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Ileal Starch Digestibility, Protein and Amino Acid Digestibility, and Nitrogen Utilization of Nutrient-Dense Corn Hybrids Fed to Growing Pigs.

presented by

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has been accepted towards fulfillment
of the requirements for

Masters degree in Animal Science

[signature]
Major professor

Date 08/01/01

O-7639

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ILEAL STARCH DIGESTIBILITY, PROTEIN AND AMINO ACID DIGESTIBILITY, AND NITROGEN UTILIZATION OF NUTRIENT-DENSE CORN HYBRIDS FED TO GROWING PIGS

By

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A THESIS

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

MASTERS OF SCIENCE

Department of Animal Science

2001

ABSTRACT

ILEAL STARCH DIGESTIBILITY, PROTEIN AND AMINO ACID DIGESTIBILITY, AND NITROGEN UTILIZATION OF NUTRIENT-DENSE CORN HYBRIDS FED TO GROWING PIGS

By

Lara Lynn Andersen

Protein and starch quality of seven corns, high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and a normal yellow dent corn (NYD), were investigated in two experiments using growing pigs. Apparent and standardized amino acid digestibilities between the corn hybrids were determined. A trend existed, in which the hybrids, HO and HL, were lower ($P \leq .10$) in apparent and standardized digestibility as compared to their respective paired normal hybrids, HOPN and HLPN. Ileal starch digestibility was determined for two separate years. For years 1 and 2, HO, WX, and HL corn hybrids were higher ($P < .05$) in ileal starch digestibility as compared to YDPN. A positive, linear correlation ($P < .05$) was found to exist between ileal starch digestibility and apparent protein, true protein, and standardized ileal indispensable amino acid digestibility. The objective of a third experiment was to determine nitrogen (N) metabolism in growing pigs fed different corn hybrids. Nitrogen retained, N digestibility, and N utilization was similar between all pre-planned comparisons: HO vs HOPN, HL vs HLPN, WX vs WXPN, HO vs NYD, HL vs NYD, and WX vs NYD ($P > .10$).

I would like to dedicate this work to the one person who has been my true inspiration: my mother, Diana. My mother has been a constant source of support and professional advice throughout my life. She has been a tower of strength for her children and has provided a stellar example of what I should strive to become as an adult.

ACKNOWLEDGMENTS

I would like to thank Dr. Nathalie L. Trottier for believing in me and giving me the opportunity to pursue my Master's degree in swine nutrition. In addition, I would like to thank the Michigan Corn Marketing board for their financial support for this research project. I also thank Dr. Pao Ku for his endless hours of support that he provided me in the lab during my time here at Michigan State University. Furthermore, I would like to thank all of the fellow graduate students and staff of Michigan State University that provided support and insight. Specifically, I want to thank Janet Snow, Emily Otto, Juliana Perez-Laspiur, Pasha Lyvers, Xinfu Guan, Jeff Hill, Bob Burnett, Jane Link, Yun Ying (Jackie), Dewey Longuski, and David Main. There are also several people that deserve acknowledgments for the support they provided throughout this project: Dr. Hans Stein, Dr. Kent Ames, Johnna Seaman, Donna Barnes, and Heather Nederveld. I also thank the staff of the Michigan State University Swine Teaching and Research Facility; especially, Al Snedegar, Ray Kromer, Dwayne Simon, and Brian Story for providing technical support both at the research metabolism unit and main farm. I also wish to acknowledge my two best friends, Bridgitt Hency and Jennifer Jarzynka, for being so understanding and supportive in every way possible. Finally, I cannot forget to thank my parents, David Andersen and Diana Krueger, for their undying love and my fiancé, Timothy Worden, for his constant love and encouragement.

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INTRODUCTION

Corn is the major cereal crop of the United States and the second most important cereal grain worldwide. Corn typically provides adequate energy to growing pigs; however, it is often deficient in protein. Recently, the use of "nutrient dense" corn hybrids in swine diets has provided an alternative to feeding normal yellow dent corn hybrids to growing pigs. However, little is known about the amino acid availability and utilization of these genetically modified corns in growing pigs. Furthermore, research is available for corn starch digestibility in young pigs; however, there is no data available on the starch digestibility of various specialty corns in growing pigs. These questions are addressed in the following chapters. The first and second chapters address the protein, amino acid, and starch digestibility of the various corn hybrids. In addition, protein utilization is addressed in the third chapter. We hypothesized that the protein and amino acid digestibility and N utilization would be superior in the nutrient-dense hybrids as compared to their respective paired normal corns. Furthermore, we hypothesized that there was a positive, linear relationship between ileal starch digestibility and the following: protein and amino acid digestibility. Thus, the present research provides some insight as to what the benefits are, in terms of protein and starch digestibility, when feeding high-oil, high-lysine, and waxy corn hybrids as a replacement for normal dent corn hybrids in growing pigs.

Literature Review

Evidence of corn production has been traced as far back as 5000 B. C. (White, 1994). Corn is thought to have originated in Mexico and other South American countries, where the Mayan, Aztec, and Inca Indians had domesticated the crop and were using it for human consumption. From there, corn production spread northward into the present day Unites States and Canada.

Today, corn is the major cereal crop of the United States and the second most important cereal grain worldwide. In the U. S., corn production provides the number one grain used in livestock feeds. Corn typically provides adequate energy for livestock; however, it is often deficient in essential amino acids, vitamins, and minerals. Therefore, researchers have spent many years developing corn hybrids with increased nutrient concentrations that provide an advantage over the normal dent corn hybrids. Some "specialty corns," currently available due to advanced research and technology, are high-oil, high-lysine (opaque-2), and waxy corns. These specialty corn hybrids have the potential to provide a nutritional advantage to producers of growing pigs; however, little information is available on their nutrient digestibility and utilization.

Structure and nutrient composition of a standard corn kernel

The mature corn kernel consists of six distinct parts: 1) the tip cap, 2) the hull (also known as the pericarp), 3) the horny gluten part (floury endosperm), 4) the horny starch part (horny or vitreous endosperm), 5) the white starch part (soft starch), and 6) the germ (Hopkins, 1974). Hopkins (1974) also stated that the horny gluten, the horny starch part, and the white starch part comprise the endosperm of a conventional yellow dent corn kernel.

Table 1. Percentage composition of each part of the corn kernel (% basis)[a]

Kernel fraction	% of kernel	% Protein	% Oil	% Ash	% Starch
Tip cap	1.40	6.90	1.80	1.30	88-90
Hull	5-6	4.25	.86	.90	90-94
Horny gluten	8-14	25	5	1.5	68-71
Horny starch	45	10	.21	.21	88-90
White starch	25	5-8	.29	.31	92
Germ	11	20	35	10	35

[a]Adapted from averaged data of corn ears of low, medium, and high protein content (Hopkins, 1974).

The tip cap covers the base or tip of the corn kernel, and provides protection to the end of the germ. The hull is the very thin outer covering of the kernel. It consists largely of carbohydrates, especially fiber. Together, the tip cap and the hull comprise only about 7.5 % of the weight of the kernel. The horny gluten portion of the kernel lies immediately under the hull, and constitutes a second covering of the corn kernel. It comprises 8–14% of the grain, and contains approximately 25% protein, making it the richest supply of protein within the standard corn kernel. The horny starch part lies next to the horny gluten and contains approximately 90% starch; yet, it also contains approximately 10% protein. The white starchy part occupies the crown end of the kernel above the germ and is also rich in starch content (92%). However, the white starchy part is low in protein (5-8%). The germ occupies the center of the corn kernel toward the tip and extends about one-half to two-thirds the length of the kernel. It comprises approximately 11% of the kernel; however, this varies depending on the type of corn hybrid (more in high-oil corns and less in low-oil corns) (Hopkins et al., 1974).

Corn kernel carbohydrates

The corn kernel is comprised of 70-75% starch (Boyer, 1994). The majority of the starch (80-90%) is found within the endosperm (the horny gluten, the horny starch, and white starch parts). Corn starch exists as two distinct polymers: amylose and amylopectin. Amylose is a linear starch polymer of α-1,4-linked glucose units (Boyer, 1994). In contrast, amylopectin is a branched-chain polymer which has elongated α-1,4-linked glucose units, but also has α-1,6-linked branching points approximately every 20-25 glucose units (Gray, 1992).

Corn kernel proteins

A portion of the protein in a standard yellow dent corn kernel is found in the horny gluten (25%) and the germ (20%). The horny gluten and germ contain approximately 5% globulins, 7% albumins, 25% glutelins, and 52% prolamins (Boyer, 1994). The prolamins, which are the major protein class, are often referred to as the zein fraction. A high percentage of total protein in corn is found in the zein fraction.

Corn kernel lipids

Hopkins (1974) and Boyer (1994) described the corn kernel as containing approximately 4.4% oil, the majority of which is found within the germ (80-85%). The horny gluten, the horny and white starch, the hull, and the tip cap, together, provide approximately 7% oil (Hopkins, 1974). Triacylglycerides, which contain a mixture of saturated and unsaturated fatty acids, are the major component of most corn oils (Boyer, 1994). The majority of commercial corn oils contain high percentages of linoleic acid (50%) and low concentrations of linolenic acid (1%). The other fatty acids commonly found in commercial corn oils are: oleic (40%), palmitic (12%), and stearic (2%) acid (Boyer, 1994).

Waxy corn

Waxy corn was discovered in Shanghai, China in 1908. The endosperm of this Chinese variety of corn had a distinctly different texture and appearance than the common dent corns grown in the United States (Hanson, 1946). The endosperm of this corn variety was described as having a very dull and hard waxy-like appearance. In addition, this endosperm trait is controlled by a single recessive gene on chromosome nine and was thus designated the waxy gene (Fergason, 1994).

Until the early to mid 1930's, waxy corn production in the United States was limited. However, early research at the Iowa Agricultural Experiment Station revealed that the amylopectin starch from waxy corn had similar properties to tapioca starch taken from the roots of cassava plants (Shopmeyer et al., 1943). Therefore, due to difficulties of importing tapioca starch from the Far East during World War II, commercial production of waxy corn was increased.

Production of waxy corn

The most common breeding program for waxy corn is the simple backcross method. This method was established due to competition among private seed companies to provide the most superior waxy hybrid as fast as possible. Yields for most waxy hybrids

have come within 5% or less of the yields for most normal dent hybrids. In addition, waxy corn hybrids have higher test weights than their corresponding dent hybrids (Fergason, 1994).

Utilization of waxy corn

According to Johnston (1991) the unique properties of waxy cornstarch can be attributed to the fact that nearly 100% of the starch in waxy corn is amylopectin, while standard dent corn varieties contain starch that is approximately 25% amylose and 75% amylopectin. The majority of the commercially produced waxy corn is contracted out to wet milling companies. Wet milling of corn grain is a process which involves the separation of starch from other constituents, such as fiber, germ, protein, and other minor materials (Fergason, 1994). Waxy starches are used in a variety of ways in the paper, textile, and adhesive industries. In addition, waxy starches are often used in the food industry to improve the uniformity, stability, and texture of various food products (Fergason, 1994).

As a result of its successful use in the textile and food industries, studies were conducted to determine if waxy corn would provide any benefits when fed to livestock. McDonald (1973) observed an increase of more than 20% in average daily gains (ADG) when lambs were fed waxy corn relative to normal dent corns. In addition, McDonald (1973) observed an increase in feed efficiency approaching 10% in finishing beef cattle when fed waxy corn as compared with normal dent corns. However, when nursery pigs were fed waxy corn, there was no difference in ADG, average daily feed intake (ADFI), or feed conversion when compared to normal dent corn (Johnston, 1991). In a similar trial, growing pigs consumed more waxy corn than normal dent corn, but once again showed no significant difference in average daily gain or feed intake between the two corns. However, when given a choice between waxy and normal dent corn, they consumed 2.6 times more normal dent corn than waxy corn (Hanson, 1946). In another study where growing-finishing pigs were fed three different types of corn hybrids (opaque-2, waxy, and normal dent corn), waxy corn diets showed a trend toward lower average daily gains; however, the differences were not significant (Sachtleben, 1975). Also, dry matter intakes of growing pigs fed waxy corn based diets were depressed by as much as 45%, but dry matter digestibilities were similar for all three corn hybrids (Sachtleben, 1975). As a result of these earlier studies, waxy corn has never been considered a good replacement for most normal dent corn hybrids in livestock feed. No additional research has been conducted to evaluate further the nutritional value of waxy corn for livestock.

