	0.86 cd	0.89 ab	0.01	0.86 ± 0.01 cd
N digestibility[e]	0.83 a	0.79 a	0.74 b	0.78 ab	0.81 a	0.83 a	0.02	0.74 ± 0.02 b
N retained/N intake	0.50 abc	0.46 abc	0.45 abc	0.42 bc	0.57 ab	0.62 a	0.05	0.39 ± 0.03 c
N retained/absorbed N	0.60 ab	0.58 ab	0.59 ab	0.53 ab	0.71 a	0.75 a	0.07	0.52 ± 0.04 b

a–c: means in rows without common letters differ ($P < 0.05$).

[a] Values are least-squares means.

[b] Standard error of the mean.

[c] N absorbed = N intake − N in feces.

[d] N retained = N intake − N in feces − N in urine.

[e] N digestibility = (N intake − N in feces)/N intake.

similar across treatments. Nitrogen intake did not differ between HO, WX, and HL maize and maizes of related genetics ($P > 0.05$). Nitrogen intake was higher ($P < 0.05$) in pigs fed HO and HL than that of pigs fed YD2. There was no difference ($P > 0.05$) in fecal N losses among any of the maize hybrids. Urinary N losses were not different ($P > 0.05$) when compared to isogenic maize and YD2. Nitrogen retention, absorption, and digestibility were higher ($P < 0.05$) for HO and HL than for YD2, but similar when compared to their respective isogenic maize, IHO, and YD1. Nitrogen retention and digestibility were not different between WX and IWX or WX and YD2. Nitrogen retained as a percentage of N absorbed was similar when compared to YD1 and higher ($P < 0.05$) than for YD2. Pigs fed HO and WX had similar N utilization compared to that of pigs fed their respective isogenic yellow dent maize or YD2. Overall, these results suggest that N in the specialty maize hybrids tested in the current study is not better retained or utilized by growing pigs than that in most yellow dent maize varieties. This finding is in contrast to data provided by Adeola and Bajjalieh (1997) for HO maize.

Nutritional benefits of HO maize compared to yellow dent maize have been reported in numerous practical feeding studies, such as increase in average daily gain (Pettigrew and Yang, 1997) and feed efficiency in grower and finisher pigs (Nordstrom et al., 1972; Orban et al., 1994), increase in weight gain in gestating sows, and colostrum fat concentration in lactating sows (Boyer, 1994). In the current study, high oil maize AA digestibility was similar to the AA digestibility measured in its paired yellow dent isogenic, and to a yellow dent of unrelated genetics. Similarly, in younger pigs fed HO, the current study shows that total tract N digestibility and N retention was not different in pigs fed most yellow dent maizes, except for YD2. Hence, the improved animal performance described above in other studies may be related to higher fat content and increased dry matter digestibility as shown in the current study. Amino acid digestibility in HL fed to 50-kg pigs was lower for most AA compared to its paired near-isogenic yellow dent maize, YD1. In addition, no differences in digestibility for the majority of AA between HL and YD2 maize were found. Furthermore, N retention, digestibility, and utilization were very similar between 19-kg pigs fed HL and those fed most of the other maizes tested, except for when compared to YD2 where HL was superior. Cromwell et al. (1984) found that compared to yellow dent maize, opaque-2 hybrids modified with single mutant genes (i.e. sugary-2, floury-2, waxy) tended to increase the rate and efficiency of gain in 14-kg pigs. In the current study, HL maize hybrid contained higher concentration of arginine and lysine and lower concentration of leucine, relative to yellow dent maize varieties. However, the improved AA profile of the HL maize did not increase N utilization compared to that in other maizes.

Waxy maize was shown to have no effect on average daily gain, average daily feed intake, or feed conversion compared to yellow dent maize fed to nursery pigs (Johnston, 1991). In parallel, the current study did not show any difference in AA ileal digestibility, N digestibility, retention or utilization in pigs fed the WX compared to that in pigs fed other yellow dent maize varieties. While waxy maize starch is unique in that it is devoid of amylose and composed of amylopectin, the current study did not show any improvement in total tract dry matter and N digestibility.

4. Conclusion

In summary, there were no differences in ileal AA digestibility and N utilization among the high oil and waxy maize and their respective isogenic maizes. High lysine maize had lower apparent ileal AA digestibility, but similar N utilization than its near-isogenic yellow dent maize. Thus, specialty maizes such as high oil, waxy, and high lysine offer no additional nutritional benefits over yellow dent maizes of similar genetic background for the growing pig. The study provides additional data to the small pool of published studies on the nutrient composition, AA digestibility and nitrogen utilization of high oil, waxy, and high lysine maize hybrids.

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