High-oil corn

The breeding of corn for higher oil contents which is of historical interest was initiated at the University of Illinois in 1896. In 1981, after greater than 80 generations of selection and "backcross" breeding, the Illinois high oil corn had an oil concentration of approximately 19% (Weber, 1983). However, the grain yields, ear size, and weights were dramatically reduced when compared to conventional corn hybrids. Furthermore, grain yields of modern high-oil hybrids generally decrease at oil levels greater than 8% (Lambert, 1994).

Production and nutritional composition of high-oil corn

Today, new high-oil hybrids are being produced under the "top-cross" breeding program. This method involves blending two types of hybrids, in which 3 % of the plants are "pollinators", while the remaining 97 % of the plants are a high performing "male-sterile" commercial hybrid. The pollen from the pollinator transfers the high oil trait onto the kernels of the male-sterile hybrids, resulting in a "top-cross" high-oil corn hybrid (Lauer, 1995). As a result of this method, new high-oil corn hybrids have kernel oil concentrations of approximately 6-8%, which is a 2-3% increase over most conventional corn hybrids (Lambert, 1994). In addition, this production strategy results in grain yields, ear size, and kernel weights similar to conventional normal yellow dent corn hybrids.

The corn germ consists of the scutellum and the embryo. The scutellum in most normal dent corn hybrids makes up about 10-12% of the total kernel dry weight; however, the scutellum contains 83-85% of the total oil in the corn kernel (Lambert, 1994). High-oil hybrids typically have a larger germ size, which is mostly scutellar tissue, and thus contributes to the increased oil content.

The increased oil content of high-oil corn hybrids have several added benefits: 1) high-oil corn has nutritional advantages for feeding because of a greater energy/unit of feed; 2) protein concentrations are higher and protein quality is enhanced because of the larger scutellum size compared to normal dent corn hybrids. Watson and Freeman (1975) reported that there is an increase of approximately .38% in protein content with each 1% increase in oil; 3) high-oil hybrids usually have a higher proportion of yellow pigments (carotenoids and xanthophylls) which are beneficial in poultry diets (Lambert, 1994).

Utilization of high-oil corn

In poultry, Han and Parsons (1987) compared high-oil and normal corn diets for laying hens and broiler chicks. Laying hens fed a high-oil corn diet containing 17% protein, from 23 to 38 weeks of age, had a better egg to feed ratio, egg production, and yield compared to laying hens fed a normal corn diet. In a second study, a comparison using broiler chicks from 8 to 22 days post-hatch fed diets containing high-oil (6-13% oil) versus normal corn (4.3% oil) showed that chicks fed the high-oil diet had superior gain/feed ratios (Han et al., 1987). In another study, Parsons et al. (1998) analyzed the true digestibility of amino acids and bioavailability of lysine in three high-oil (5.9-9.5% ether extract) corns and one conventional (4.3% ether extract) corn in cecectomized roosters. True digestibility of most amino acids for two of the high-oil (6.6 and 9.5%) corns were significantly higher than in conventional corn and the third high-oil (5.9%) corn. In addition, the bioavailability of lysine for all three high-oil corns was equal to or greater than that in conventional corn.

Several studies have also looked at the effects of feeding high-oil corn to pigs. Nordstrom et al. (1972) showed that a significant reduction in feed/gain occurred in growing pigs fed high-oil corn varieties when compared to pigs fed a normal corn diet. The high oil corn varieties had higher percent dry matter, percent ether extract, and gross energy (kcal/kg) than the normal corn. The high-oil varieties also contained more protein and slightly more of the essential amino acids on a dry weight basis. However, when calculated as a percent of protein, the amino acids and protein quality of the high-oil varieties were equal to that of the normal corn.

Adeola et al. (1994) measured the growth performance and utilization of energy of three high-oil (5.4-9.7% ether extract) corn varieties and a normal corn (4.2% ether extract). The digestible and metabolizable energy content of the normal corn was consistently lower than all three of the high-oil corns. In addition, pigs fed the high-oil corn with 9.7% ether extract gained 9% more weight daily than pigs fed the diet containing the normal corn. Also, there was an improvement in feed efficiency of 8-10% in pigs fed the high-oil corns when compared to the normal corn. Therefore, the data suggests that high-oil corn is beneficial as a replacement for conventional corn in the livestock industry.

Opaque-2/High-lysine corn

The existence of the opaque-2 gene has been known since 1935. Yet, it was not until 1963 that Mertz et al. (1964) determined that the opaque-2 mutant endosperm had a different amino acid pattern. There were increases in amino acids such as tryptophan, histidine, arginine, aspartic acid, glycine, and cystine, but less glutamic acid, alanine, methionine, leucine, and tyrosine. Furthermore, the opaque-2 kernel contained 69% more lysine than most standard dent corns. The major reason for the change in the amino acid pattern in opaque-2 hybrids is attributed to a reduction in the ratio of zein (15.7%) to glutelin (42.3%) based on total protein as well as an increase in the lysine content of the acid and alcohol-soluble zein fractions (Mertz, 1964). Murphy and Dalby (1971) showed that the opaque-2 gene actually suppresses the synthesis of the zein, especially during early development of the endosperm, resulting in a lower zein fraction and a higher lysine and tryptophan content of opaque-2 corn at maturity. Most standard dent corns from North America contain 41 – 52% zein and 17 – 28% glutelin (Mertz and Bates, 1964).

Production of Opaque-2/ High-lysine corn

The opaque-2 gene, using the backcross method, has been incorporated into parental seed stocks to produce high-lysine corn hybrids (West and Kincer, 1985). Although these hybrids have an amino acid composition that improves the nutritional quality of corn, their utilization in animal feeds is currently limited. Reasons for the lack of use of these hybrids in the U.S. are lower agronomic performances, such as lower yields due to lower endosperm size and reduced kernel weight, in comparison with normal dent corns. Also, the soft chalky appearance of high-lysine kernel is undesirable to producers (Boyer, 1994). Other problems previously associated with high-lysine hybrids included increased moisture content, higher incidence of ear rot, greater damage from insects, poor germination, increased kernel breakage, and a thicker pericarp (Boyer, 1994). Finally, the availability of relatively inexpensive protein supplements, primarily soybean meal, have also limited the use of high-lysine hybrids in livestock feeds.

Utilization of Opaque-2/ High-lysine corn

The use of high-lysine hybrids as a nutritional supplement for malnourished children in underdeveloped countries has been widely accepted. In 1980 Graham et al. tested the digestibility of energy and protein of normal, opaque-2 and a sugary-2 opaque-2 hybrid, both as a degerminated endosperm and as a whole kernel meal in eight convalescent malnourished children from 10 to 25 months of age. The results showed that the energy provided to malnourished infants by feeding the opaque-2 (91.2%) endosperm meal was greater than that provided by the normal corn (83.2%) and the sugary-2 opaque-2 (82.1%) endosperm meals. However, the normal corn (73.2%) whole kernel meal provided greater energy than that provided by opaque-2 (68.6%) and sugary-2 opaque-2 (67.2%) whole kernel meals. Apparent absorption of nitrogen (N) from the three whole kernel corn meals were not significantly different. Furthermore, apparent retention of N from the normal whole kernel meal was lower than from the opaque-2 and sugary-2 opaque-2 meals, but not significantly so. In a similar study by Graham et al. (1989) the digestibility and utilization of casein, high-lysine corn and normal corn was determined in six recovering malnourished children of varying age from 7.9 to 18.5 months. Results showed that energy digestibility of high-lysine corn (87%) was less than the casein diet (94%), but greater than the normal corn diet (84%). Apparent N absorption from high-lysine corn (70%) and normal corn (69%) were much lower than from casein (82%). In addition, apparent retention of N from high-lysine corn (34%) was less than from casein (41%) but greater than from normal corn (22%). Thus, opaque-2/ high-lysine corn provides an important nutritional advantage to malnourished children when compared with normal corn in underdeveloped countries.

Several studies have also been conducted to determine the effects of feeding opaque-2/ high-lysine corn to swine. The initial opaque-2 corn work with pigs was conducted by Beeson and Picket of Purdue University (Maner, 1975). They showed that pigs between 13.8 and 25.7 kg grew 3.6 times faster on opaque-2 corn than on normal corn. Also, pigs fed opaque-2 corn grew at a rate equal to that of pigs fed a diet of normal corn and soybean meal that supplied the same amount of crude protein (11.6%). In addition, finishing pigs, with an initial body weight of 59 kg, gained weight 50% faster when fed opaque-2 corn based diets compared to pigs fed normal corn based diets and at about the same rate as pigs fed normal corn and soybean meal based diets containing 13% protein.

Cromwell et al. (1967) conducted two experiments to determine whether the improved performance of swine fed opaque-2 corn was due to its high lysine content alone. In the first experiment, the diets tested were two basal diets consisting of approximately 97% opaque-2 corn and normal corn, respectively. In addition, L-lysine HCl was added alone and in combination with L-tryptophan, to raise the dietary lysine and tryptophan levels to that of the opaque-2 corn. In the second experiment, opaque-2 and normal corn in conventional corn-soybean meal diets were compared at 16, 14, and 11.8% protein. Again, L-lysine HCl and L-tryptophan, singly or in combination, were added to all the normal corn diets. In both experiments, pigs fed the opaque-2 corn gained significantly faster and more efficiently than pigs fed the normal corn without lysine and tryptophan supplementation. Compared with pigs fed the normal corn diets in both experiments, the results showed no beneficial responses in gains and only a slight improvement in feed efficiency by raising the lysine content of the normal corn diet to that of the opaque-2 diet; indicating that the beneficial effects of opaque-2 corn for the pig do not lie solely in its higher lysine content. Pigs responded more to tryptophan than to lysine supplementation, suggesting that tryptophan was more limiting than lysine in normal corn at low dietary protein levels. Thus, the data suggests that the improved response in pigs fed opaque-2 corn is primarily due to its higher content of both lysine and tryptophan.

Asche et al. (1986) determined the effects of corn type, normal yellow dent corn and high-lysine corn, on energy and N digestibility. The results showed that dry matter, en

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energy and N digestibilities were not significantly different between corn types. Thus, this indicates that energy and N digestibility of high-lysine corn in typical diets for growing pigs are similar to those on normal yellow dent corn diets.

Burgoon et al. (1992) tested a low-protein, high-lysine corn diet in starter and grow-finishing pigs and determined that high-lysine corn did not provide an adequate supply of protein to starter pigs but was adequate for grow-finishing pigs. Therefore, even with the agronomic problems often associated with the opaque-2/ high-lysine corns, the high protein quality provides an important nutritional advantage to malnourished infants and growing pigs.

Starch: Digestion and utilization

Starch is the major storage carbohydrate and the most common digestible polysaccharide found in plants. Starch represents about 70-80% of most corn grains, a large percentage of many roots and tubers, and is a major component of many grain legumes. Corn is the most common source of starch in the world. In the U.S., approximately 95% of commercial starch is produced from corn. The pericarp of the corn kernel, which encases the embryo or germ as well as the endosperm, contains most of the starch. The typical corn endosperm is approximately 87% starch, which comprises 82% of its total grain weight (White, 1994).

Starch molecule

Starch is a polymeric carbohydrate consisting of glucose units linked together through α-1,4 and α-1,6 D-glucosidic bonds. Starch is stored in highly organized granules enmeshed in a protein matrix as two major types of polymers, i.e., amylose and amylopectin.

The average amylose molecule is essentially a linear polymer of α-1,4-linked D-glucose units having a molecular weight of 100 kDa (~ 600 glucose units). The proportion of amylose in starch ranges from 0 to 80%, depending upon the plant species; however, normal cereal starches contain approximately 20 to 30% amylose (Rooney and Pflugfelder, 1986).

Amylopectin is a much larger, branched polymer which is the most abundant component of normal starches (Rooney and Pflugfelder,1986). Amylopectin also contains linear chains of α-1,4-linked D-glucose, but has α-1,6 branch points every 20-25 glucose units. Amylopectin comprises 70-80% of most cereal grain starches and is the only starch in waxy genotypes of corn, sorghum, barley, rice, and millet. In general, amylopectin's molecular weight is approximately 1000 kDa (~ 6000 glucose units).

The amylopectin, amylose and intermediate fraction molecules are packed tightly within tiny water-insoluble starch granules and are held together by hydrogen bonding. The starch granules are formed inside the cellular organelle called the amyloplast; however, each species within the plant kingdom produces starch granules of different sizes, shapes, and stability. Grain starches usually have smaller granules than root and tuber starches, and their size distribution is usually very wide. Root and tuber starch granules are much larger and of a narrower size distribution. Legumes generally have granules of intermediate size, and their distribution falls between the grains and tubers (Moran et al., 1982).

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Starch granule

Starch granules are pseudo-crystals that have organized (crystalline) and relatively non-organized (amorphous) areas. These granules resist water entry and enzyme attack (Rooney and Pflugfelder, 1986). Rooney and Pflugfelder (1986) stated that the amylopectin comprises the crystalline region, and has a cluster-like structure, whereas the amylose may be found in both crystalline and amorphous regions. The amorphous region is rich in amylose and less dense than the crystalline areas. Water moves freely through the amorphous region, and amylase attack on the granule occurs here. In addition, any chemical modification of starches for industrial use primarily affects the amorphous region.

Starch digestion in livestock

In most animals the vast majority of starches are digested within the intestinal lumen by α-amylase (amylase, also known as α-1,4 glucano-hydrolase), which converts starch to maltose. Amylase randomly hydrolyzes α-1,4 glucosidic bonds within starch molecules, generating maltose, and branched and linear dextrins (principally from hydrolysis of amylopectin). A small amount of amylase is present in the saliva of some species; however, amylase is synthesized in the pancreas and secreted via the pancreatic duct into the duodenum of the small intestine. Salivary amylase and pancreatic amylases are of critical importance in starch digestion in nonruminants (Rooney and Pflugfelder, 1986). In fowl, starch digestion is almost exclusively accomplished by pancreatic amylase as there is no salivary amylase available (Moran et al., 1982). Although swine have salivary amylase, pancreatic amylase digests the majority of the starch. In addition, the pancreatic sources found in swine and fowl are very similar. In contrast, ruminants fe

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fed oats, barley, or wheat as whole or crushed grain, will ferment up to 90% of the starch within the rumen (Orskov, 1986). Due to a slower rate of starch digestion in corn, up to 40% of corn starch can bypass the rumen and undergo further digestion within the intestine (Orskov, 1986).

The digestibility of starch can be affected by several factors, including the structure of the starch granule and(or) grain kernel, protein-starch interactions, amount of amylase production and(or) secretion, pH levels within the small intestine and the rate of passage in the gastrointestinal tract. In general, cereal starches are more easily digested than root and tuber starches, while legume starches have intermediate digestibility (Rooney and Pflugfelder, 1986). Digestibility of a starch is generally inversely proportional to amylose content. For example, high-amylose corn has poor digestibility in both raw and cooked forms, while waxy cereal starches are among the most digestible of all starches. In addition, interactions with proteins from cereal grains, such as corn and sorghum, can reduce the susceptibility of both native and processed starch to enzyme hydrolysis.

Cunningham (1959) studied the ability of baby pigs to digest carbohydrates prior to weaning. Baby pigs at birth, 15, 24, and 25 days were starved for 16 hours, after which a stomach tube was inserted. Raw cornstarch, soluble starch, maltose, and glucose were injected into the gut via a stomach tube. Digestibility of glucose (98%) and maltose (89%) at the large intestine was highest in 25 day-old pigs. Raw cornstarch digestibility increased with age, but was still very inefficient (48%) at 25 days of age. No consistent trend was observed for soluble starch digestibility at the end of the large intestine; however, soluble starch was significantly higher than raw cornstarch digestibility values.

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Van der Poel et al. (1992) conducted a study in which grower pigs were fed diets containing 30% raw or processed whole faba beans. The effects of treatment on apparent ileal and fecal digestibility of starch were investigated. No difference was observed in ileal starch digestibility between the raw (97.7%) and processed (98%) faba bean diets. Furthermore, fecal starch digestibility was complete (99.9%) for both raw and processed faba bean diets.

In another study, Walker et al. (1993) determined the effects of carbohydrate source on starch digestibility in mature dogs. Diets consisting of 67% extruded grain (corn and rice) and 33% meat-based were fed to eight dogs fitted with ileal T-cannulas. Initial starch content of the diet was different for corn (47.8%) and rice (57.4%). The results indicated that ileal starch digestion was similar between corn (99.4%) and rice (99.5%). Fecal starch digestion was nearly complete for rice (99.9%) and corn (99.8%).

In a similar study conducted with growing pigs, Everts et al. (1996) determined the ileal starch digestibility of cornstarch and native pea starch. Once again, ileal starch digestibility was similar between cornstarch (98.3%) and native pea starch (97.5%). In addition, starch digestibility at the end of the large intestine was nearly complete (99%) for both cornstarch and native pea starch.

Thus, the four studies discussed above suggest that starch digestion is complete at the terminal ileum with a very low level of starch digestion occurring in the large intestine, and is unaffected by starch source.

Protein digestibility

Digestibility of amino acids (AA) can be measured by two different procedures. Initially, the fecal collection procedure, developed by Kuiken and Lyman (1948), was used to determine AA digestibility. Using this procedure, digestible AA values represent the amount of AA in the feedstuff that disappear over the total digestive tract of the pig. However, due to recent experiments, it is generally agreed that the ileal collection of digesta from the terminal ileum is more accurate than the traditional fecal approach (Sauer and Ozimek, 1986). This is due to the fact that estimates of nutrient digestibility in the pig obtained by comparing the composition of fecal matter to feed are confounded by digestive processes in the lower tract, particularly the microbial activity in the cecum and large intestine (Easter and Tanksley, 1973). Thus, AA digestibilities obtained by the fecal analysis method are, for most AA in feedstuffs, higher than those obtained by the ileal digesta collection method. Therefore, depending on the AA and on the feedstuff, digestibilities obtained by the fecal analysis method overestimate those obtained by the ileal digesta collection method (Sauer et al., 1989). However, ileal digesta collected at the terminal ileum is confounded by the presence of endogenous AA. Also, digestibility of AA can be measured by two different methods. Most of the ileal AA digestibility coefficients are obtained with the direct method. Using this method, the test diet is formulated in such a manner that the test feedstuff provides the sole source of protein; therefore, the digestibility coefficients can be directly determined by the difference between the amount of feedstuff ingested and the amount collected at the terminal ileum.

There are several techniques used to collect digesta from pigs. The simple "T"-piece cannula is the most commonly used cannulation technique in the U.S. and the Netherlands. The "T" cannula is inserted into the terminal ileum about 5-10 cm anterior of the ileocecal valve (Sauer et al., 1989). Digesta is collected from the cannula after the pigs have been on the test diets for 5-10 days. The advantages of this technique are: 1) the

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surgery is relatively simple; 2) collections can be made over a long period of time; 3) fecal sampling can also be undertaken; and 4) it is possible to utilize one set of pigs for a number of collections. The disadvantages are: 1) leakage occurs around the base of the cannula which causes discomfort to the pig; 2) considerable labor and expertise are required to minimize irritation from the leakage (Batterham, 1994); and 3) an indigestible marker must be included in the test diet. Other problem associated with the "T" cannula is the question of obtaining a "representative" sample of digesta and possible shortcomings of the indigestible markers (Sauer, 1989).

Due to the uncertainties associated with obtaining a representative sample and the shortcomings of indigestible markers, pigs are often fitted with re-entrant cannulas. This type of cannula is inserted into either the terminal ileum, or either side of the ileocecal valve or posterior to it (Sauer et al., 1989). The advantage with this technique is that a total collection of digesta is possible without feeding an indigestible marker. The major disadvantage is that the small intestine is severed leading to possible blockage of the cannula depending on what feedstuff is fed to the animal. The extent to which blockage occurs increases with increasing particle size, crude fiber content, feed intake, and factors that increase the viscosity of the digesta (Sauer et al., 1989).

Within the past decade, a technique called the "ileal-rectal shunt" has become popular. With this technique the terminal ileum is anastomosed to the rectum, thereby allowing the digesta to bypass the large intestine and be collected from the anus. However, since the large intestine is by-passed it is necessary to compensate the pig for mineral losses (Sauer et al., 1989). The advantages of this technique are that it allows for complete collection of digesta over the growth span of the pig and that it is also suitable for routine

collections. The disadvantages of this technique are that substantial surgery is involved and that the technique is possibly unacceptable in many areas of animal ethics. Collection is often messy, due to the fact that the pig has little control over rectal function. There is also the question of whether the pig is functioning in a normal physiological manner.

The choice of technique may affect the calculated digestibility coefficients. For example, with the re-entrant cannulas, feeding high-fiber diets and diets of increased particle size often causes blockage, which ultimately affects the complete collection of endogenous losses (Sauer, 1989). This effect has not been observed with the "T" cannula or the "ileal-rectal shunt."

Apparent digestibility

Apparent digestibility measures the difference between the AA intake and AA excreted in the digesta, divided by the AA intake. The main disadvantage of measuring apparent digestibility is that it underestimates the actual digestibility of a feedstuff by not adjusting for endogenous nitrogen (N) or AA losses. In addition, apparent digestibility coefficients are dependent on the crude protein/AA levels in the test diet. Thus, apparent ileal AA digestibility coefficients increase curvilinearly with increasing AA levels in the diet (Furuya and Kaji, 1989).

Methods used to determine endogenous losses

Endogenous secretions are proteins or AA that originate from various regions within the body, including saliva, gastric juices, bile acids, intestinal juices, sloughed off epithelial cells and mucin (Soufrant, 1991; Grala et al., 1998). The endogenous crude

protein and AA losses are divided into two origins: basal (minimum) and specific endogenous losses. The basal loss is non-specific and related to dry matter intake, whereas the specific loss is related to inherent factors in the feedstuff, e.g. fiber and anti-nutritive factors (Rademacher et al., 1999). The feeding of a protein-free diet is one of the most common methods used to estimate basal ileal endogenous secretions. It is believed with this method that all nitrogen-containing compounds in the digesta are of endogenous origin. However, a problem associated with this method is that a protein-free diet fed to growing pigs may overestimate endogenous proline recovery as compared with feeding a protein-containing diet (de Lange et al., 1989). Thus, the proline recovered from a protein-free diet can then make up 30 % or more of the total amount of AA in the digesta. These high levels of proline are never observed when other methods are used. Another commonly used method is feeding a highly digestible protein source (e.g. wheat gluten or casein). With this method, it is assumed that the digestibility of these protein sources are 99%, and that the AA are completely absorbed. The regression method is another method for estimating endogenous losses, in which pigs are fed graded levels of protein in the diet and the recovery of N and AA at the terminal ileum is related to N and AA intake. Thus, via mathematical extrapolation, the recovery of N and AA at zero N and AA intake can be estimated (Fan et al., 1995). A final method that is not as commonly used as the above methods involves feeding a diet in which the sole source of N is enzymatically hydrolyzed casein. This hydrolyzed casein contains approximately 6 % free AA and 41 % di- and tri-peptides with a molecular weight of less than 5,000 Dalton (Da) (Leterne et al., 1994). It is assumed that all endogenous N is found in the ultrafiltrated fraction of the digesta with molecular weights greater than 10,000 Da. Thus, by separating the low

(<5,000 Da) and the high (>10,000 Da) molecular weight N-containing compounds in ileal digesta, a distinction is made between non-absorbed exogenous and endogenous nitrogen.

Factors that affect endogenous losses

Secretion of endogenous N is influenced by a number of animal factors, such as age and body weight, and several dietary factors (Nyachoti et al., 1997). The dietary factors that affect endogenous N losses include dry matter (DM) intake (Butts et al., 1993), level and quality of dietary protein (de Lange et al., 1990), and the presence of anti-nutritional factors, such as trypsin inhibitors and lectins (Schulze, 1995). Grala et al. (1998) found that a high trypsin inhibitor activity in soybean products fed to pigs was associated with high ileal losses of endogenous N. Fiber can also influence the secretion of endogenous gut proteins and N. Schulze et al. (1995) showed that increased dietary neutral detergent fiber content increased ileal DM and N flow, reduced N utilization, and resulted in an increased endogenous N loss. Therefore, the relationship between the amount of endogenous protein secreted into the gut and the endogenous N losses are dependent on the type of diet fed to pigs (Schulze, 1995; Grala et al., 1998).

True digestibility

True digestibility adjusts apparent digestibility measurements by correcting for endogenous N secretions. As a consequence, true digestibility values should be unaffected by the crude protein (CP) content of the diet (Batterham, 1994). Therefore, it can be assumed that true digestibility is a more accurate measurement of ileal AA

digestibility. However, true digestibility does not account for diet specific endogenous losses.

Standardized ileal digestibility

Recent research from France and the Netherlands has addressed the problem associated with true digestibility and diet specific endogenous losses. According to a reseach review by Rademacher et al. (1999), endogenous protein and AA losses can be separated into a basal (minimum) and an additional specific loss. The basal loss is non-specific and related only to DM intake. However, the specific losses are associated with the nutrient quality and inherent factors in the feedstuffs, i.e., fiber and anti-nutritive factors. If corrections are made for basal endogenous AA losses, then the corrected "standardized" ileal AA digestibility coefficients are independent of the AA levels within the diet. Therefore, apparent AA digestibility coefficients can be easily modified to standardized digestibility coefficients.

Conclusion

From the above literature, it is obvious that there are several advantages to feeding specialty corn hybrids. However, there are limited published values in terms of nutrient digestibility of these corn hybrids. Further research into protein, amino acid, and starch digestibility is warranted. Therefore, it is the objective of this thesis to determine the starch digestibility, protein digestibility, and protein utilization of waxy, high-oil, and high-lysine corn varieties.

CHAPTER 2: APPARENT AND STANDARDIZED ILEAL AMINO ACID DIGESTIBILITIES OF VARIOUS NUTRIENT-DENSE CORN HYBRIDS FED TO GROWING PIGS

Abstract

Eight ileally cannulated Yorkshire barrows (44.54 ± .80 kg) were used in an 8 x 8 Latin square design to determine apparent and standardized amino acid digestibilities among various nutrient-dense corn hybrids. The corn hybrids used in the study were: high-oil (HO), high-oil paired normal (HOPN), high-lysine (HL), high-lysine paired normal (HLPN), waxy (WX), waxy paired normal (WXPN), and normal yellow dent corn (NYD). Each diet consisted of one of the respective test corn hybrids (96.6%) providing the sole source of energy and protein. An additional 3.15% of the diet was made up of vitamins, minerals, dicalcium phosphate, limestone, and salt, which met or exceeded nutrient requirements of growing pigs (NRC, 1988). Chromic oxide (0.25%) was added as an indigestible marker. An amino acid top dress was also applied to the diets to meet or exceed NRC (1988) amino acid requirements for growing pigs. Pigs were allowed a 5-day adaptation to experimental diets, followed by two 12-hr digesta collections on d 6 and 7. The amino acid top dress was removed on d 5 of adaptation. A protein-free diet consisting of 81.93% cornstarch, 5% solka floc, 4% corn oil, and 5% sugar was fed to estimate endogenous amino acid losses at the terminal ileum. Apparent threonine (Thr), and alanine (Ala) digestibility coefficients for HO and HL were lower ($P \leq .10$) than their respective paired normal corn hybrids, HOPN and HLPN. In addition, standardized Phe, Thr, and Ala digestibility coefficients for HO and HL were lower ($P \leq .10$) than the paired normal corn hybrids, HOPN and HLPN. Overall, the hybrids had similar digestibility coefficients as compared to their respective paired normal corn hybrids.

Introduction

Many studies conducted by nutritionists indicate that formulating swine diets based on digestible rather than total amino acid content results in a better prediction of performance (Rademacher et al., 1999). Therefore, determining the amino acid utilization of various feedstuffs in growing pigs, the potential for obtaining maximum growth performance at cost effective rates is within our grasp. Recently, the use of "nutrient-dense" corn grains in swine diets has provided an alternative to feeding normal yellow dent corn to growing pigs. However, little is know about the amino acid availability and utilization of these corn hybrids in growing pigs. Thus, the goal of the present study was to determine the apparent and standardized ileal amino acid digestibility coefficients of high-oil corn, high-lysine corn, waxy corn, and their respective paired normal corn hybrids when fed to growing pigs.

Materials and Methods

Six corn hybrids: high-oil (HO; Cargill LH 202), high-oil paired normal (HOPN; Cargill 5990), waxy (WX; Pioneer 3528E), waxy paired normal (WXPN; Pioneer 3527), high-lysine (HL; Crows SL20), and a high-lysine paired normal (HLPN; Crows 375) were obtained from different commercial seed companies. The three seed companies provided the specialty corn hybrids along with their respective paired normal corn hybrids. An additional yellow dent corn (NYD; Citizens Elevator, Charlotte, MI) was used to represent a control, which had no known genetic similarities to that of the other six corn hybrids.

According to Jones and Andersen (1999), delayed planting combined with below normal temperatures for the 1997 growing season resulted in a corn crop that was 2-3 wk behind normal crop development. This made the 1997 corn crop more vulnerable to early frost damage before it reached maturity. Even if the corn was not damaged by frost, Jones and Andersen (1997) stated that immature corn would most likely exhibit a higher moisture, which would increase drying costs, and have a lower test weight. Therefore, harvest conditions for fall 1997 were not optimal for a good corn harvest in Michigan.

Eight Yorkshire barrows, with an initial average body weight of 40 kg, were fitted with simple T cannulas at the terminal ileum. Cannulas were surgically fitted and maintained according to Stein et al. (1998). The barrows were moved to smooth sided individual pens (1.78 m x 0.76 m) immediately following surgery and allowed 21 days of recuperation. Naxcel™ (3 cc per pig, Pharmacia and Upjohn Co., Kalamazoo, MI) was administered for the first three days post surgery. Daily feed intake, internal body temperature, and integrity of the cannulas were monitored daily during the recovery period. All pigs had free access to water. At the end of the recovery period, pigs were randomly assigned to one of seven corn hybrid diets plus a protein free diet in the 8 x 8 Latin square designed experiment. The pigs were allowed five days to adjust to the diets. On d 6 and 7 of each period, digesta was continuously collected from each pig for 12 h. Pigs were weighed at the beginning and at the end of the trial. Initial average body weight was 44.5 ± .8 kg and the final average body weight was 64.2 ± 1.5 kg. Environmental temperature of the room ranged from 21 to 28°C with a mean temperature of 21°C. The Michigan State University All University Committee for the Use and Care of Animals approved all animal protocols.

Diets

Each corn hybrid provided 96.6% of the total diet. Vitamins, minerals, dicalcium phosphate, limestone, and salt were included at 3.15% of the test corn diets. A protein free diet containing 81.93% cornstarch, 5% sugar, 5% solka flock, and 4% corn oil was also provided. Vitamins, minerals, dicalcium phosphate, limestone, and salt were included at 3.82% of the protein free diet. All vitamins and minerals met or exceeded NRC (1988) requirements. Chromic oxide was included at 0.25% of the diets as the marker for the determination of the recovery of protein and amino acids in the ileal digesta (Table 1). Barrows were allowed ad libitum access to feed during the three-week post-surgical recovery period and then restricted to approximately 90% of ad libitum intake during the experiment. Average daily feed intake (ADFI) was recorded by measuring daily feed allocations and then weighing back any waste feed. Diets were offered in two equal sized meals daily. An amino acid top dress was added to each meal during the adaptation period to meet the amino acid requirements for the seven deficient amino acids: lysine, methionine, isoleucine, threonine, valine, phenylalanine, and tryptophan (NRC, 1988). Amino acid top dresses were removed one day prior to the two-day digesta collection. The inclusion rates of the seven amino acids are reported in Table 4 in g/kg of diet for growing pigs between 50 and 80 kg. In addition, lysine intake was calculated for both the 5-day adaptation period in g/d and the 2-day collection period in g/d (Table 5).

Sample Preparation and analysis

Collected digesta and samples from each pig were homogenized and pooled over the 2-day collection and stored at -20°C until samples were prepared for further analysis. Digesta samples were thawed, freeze-dried, and finely ground through a cyclone mill (Cyclotec Sample Mill 1093; Tecator Co., Hoganas, Sweden) for dry matter (DM), crude protein (CP), amino acid (AA), and chromium analysis. Dry matter content of each corn sample, each diets, and each digesta sample was determined using a vacuum oven at 60°C for sixteen h. Gross energy of each corn hybrid sample and diet was determined via adiabatic bomb calorimetry (Parr Instrument Co., Moline, IL). Crude protein content of the respective test corn hybrid was determined using an automated LECO® elemental analysis instrument (AOAC # 990.03, crude protein and animal feeds; LECO® FP-2000; LECO Co., St. Joseph, MI).

Amino acid determination was performed using the Pico Tag® method (Waters Co., Milford, MA) which included acid hydrolysis of samples in an autoclave for 24 h at 110°C. Samples were then brought up to a volume of 40 mL, homogenized and filtered. The AA filtrate was then sub-sampled and dried using high-speed vacuum centrifugation. The AA hydrolysate was then reconstituted, re-dried, and derivatized with PITC® and separated using a Waters high pressure liquid chromatographer (Waters, Co., Milford, MA) fitted with a 15 cm hydrolysate column (Pico Tag® free amino acid analysis column, 3.9 mm x 300 mm; flow rate of 1 mL per min).

Chromium (Cr) concentration in diets, digesta and fecal matter was determined via perchloric digestion (Cantle, 1982). A 0.3 g sample was digested using 20 mL concentrated nitric acid and heated. After digestion, 10 mL of perchloric acid was added to oxidize the Cr^{3+} to Cr^{6+}. Oxidation completion was indicated when the solution turned from a bright orange to a clear, pale yellow. Samples were then weighed, diluted and analyzed by atomic absorption spectrophotometry (Unicam 93, TJA Unicam Co.; Cambridge, UK).

Statistical analysis

Data was analyzed using the Mixed procedure of SAS (1998) for amino acid digestibility in a Latin square design. A linear model with main effects of period, diet, and pig were used to test the dependent variable: amino acid digestibility. Three orthogonal and Three non-orthogonal contrasts were used to determine differences between the following pre-planned comparisons: HO vs. HOPN, WX vs. WXPN, HL vs. HLPN, HO vs. the four control corn hybrids (HOPN, WXPN, HLPN, and NYD), WX vs. the four control corn hybrids, and HL vs. the four control corn hybrids at one levels of significance ($P < .05$). The General Linear Model procedure of SAS (1998) was used to determine if pig and period were significant within the model. Both pig and period were found to be significant ($P < .05$), except for Thr, His, and Asp. The apparent and standardized amino acid digestibilities by age of pigs in weeks are found in Appendices B, C, D and E.

Results

Table 2 represents the chemically determined nutrient composition of the seven corn hybrids. Dry matter and gross energy was similar across all seven corn hybrids. Crude protein ranged from 6.88 to 8.39% in the corn varieties with HOPN having the lowest protein content and HLPN having the highest protein content. The HO hybrid had the lowest ether extract at 3.52% while all the other corn hybrids ranged from 3.85 to 5.54%. Amino acid content of the corn hybrids were determined on a dry matter basis (Table 2). The highest lysine content was found in the HL hybrid at 0.30%. Arginine (Arg), histidine (His), isoleucine (Ile), leucine (Leu), phenylalanine (Phe), threonine (Thr), and valine (Val) concentrations ranged from 0.39 to 0.53, 0.29 to 0.37, 0.23 to 0.33, 0.60 to 1.00, 0.31 to 0.42, 0.23 to 0.32, and 0.36 to 0.43, respectively. Dry matter was similar

across all test corn hybrids (Table 2). Gross energy was highest in the HOPN diet at 4.78 Mcal/kg and lowest in the NYD diet at 4.35 Mcal/kg. All the other test diets contained approximately 4.51 Mcal/kg (Table 2).

Average daily feed intake ranged from 1.77 to 1.98 kg/d with a mean of 1.86 kg/d. Lysine intake (Table 5) during the adaptation period was highest in the HO diet at 20.77 g/d and lowest in the WXPN diet at 18.23 g/d. Lysine intake during the collection period was highest in the HL diet at 5.85 g/d and the lowest in the HLPN diet at 3.55 g/d.

Apparent indispensable ileal amino acid digestibilities (AIID) are reported in Table 6. There were no differences in AIID ($P > .05$) observed between WX vs WXPN and WX vs. the average of the four control corn hybrids (HOPN, WXPN, HLPN, and NYD). The HO corn had less ($P < .05$) Ile, Thr, Val, and lysine (Lys) than the HOPN corn hybrid. The HO had less ($P < .05$) Ile, Lys, Phe, Thr, and Val than the average of the four control corn hybrids. The HL corn had less ($P < .05$) Leu, Phe, and Thr than the HLPN corn. The HL corn had less ($P < .05$) Leu, Phe, and Thr than the average of the four control corn hybrids. Total AIID was lower ($P < .05$) in HO for the comparisons HO vs. HOPN and HO vs. the four control corn hybrids.

Apparent dispensable ileal amino acid digestibilities (ADID) are reported in Table 7. There were no significant differences in ADID ($P > .05$) reported between WX and WXPN. However, the WX corn had less ($P < .05$) aspartate (Asp) and higher ($P < .05$) glutamate (Glu) and proline (Pro) than the average of the four control corn hybrids. The HO corn had less ($P < .05$) alanine (Ala) and Asp than the HOPN corn. Furthermore, the comparison between HO and the four control corn hybrids resulted in lower ($P < .05$) values for Ala and Gly in HO. The HL corn had less($P < .05$) Ala and Pro, and higher

Asp ($P < .05$) than the HLPN corn. In addition, the HL had less Pro ($P < .05$), and higher Asp ($P < .05$) than the average of the four control corn hybrids.

Standardized ileal amino acid digestibilities in Table 9 and 11 were calculated using the endogenous amino acid losses (mg/kg DMI) reported in Table 8. Standardized ileal digestibilities for the indispensable amino acids (SIID) are reported in Table 9 and 11. Values from Table 9 ranged from 71.90 to 95.30%. Values from Table 11 represent SIID values obtained from using endogenous amino acid losses from Rademacher et al. (1999), and ranged from 79.17 to 96.33%. No differences in SIID were detected for the comparison of WX vs. WXPN and WX vs. the average of the four control corn hybrids (Table 9 and 11). The HO corn had less ($P < .05$) Ile, Lys, Phe, and Val than HOPN (Table 9 and 11). Also, the HO corn hybrid had less ($P < .05$) Ile, Lys, Phe, Thr, and Val than the average of the four control corn hybrids (Table 9). The HL corn had less Arg, Leu, Phe, Thr ($P < .05$; Table 9 and 11), Ile, and Val (Table 11) than HLPN. However, only Thr and Phe was lower ($P < .05$) in the HL corn as compared to the average of the four control corn hybrids (Table 9 and 11).

Standardized dispensable ileal amino acid digestibilities (SDID) are reported in Table 10 and ranged from 64.87 to 132.65%. There were no differences reported for WX vs. WXPN and WX vs. the average of the four control corn hybrids. The HO corn had less ($P < .05$) Ala than the HOPN corn. Also, the HO corn had less ($P < .05$) Ala and Gly than the average of the four control corn hybrids. The HL corn had less ($P < .05$) Ala, Pro, Ser, and Gly than the HLPN corn. In addition, Asp was higher ($P < .05$) and Pro ($P < .05$) was lower in the HL corn, as compared to the average of the four respective control corn hyb

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hybrids. The only difference found for total SDID was between HL and HLPN, in which HL was lower ($P < .05$) than HLPN.

Discussion

The amino acid compositions of the corn hybrids were similar to other reported values for high-oil, high-lysine, and waxy corn (Cromwell et al., 1967; Adams and Jensen, 1987; Adeola and Bajjalieh, 1997; Burgoon et al., 1992; Nordstrom et al., 1972; Rosa et al., 1977; Wahlstrom et al., 1977; Parsons et al.,1998; and Snow et al., 1998). However, reported values for Leu concentration tended to be numerically higher as compared to our reported values.

The ratio of Lys as a percent of crude protein from HL and NYD were similar to reported values of Pond and Maner (1984) and Cromwell et al. (1967). Amino acid concentrations as a percent of crude protein for HL corn from the present study were similar to reported values of Cromwell et al. (1967) for Arg, His, Thr, Val, Asp, Gly, and Ser; but lower for Ile, Leu, Phe, Ala, Glu, Pro, and Tyr. In addition, all the indispensable amino acid ratios as a percent of crude protein for NYD were within range of published values (Pond and Maner, 1984; Cromwell et al., 1967); but all the dispensable amino acids ratios, except Ala and Ser, were lower than published values.

Apparent indispensable amino acid digestibilities for high-lysine corn fell within range of published values reported by Burgoon et al. (1992); but were higher than reported values from Snow et al. (1998). Apparent indispensable amino acid digestibilities for waxy corn from this study were higher than other published values (Soltwedel, 1996; Snow et al., 1998); except for Lys, which fell within the ranges of other reported values (Soltwedel, 1996; Snow et al., 1998). Apparent indispensable amino acid dige

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digestibility values for high-oil corn from this study were low for Ile and Lys, and high for His as compared to Carr (1994), Soltwedel (1996), and Snow et al. (1998). However, all other AIID fell within range of published values (Carr, 1994; Soltwedel, 1996; and Snow et al., 1998). In addition, all AIID for normal yellow dent corn fell within range of other published values (Sauer et al., 1977; Carr, 1994; Soltwedel, 1996; and Snow et al., 1998). Differences in ADID were observed in HO, HL, and NYD when comparing our values with published values from Snow et al. (1998). Our ADID values for HO corn were lower than reported values by Snow et al. (1998); however, our values for HL and NYD were numerically higher. In the present study, the apparent amino acid digestibility in HO was much lower than in HOPN. This may have been due to poor harvest conditions. Also, our HO results contradicted results reported by Snow et al. (1998), in which the HO hybrid out performed the HOPN corn for apparent amino acid digestibility. However, in the present study, the HLPN corn out performed the HL hybrid for apparent amino acid digestibility, which follows results reported by Snow et al. (1998) and suggests that the HLPN corn was superior to the HL hybrid.

A study conducted by Carlson and Bayley (1970) showed that endogenous amino acid losses could not be quantified when feeding a protein-rich diet; therefore, a protein free diet must be fed to account for endogenous ileal amino acid losses. Taverner (1981) reported that when protein free diets were fed, the greatest endogenous amino acids recovered in the ileal digesta were (in order from highest to lowest) proline, glycine, glutamic acid, aspartic acid, serine and threonine. De Lange et al. (1989) also reported that regardless of the kind of protein free diets fed (cornstarch, pectin, cellulose, or fat-based), the greatest endogenous losses at the distal ileum were proline, glycine, glutamic

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acid, aspartic acid, arginine, and serine. The amount of endogenous amino acids recovered at the terminal ileum were measured in the present study by feeding a protein free diet, consisting primarily of cornstarch. From our trial, the five greatest endogenous amino acid losses from highest to lowest were proline, glycine, glutamate, arginine, and alanine (Table 8). Therefore, our results follow closely with Taverner (1981) and de Lange's (1989) published values. In addition, our value for average endogenous arginine losses, 420 mg/kg of DMI, at the terminal ileum was higher than the reported values from feeding a protein free diet (Rademacher et al., 1999) and averaged values determined from five different methods from Rademacher et al. (1999). The rest of our amino acid losses at the terminal ileum were lower as compared to protein free values and averaged values from five different methods reported by Rademacher et al. (1999); however, values for the indispensable amino acids are not reported.

Standardized digestibility values for these nutrient-dense corn hybrids have not been published; however, Jondreville et al. (1995) and Rademacher et al. (1999) have published SIID values for normal dent corn. The SIID values from the present study were lower than published values reported by Jondreville (1995) and Rademacher et al. (1999), except for histidine, which was higher in the present study. However, our values for AIID for NYD were similar, if not the same, as values reported by Rademacher et al. (1999) for AIID. Thus, the differences in SIID for NYD are most likely due to endogenous secretions as mentioned above. Also, the standardized HO and HL amino acid digestibility values were lower as compared to the HOPN and HLPN digestibility values. This was not expected. Furthermore, the high-oil corn tested in this study had a lower oil content as compared to its respective paired normal corn, which probably contributed to the results that we obtained. In addition, the HLPN corn consistently outperformed the HL hybrid for feed intake, feed efficiency, and amino acid digestibility. The lower oil content in the HO hybrid and the poor performance of both the HO and HL hybrids may have been due to the poor growing and harvesting conditions in 1997. Therefore, we can assume that the HO and HL hybrids in the present study were not true 'nutrient-dense' corn hybrids. In the case of WX vs. WXPN for both apparent and standardized digestibility, no differences were detected. Furthermore, the WX hybrid was, in some cases, lower in apparent and standardized dispensable amino acid digestibility, when it was compared to the four control corn hybrids. Therefore, the amylopectin starch was probably not as readily digested by the pig as previously thought.

Table 11 represents SIID values using the averaged endogenous amino acid losses reported by Rademacher et al. (1999). These values were compared to the SIID values we calculated using the endogenous amino acid losses obtained from feeding a protein free diet (Table 9). Since our endogenous amino acid losses for arginine were higher than values reported by Rademacher et al. (1999), our SIID values were also numerically higher. However, the SIID values using Rademacher et al. (1999) averaged endogenous amino acid losses were numerically higher than our reported values for histidine, isoleucine, leucine, lysine, phenylalanine, threonine, and valine. Overall, our calculated SIID values were relatively close to calculated SIID values using Rademacher et al. (1999) averaged endogenous amino acid losses.

Implications

Apparent and standardized amino acid digestibility coefficients for nutrient-dense corn hybrids are now available. Amino acid digestibility in specialty corn hybrids was similar or in some cases higher when compared to normal dent corn. However, the year to year variability within corn hybrids makes it difficult to obtain consistent digestibility coefficients. Thus, more amino acid digestibility data of nutrient-dense corns are needed.

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Table 1: Composition of experimental diets (as-fed basis, %)

	Diets	
Ingredients	Corn-based	Protein free
Corn[a]	96.60	—
Cornstarch[b]	—	81.93
Solka flock[c]	—	5.00
Sugar	—	5.00
Corn oil[d]	—	4.00
Dicalcium phosphate	1.25	2.70
Limestone	0.85	0.07
Vitamin premix[e]	0.50	0.50
Trace mineral premix[f]	0.25	0.25
Salt	0.30	0.30
Chromic oxide[g]	0.25	0.25

[a] Corn varieties used were normal yellow dent corn (NYD), waxy (WX), waxy paired normal (WXPN), high-oil (HO), high-oil paired normal (HOPN), high-lysine (HL), andhigh-lysine paired normal (HLPN).
[b] Argo Foods, CPC International, Inc., Englewood Cliffs, NJ 07632-9976.
[c] Harland Teklad, Madison, WI 53744-4220.
[d] Kraft Foodservice, Inc., Glenview, IL 60025.
[e] Provided the following per kilogram of diet: 4,583 IU vitamin D_3, 55 IU vitamin E, 11 mg vitamin K, 3.66 mg menadione, 0.0275 mg vitamin B_{12}, 3.66 mg riboflavin, 14.67 mg d-pantothenic acid, 22 mg niacin, 0.913 mg thiamine, 0.825 mg pyridoxine.
[f] Provided the following per kilogram of diet: 335 g Ca, 5 g Fe, 5 g Zn, 5 mg Cu, 5 mg Mn, 150 μg Se and 75 μg I.
[g] Fisher, Itasca, IL 60143.

Table 2: Nutrient composition of corn hybrids[a] (dry matter basis)

Items	HO	HOPN	WX	WXPN	HL	HLPN	NYD
Dry matter, %	86.35	85.73	84.97	85.85	86.45	86.03	86.12
Crude protein, %	7.09	6.88	7.31	7.33	7.97	8.39	8.34
Gross energy, Mcal/kg	4.58	4.78	4.27	4.50	4.61	4.60	4.35
Ether Extract, %	3.52	5.54	4.24	4.01	4.50	3.85	4.00
Amino acids, %							
Indispensable							
Arg	0.43	0.41	0.40	0.39	0.53	0.42	0.40
His	0.30	0.29	0.29	0.30	0.37	0.33	0.34
Ile	0.23	0.24	0.26	0.23	0.26	0.29	0.33
Leu	0.74	0.70	0.71	0.73	0.60	0.94	1.00
Lys	0.19	0.20	0.21	0.21	0.30	0.22	0.20
Phe	0.32	0.31	0.32	0.32	0.31	0.39	0.42
Thr	0.23	0.27	0.26	0.24	0.26	0.32	0.31
Val	0.36	0.36	0.36	0.37	0.42	0.42	0.43
Dispensable							
Ala	0.50	0.49	0.49	0.50	0.48	0.61	0.62
Asp	0.36	0.45	0.39	0.48	0.66	0.36	0.28
Glu	1.05	1.11	1.09	1.13	1.15	1.16	0.92
Gly	0.27	0.28	0.28	0.27	0.34	0.30	0.29
Pro	0.57	0.51	0.56	0.54	0.58	0.96	0.71
Ser	0.38	0.34	0.35	0.35	0.36	0.39	0.42
Tyr	0.27	0.27	0.28	0.28	0.30	0.32	0.31
ΣAmino Acids	6.20	6.23	6.25	6.34	7.22	7.43	6.98

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and a normal yellow dent corn (NYD).

Table 3: Amino acid concentration as a percent of total crude protein[ab]

Amino acid	HO	HOPN	WX	WXPN	HL	HLPN	NYD
Indispensable							
Arg	6.06	5.96	5.47	5.32	6.65	5.01	4.80
His	4.23	4.22	3.97	4.09	4.64	2.93	4.08
Ile	3.24	3.49	3.56	3.14	3.26	3.46	3.96
Leu	10.44	1.02	9.71	9.96	7.53	11.20	11.99
Lys	2.68	2.91	2.87	2.86	3.76	2.62	2.40
Phe	4.51	4.51	4.38	4.37	3.89	4.65	5.04
Thr	3.24	3.92	3.56	3.27	3.26	3.81	3.72
Val	5.08	5.23	4.92	5.05	5.27	5.01	5.16
Dispensable							
Ala	7.05	7.12	6.70	6.82	6.02	7.27	7.43
Asp	5.08	6.54	5.34	6.55	8.28	4.29	3.36
Glu	14.81	16.13	14.91	15.42	14.43	13.83	11.03
Gly	3.81	4.07	3.83	3.68	4.27	3.58	3.48
Pro	8.04	7.41	7.66	7.37	7.28	11.44	8.51
Ser	5.36	4.94	.479	4.77	4.52	4.65	5.04
Tyr	3.81	3.92	3.83	3.82	3.76	3.81	3.72

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal dent corn (NYD).
[b] Calculated as (% amino acid / % protein) x 100.

Table 4: Amino acid top dress composition[abc] (g/kg)

Amino acid	HO	HOPN	WX	WXPN	HL	HLPN	NYD
Ile	1.86	1.76	1.65	1.80	1.63	1.32	.933
Leu	—	.150	—	—	1.06	—	—
Lys	6.89	6.71	6.57	6.57	5.48	6.50	6.66
Met	.070	.160	.010	—	.120	—	.050
Phe	1.18	1.34	1.20	1.19	1.30	.550	.160
Thr	2.82	2.43	2.49	2.70	2.46	1.93	1.96
Trp	1.70	1.70	1.70	1.70	1.70	1.70	1.70
Val	1.60	1.57	1.56	1.50	.983	.958	.908

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal dent corn (NYD).

[b] Amino acid top dress = amino acid requirement (NRC, 1988) for 50 to 80 kg pigs – amino acid content in the corn varieties.

[c] Added back to the test diets to meet the amino acid requirements.

Table 5: Lysine and feed intake of growing pigs fed corn hybrids[a]

	HO	HOPN	WX	WXPN	HL	HLPN	NYD	PF[b]
Feed intake[c], kg/d	2.38	2.34	2.28	2.10	2.17	1.97	2.39	1.96
Lysine intake[d], g/d	20.77	20.42	19.85	18.23	18.43	17.10	20.76	–
Feed intake[e], kg/d	2.06	1.99	1.98	1.97	1.95	1.64	2.05	1.70
Lysine intake[f], g/d	3.81	3.99	4.19	4.18	5.85	3.55	4.17	–

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal dent corn (NYD).
[b] A protein free (PF) diet was feed.
[c] Average daily feed intake during five-day adaptation to test diets.
[d] Average daily lysine intake during five-day adaptation to test diets.
[e] Average daily feed intake during two-day digesta collection.
[f] Average daily lysine intake during two-day digesta collection.

Table 6: Apparent indispensable amino acid digestibilities of the corn hybrids[a] (%)

	HO[c]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[b]
N	8	8	8	8	8	8	8	
Indispensable								
Arg	74.95	77.27	74.28	76.58	77.26	82.74	74.91	2.75
His	85.75	88.01	86.77	88.24	88.57	88.32	86.54	1.07
Ile	67.48*	74.60*	75.26	71.08	71.19	75.54	75.57	2.06
Leu	79.20	81.64	82.64	81.74	78.05*	84.71*	81.53	1.60
Lys	56.98*	65.89*	65.18	65.49	68.84	66.12	61.90	2.32
Phe	77.66*	81.00	81.62	80.45	77.18*	82.12*	80.66	1.54
Thr	60.99*	68.59*	66.27	65.67	60.66*	71.23*	70.63	2.40
Val	70.26*	75.49*	75.46	74.62	72.86	76.11	74.44	1.84
Mean	71.66*	76.56*	75.94	75.48	74.32	78.36	75.77	1.68

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c] If the superscript is on the paired normal corn, the comparison is between the hybrid and the respective paired normal corn. If the superscript is on the corn hybrid, the comparison is between the hybrid and the four control corns (HOPN, WXPN, HLPN, NYD).
* Means in rows with different superscripts are different ($P<.05$).

Table 7: Apparent dispensable amino acid digestibilities of the corn hybrids[a] (%)

	HO[c]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[b]
N	8	8	8	8	8	8	8	
Dispensable								
Ala	67.97*	74.68*	73.55	73.12	70.61	79.21*	72.04	2.39
Asp	69.08	79.32*	74.50*	75.46	81.77*	71.71*	57.70	3.67
Glu	76.00	80.24	80.23*	79.16	79.66	78.75	67.55	1.75
Gly	28.06*	35.95	35.33	32.43	39.18	49.56	37.32	6.95
Pro	1.52	-2.21	-17.01*	-4.50	-20.71*	76.96*	26.11	19.20
Ser	74.46	74.44	74.41	75.66	72.05	75.97	75.32	1.73
Tyr	78.50	81.44	82.25	81.34	79.67	82.46	79.45	1.60
Mean	56.51	60.55	57.61	58.96	57.46	73.52*	59.35	1.60

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).

[b] Pooled SEM represents the square root of the mean standard error divided by n.

[c] If the superscript is on the paired normal corn, the contrast is between the hybrid and its respective paired normal corn. If the superscript is on the corn hybrid, the contrast is between the hybrid and the four control corns (HOPN, WXPN, HLPN, and NYD).

* Means in rows with different superscripts are different (P<.05).

Table 8: Average values of the amount of endogenous AA losses determined at the terminal ileum with a protein free diet (mg/kg DMI)[a]

Amino Acid	Protein free diet[b]	Rademacher et al. Protein free diet[c]	Rademacher et al. Avg Values[d]
Indispensable			
Arg	420 ± 63	400 ± 80	390
His	118 ± 17	160 ± 20	190
Ile	204 ± 18	290 ± 80	380
Leu	327 ± 28	440 ± 10	490
Lys	203 ± 24	360 ± 10	400
Phe	181 ± 14	310 ± 70	340
Thr	338 ± 27	510 ± 80	610
Val	287 ± 27	410 ± 90	540
Dispensable			
Ala	415 ± 46	–	–
Asp	256 ± 41	–	–
Glu	561 ± 60	–	–
Gly	1027± 143	–	–
Pro	4313 ± 1019	–	–
Ser	329 ± 12	–	–
Tyr	160 ± 12	–	–

[a] DMI = Dry matter intake

[b] Average endogenous AA losses determined by using a protein free diet (Andersen, 2000).

[c] Average endogenous AA losses obtained from Rademacher et al. (1999) using a protein free diet.

[d] Average endogenous AA losses obtained from Rademacher et al. (1999) from five different methods (Protein free diet, wheat gluten/casein, regression analysis, enzymatically hydrolyzed casein, and infusion).

Table 9: Standardized indispensable amino acid digestibilities of the corn hybrids[ab] (%)

	HO[d]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[c]
N	8	8	8	8	8	8	8	
Indispensable								
Arg	85.62	87.93	84.99	87.61	85.52	95.30*	85.61	3.19
His	89.64	92.81	90.90	92.22	91.91	92.81	90.10	1.19
Ile	76.00*	83.26*	83.33	80.10	79.47	84.34	81.84	2.22
Leu	83.36	86.35	87.13	86.12	83.50†	88.90*	84.71	1.59
Lys	67.71*	76.41*	74.83	75.28	75.88	77.75	71.90	2.65
Phe	83.16*	87.13*	87.32	86.21	83.26*	87.97*	84.95	1.63
Thr	75.49*	81.71	79.32	80.05	74.01*	84.49*	81.46	2.44
Val	78.06*	83.68*	83.40	82.55	79.95	84.53	81.17	1.98
Mean	79.76*	84.84*	83.90	83.76	81.69	87. 01*	82.72	1.87

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).

[b] Calculated using endogenous amino acid losses obtained from feeding a protein free diet.

[c] Pooled SEM represents the square root of the mean standard error divided by n.

[d] If the superscript is on the paired normal corn, the contrast is between the hybrid and its respective paired normal corn. If the superscript is on the corn hybrid, the contrast is between the hybrid and the four control corns (HOPN, WXPN, HLPN, and NYD).

* Means in rows with different superscripts are different ($P<.05$).

Table 10: Standardized dispensible amino acid digestibilities of the corn hybrids[ab] (%)

	HO[d]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[c]
N	8	8	8	8	8	8	8	
Dispensable								
Ala	76.16*	83.38*	82.13	81.63	79.63	87.64*	78.75	2.59
Asp	76.05	85.21	81.10	80.94	85.80	80.67	67.03	3.67
Glu	81.23	85.47	85.42	84.24	84.75	84.76	73.68	1.82
Gly	64.87*	74.37	72.42	71.29	70.67	91.70*	72.58	8.53
Pro	75.42	85.09	60.88	76.93	56.96*	132.65*	87.47	22.89
Ser	82.98	84.56	83.84	85.15	81.48	86.43*	83.27	2.04
Tyr	84.21	87.65	88.03	87.20	85.27	88.77	84.56	1.72
Mean	77.27	83.68	79.11	81.05	77.79	93.23*	78.19	5.38

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).

[b] Calculated using endogenous amino acid losses obtained from feeding a protein free diet.

[c] Pool SEM represents the square root of the mean standard error divided by n.

[d] If the superscript is on the paired normal corn, the contrast is between the hybrid and its respective paired normal corn. If the superscript is on the corn hybrid, the contrast is between the hybrid and the four control corns (HOPN, WXPN, HLPN, and NYD).

* Means in rows with different superscripts are different (P<.05).

Table 11: Standardized indispensable amino acid digestibilities of the corn hybrids calculated using endogenous amino acid losses from Rademacher et al.[ab] (%)

	HO[d]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[c]
N	8	8	8	8	8	8	8	
Indispensable								
Arg	84.37	87.66	84.72	87.32	85.31	94.97*	85.33	3.18
His	92.32	95.14	93.75	94.96	94.21	95.90	92.56	1.35
Ile	84.15*	91.53*	91.02	88.71	87.37	92.75*	87.83	2.68
Leu	86.01*	89.30	89.91	88.95	86.92	91.52*	86.72	1.73
Lys	79.17*	87.63*	85.13	85.72	83.38	90.17*	82.59	3.41
Phe	83.01*	87.00*	88.17†	86.04	83.14*	87.84*	84.85	1.57
Thr	88.46	93.43	90.97	92.91	85.94*	96.33*	91.13	3.13
Val	85.66*	91.66*	91.14	90.26	86.86	92.73*	87.73	2.43

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).
[b] Calculated using endogenous amino acid losses from Rademacher et al. (1999).
[c] Pooled SEM represents the square root of the mean standard error divided by n.
[d] If the superscript is on the paired normal corn, the contrast is between the hybrid and its respective paired normal corn. If the superscript is on the corn hybrid, the contrast is between the hybrid and the four control corns (HOPN, WXPN, HLPN, and NYD).
* Means in rows with different superscripts are different ($P<.05$).

CHAPTER 3: ILEAL STARCH, APPARENT PROTEIN, AND TRUE PROTEIN DIGESTIBILITY VALUES FOR NUTRIENT-DENSE CORN HYBRIDS AND THE RELATIONSHIP BETWEEN ILEAL STARCH AND THE FOLLOWING: APPARENT PROTEIN, TRUE PROTEIN, AND STANDARDIZED INDISPENSABLE AMINO ACID DIGESTIBILITY

Abstract

Four ileally cannulated Yorkshire barrows (44.54 ± .80 kg) were used in two consecutive 4 x 4 Latin square experimental designs (Year 1; Snow et al. 1998) and 8 barrows were arranged in an 8 x 8 Latin square design (Year 2; Andersen, 2001) to determine ileal starch digestibilities and the relationship between ileal starch digestibility and the following: apparent protein, true protein, and standardized indispensable amino acid digestibility among various corn hybrids. The corn hybrids, diets, and amino acid top dress were the same as described by Andersen (2001). Pigs were allowed a 5-day adaptation to the test diets, followed by two 12-h digesta collections on d 6 and 7. Two fecal grab samples were taken from each pig during each 12-h digesta collection True protein digestibility of high-lysine paired normal (HLPN) ($P < .05$) was higher than the true protein digestibility of high-lysine (HL). In addition, HLPN ($P < .05$) was higher than HL for apparent protein digestibility. Year 2 ileal starch digestibility values were numerically higher than Year 1 ileal starch digestibility values. For Year 2, high-oil (HO) and HL ($P < .05$) corn hybrids had higher ileal starch digestibility than the four control corns (high-oil paired normal, HOPN; waxy paired normal, WXPN; HLPN, and normal yellow dent, NYD). The higher starch digestibility for Year 2 was probably due to variations in growing conditions from year to year. In addition, there was a positive correlation ($r = .175$, $P < .05$) between ileal starch digestibility and apparent and true protein digestibility.

Introduction

Many studies have determined protein, amino acid, and energy digestibility of various feedstuffs in growing pigs; however, little data is available for starch digestibility. Therefore, the objective of this study was to determine the ileal and fecal starch digestibility of various "nutrient-dense" corn hybrids and the relationship between starch digestibility and the following: protein and amino acid digestibility. Furthermore, we hypothesized that the relationship between ileal starch digestibility and protein and indispensable amino acid digestibility is positive and linear. In addition, we wanted to see if there would be any year to year variation in corn hybrid digestibility due to growing conditions from one year to the next.

Materials and Methods

Animals, diets, and experimental design were approved by Michigan State University All University Committee for Animal Use and Care. The same eight cannulated barrows, as described by Andersen (2001), were used to determine apparent ileal protein, true protein, and ileal starch digestibility (Year 2) coefficients of the seven corn hybrids: high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and a normal yellow dent corn (NYD). Year 2 data was obtained from feeding seven "nutrient-dense" corn hybrids (Andersen, 2001) that were harvested in 1997. Data for Year 1 (the same corn hybrids as in Year 1, but harvested in 1996) starch digestibility was obtained from a consecutive 4 x 4 Latin square design in which the seven corn hybrids were fed to four ileally cannulated barrows and the NYD hybrid was used in each square to make cross comparisons.

Furthermore, the seven corn treatments fed to the two groups of barrows were used to investigate the relationship between ileal starch digestibility and the following: apparent protein, true protein, and standardized ileal indispensable amino acid digestibility (SIID) coefficients. The diets, feed intake, and environmental conditions were the same as described by Andersen (2001). The experimental design was also the same as described by Andersen (2001); however, during each digesta collection (d 6 and 7), two fecal grab samples were also collected from each pig for each 12 hr digesta collection.

Sample Preparation and analysis

Collected digesta and fecal samples from each pig were homogenized and pooled over the 2-day collection and stored at -20°C until samples were prepared for further analysis. Digesta samples were thawed, freeze-dried, and finely ground through a cyclone mill (Cyclotec Sample Mill 1093, Tecator Co., Hoganas, Sweden) for dry matter (DM), crude protein (CP), amino acid (AA), starch and chromium analysis. Fecal samples were freeze-dried and finely ground through a 1 mm screen using a cyclone mill (Cyclotec Sample Mill 1093, Tecator Co., Hoganas, Sweden) for dry matter, chromium, and starch analysis. Dry matter content of corns, diets, digesta, and fecal matter was determined using a vacuum oven at 60°C for 16 h. Crude protein content of the respective corn treatments and digesta was determined using an automated LECO® elemental analysis istrument (AOAC # 990.03, crude protein and animal feeds; LECO® FP-2000; LECO Co., St. Joseph, MI). Amino acid determination of diets and digesta and chromium analysis of diets, digesta, and fecal matter were analyzed according to procedures described by Andersen (2001).

Starch concentration of digesta samples were determined using the following method. A 0.2 g sample was placed in a 100 mL beaker and dispensed in 20 mL of ddH_2O. While each beaker was swirled, 0.5 mL of 50% sodium hydroxide was added and allowed to gelatinize for 15 min. The alkali solution was then neutralized with 15 mL of ddH_2O, 10 mL of acetate buffer (2 M, pH 4.9), and 0.8 mL of concentrated hydrochloric acid. After the addition of an amylase enzyme (Optidex L-300, Bio-cat Co.), each beaker was sealed in aluminum foil and placed in a 55°C water bath for 16 h. The beakers were then cooled and brought up to volume with ddH_2O in 200 mL volumetric flasks. Standard glucose solutions containing 0, 10, 20, 30, 40, and 50 mg of D-glucose per 100 mL ddH_2O were prepared. Aliquots of glucose standards and samples (20 μL) were then transferred into microplate wells. A 250 μL glucose oxidase-peroxidase (GOP) reagent was added to each well. Wells were covered with tin foil to remove any sunlight and were allowed to remain at room temperature for 60 ± 5 min. The glucose absorbance of the samples were read and starch content (%) in samples calculated.

Fecal starch analysis followed the same procedure as above with the modification that Crystalzyme 40L was used instead of the Optidex L-300 enzyme. Tin foil insulation time followed the GOP addition, but was reduced to 18 ± 5 min (required time for Crystalzyme 40L enzyme) before reading the glucose absorbance.

Statistical analysis

Data on protein digestibility (Year 2) was analyzed using the General Linear Model procedure of SAS (1998) for a Latin square design. A linear model with main effects of period, diet, and pig as a random variable were used to test the dependent variables: apparent and true protein digestibility. Three orthogonal and three non-orthogonal contrasts were used to determine differences between the following pre-planned comparisons: HO vs. HOPN, WX vs. WXPN, HL vs. HLPN, HO vs. the four control corns (HOPN, WXPN, HLPN, and NYD), WX vs. the four control corns, and HL vs. the four control corns at one level of significance, $P < .05$.

The MIXED procedure of SAS (1998) was employed for ileal starch digestibility for both Year 1 and 2. A linear model with main effects of square, collection nested within square, diet, and pig as a random variable were used to test the dependent variable: Year 1 ileal starch digestibility. Data for Year 2 starch digestibility was obtained from a complete 8 x 8 Latin square design. A linear model with main effects of period, diet, and pig as a random variable were used to test the dependent variable: Year 2 ileal starch digestibility. Orthogonal and non-orthogonal contrasts were used to determine differences between the means of the same pre-planned comparisons as described above.

The relationship between ileal starch digestibility and apparent protein, true protein, and standardized indispensable ileal amino acid digestibility values were determined using the General Linear Model and Regression procedures of SAS (1998) in order to obtain the slope, intercept, and R-squared values of the various relationships investigated above. Also, the relationship between fecal starch digestibility and standardized indispensable ileal amino acid digestibility was tested following the procedure described above.

Results

Apparent and true protein digestibility values are reported in Table 12. No differences were observed between the pre-planned comparison, HO vs. HOPN, WX vs. WXPN, HO vs. the four control corns (HOPN, WXPN, HLPN, and NYD), WX vs. the four control corns, and HL vs. the four control corns for apparent and true protein digestibility.

However, apparent and true protein digestibility was greater in the HLPN ($P < .05$) corn as compared to the HL corn hybrid.

Ileal starch digestibilities are reported in Table 13. Year 1 ileal starch digestibilities ranged from 79.56 to 92.50 %. Year 2 ileal starch digestibilities were numerically higher than Year 1 digestibilities and ranged from 88.03 to 94.71 %. For Year 2, HO and HL were higher ($P < .05$) than the four control corns for ileal starch digestibility. In addition, HL was greater ($P < .05$) than HLPN for Year 2 ileal starch digestibility. Fecal starch digestibilities for Year 2 (Table 13) ranged from 95.46 to 99.18 % with an average of 97.28 %. Fecal starch digestibility for HL was higher ($P < .05$) HLPN and the four control corns.

In the present study, apparent and true protein digestibility from Year 2 was shown to be positively ($r = .175 - .176$, $P < .05$) related to ileal starch digestibility (Figure 1 and 2) for the specialty corn hybrids. The mean digestibility values of the corn hybrids (Figures 3 to 10) were compared to the mean ileal starch digestibility values. No significantly positive correlation ($P < .05$) was found to exist between ileal starch and indispensable ileal amino acid digestibility values; however, there was a positive correlation trend ($r = .272 - .274$, $P < .07$) for histidine and phenylalanine. Correlation coefficients were .179, .133, .054, .035, .243, and .096 for Lys, Val, Ile, Leu, Arg, and Thr respectively. However, no relationship existed between fecal starch and standardized indispensable amino acid digestibility.

Discussion

The apparent protein digestibility value for the Year 2 HO corn hybrid was lower than the value of 87.1 % reported by Risley et al. (1996); however, differences are probably due to the fact that Risley (1996) fed a complete corn-soybean meal diet to weanling pigs, whereas we fed a deficient diet. The apparent protein digestibility value for the WX corn at 61.36 % was lower than the value (68.48 %) reported by Soltwedel (1994). No published values are available for true protein digestibilities for the WX corn hybrids. In addition, no published values are available for apparent and true protein digestibility of the HL corn hybrids.

In a review of digestion and absorption of carbohydrates, Rerat (1978) commented that starch constitutes the major part of usual diets for non-ruminants and its digestibility is around 100% in rats and mice for cereal starches. However, recent in vitro studies conducted by Cone and Vlot (1990) suggest that enzymic digestion of starch in the small intestine is incomplete.

Several studies have been conducted in ruminants to determine starch digestibility of various feedstuffs (Owens et al.. 1986; Rooney and Pflugfelder, 1986; Cone and Vlot, 1989); however, few studies have assessed starch digestibility of various feedstuffs in growing pig. No studies have assessed the ileal starch digestibility of various specialty corn hybrids in growing pigs. The present study determined the ileal digestibilities of HO, HL, and WX corn hybrids. The average ileal starch digestibilities of HO, HL, and WX corn diets (Year 1 and 2 compiled) were 89.83, 91.33, and 93.61 %, respectively. In maize and pea starch, Everts et al. (1996) reported ileal starch digestibility values of 98.3 and 97.5% in 30 kg pigs. In terms of ileal starch digestibility, our values were lower than values reported by Everts et al. (1996). Differences in results may be due to the fact that each study used different size and age of pigs, and employed different methods to determine ileal starch digestibility. Rerat (1978) concluded that ileal starch digestibility does not always equal 100% and is often related to the age of the animal, the source of starch (Graham et al., 1989), and the processing of starch (Rerat, 1978; Graham et al., 1989).

Also, no studies have assessed the fecal starch digestibility of various specialty corn hybrids fed to growing pigs. The highest fecal digestibility in the present study was the HL diet at 99.18%. Fecal starch digestibilities for maize and pea starch were 99.0 % (Everts et al., 1996). Lin et al. (1987) and Sauer et al. (1977) reported fecal starch digestibility values of 100 and 98.2 % for growing pigs fed corn as a sole source of protein and energy. Cunningham (1959) also reported a fecal starch digestibility value of 76 % for soluble starch in 25 day-old pigs. The fecal starch digestibility in the present study varied between 95.46 and 99.18 %. Thus, our reported values for fecal starch digestibility are comparable to other published values (Sauer et al., 1977; Lin et al., 1987; Everts et al., 1996).

According to Johnston (1991) the unique properties of waxy cornstarch can be attributed to the fact that nearly 100 % of the starch in waxy corn is amylopectin, which is assumed to be more digested within the animal than amylose. However, in the present study the waxy corn did not have the highest ileal and fecal starch digestibility values as was expected, suggesting that the amylopectin starch was not as readily available to the animal as we had previously thought.

No studies have assessed the effect of apparent protein, true protein and standardized ileal amino acid digestibility on ileal starch digestion in non-ruminants. However, Philippeau et al. (2000) conducted a study to investigate the influence of endosperm protein distribution in dent and flint corns on ruminal starch digestion. The results showed that ruminal starch degradablility was negatively linked to the amount of zein proteins ($P < .05$) and positively linked to the amount of glutelins ($P < .05$) for both dent and flint corn. However, the flint corn was defined as being surrounded by protein storage bodies and embedded in a dense matrix of endosperm cells (zein proteins), whereas the dent corn endosperm had little cellular structures and the highest density of starch granules and true glutelins. Thus, Philippeau et al. (2000) suggested that the dent corn would induce an increase in the accessibility of starch granules to degradation in the rumen as compared to the flint corn endosperm, due to increased glutelin composition. Thus, their results suggest that the composition of maize endosperm may in fact affect starch degradation within the rumen.

Our study showed that a positive relationship exists between apparent protein and true protein digestibility and ileal starch digestibility. Whether this is related to cellular structure and protein distribution within the endosperm as described by Philippeau et al. (2000) is unknown. It could also be hypothesized that certain enzymes, activated by specific amino acids and an acid environment in the duodenum, play an important role in starch degradation.

The principal stimulant of enzymic secretions from the pancreatic acinar cells is cholecystokinin (CCK), which in turn is released in response to the presence of amino acids and fatty acids in the duodenum. The enzyme, α-amylase, is secreted by the pancreatic acinar cells and is the enzyme responsible for degrading starch. The release of α-amylase is stimulated by CCK acting on the pancreatic acinar cells. Only L-isomer forms of amino acids are effective in CCK release. Furthermore, phenylalanine and tryptophan are potent releasers of CCK (Meyer et al., 1976). There is also strong evidence that some peptides also release CCK. Three dipeptides, all of which contain glycine (glycylphenylalanine, glycyltryptophan, and phenylalanylglycine), have been proven to be strong releasers of CCK. Although we did not look at glycine's relationship with ileal starch digestibility, the indispensable amino acids, phenylalanine and histidine, tended to be positively correlated to ileal starch digestibility. There is also some evidence that some peptides containing at least four amino acids are also effective releasers of CCK (Johnson, 1997). Furthermore, CCK is known to be active throughout the small intestine, up to the ileum (Johnson, 1997).

In addition to CCK, secretin reduces the amount of acid in the duodenum by stimulating the release of bicarbonate from the pancreatic duct cells. The amino acid, phenylalanine, and an acid environment stimulate the continuous release of secretin. CCK and secretin potentiate each other for stimulation of release of bicarbonate and pancreatic enzymes (Johnson, 1997).

The puzzling fact about this study is that the HL hybrid was found to have a lower true protein digestibility than the HLPN corn, yet the HL hybrid had a higher ileal starch digestibility than HLPN for both year 1 and 2. This may be due to the fact that protein digestion and even protein content of the corn may be directly stimulating starch digestion in the gut as mentioned above.

Implications

The present study provides apparent and true protein digestibility and ileal starch digestibility coefficients for specialty corn hybrids, which are gaining popularity within the swine industry as a replacement for normal dent corn. This study showed that the apparent and true protein digestibility in specialty corn hybrids were similar when compared to normal dent corns. In addition, this study demonstrated that starch degradation is not complete (~ 90 %) at the terminal ileum, regardless of what type of corn is fed to growing pigs and that a definite relationship exists between starch and protein digestibility. However, further research is warranted to identify the exact relationship between starch degradability and specific amino acids present in growing pigs.

Table 12: Apparent and true protein digestibility of the corn hybrids for Year 2[a] (%)

Item	HO[c]	HOPN	WX	WXPN	HL	HLPN	NYD	Pooled SEM[b]
Apparent protein digestibility (%)	63.59	62.27	61.36	56.43	61.60	71.30*	62.44	2.65
True protein digestibility (%)	78.93	78.60	75.89	71.92	76.17	87.97*	75.95	2.78

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal yellow dent corn (NYD).
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c] If the superscript is on the paired normal corn, the comparison is between the hybrid and the paired normal corn. If the superscript is on the corn hybrid, the comparison is between the hybrid and the four control corns (HOPN, WXPN, HLPN, NYD).
* Means in rows with different superscripts are different ($P<.05$).

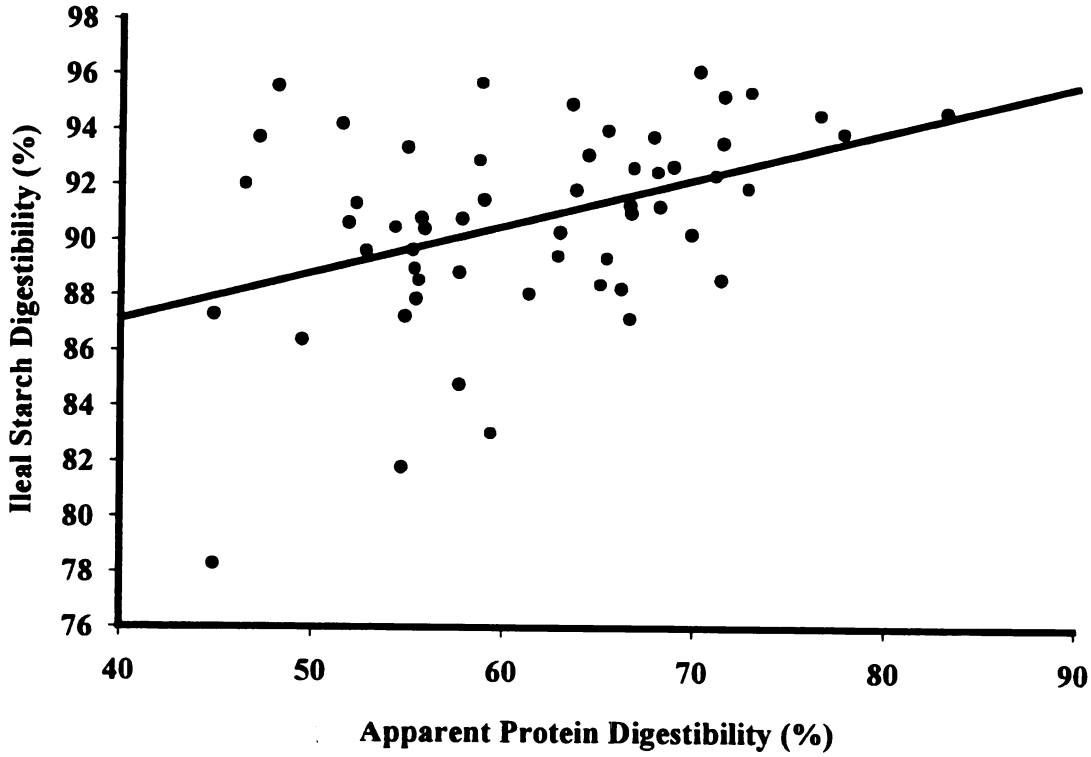
Table 13: Ileal and fecal starch digestibility of the corn hybrids[a] (%)

Item	HO[c]	HOPN	WX	WXPN	HL	HLPN	NCPN	Pooled SEM[b]
Year 1[d]: ileal Starch dig., %	88.48	89.67	91.04	86.46	92.50	91.15	79.56	3.31
Year 2[e]: ileal Starch dig., %	91.18*	90.33	91.62	89.91	94.71*	91.62*	88.03	.996
Year 2[e]: fecal Starch dig., %	96.46	95.46	97.21	98.87	99.18*	96.99*	96.81	.608

[a] Corns tested were high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and normal dent corn (NCPN).
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c] If the superscript is on the paired normal corn, the comparison is between the hybrid and the paired normal corn. If the superscript is on the corn hybrid, the comparison is between the hybrid and the four control corns (HOPN, WXPN, HLPN, NYD).
[d] Corns harvested in 1996.
[e] Corns harvested in 1997.
* Means in rows with different superscripts are different ($P<.05$).
† Means in rows with different superscripts are different ($P\leq .10$).

Figure 1: Relationship between apparent protein and ileal starch digestibility.
$Y = 80.35 - 0.169X$. $r^2 = 0.175$, $P = .001$.

Figure 2: Relationship between true protein and ileal starch digestibility.
$Y = 79.56 - 0.143X$. $r^2 = 0.176$, $P = .001$.


Ileal Starch Digestibility (%)
98
96
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88
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76
40
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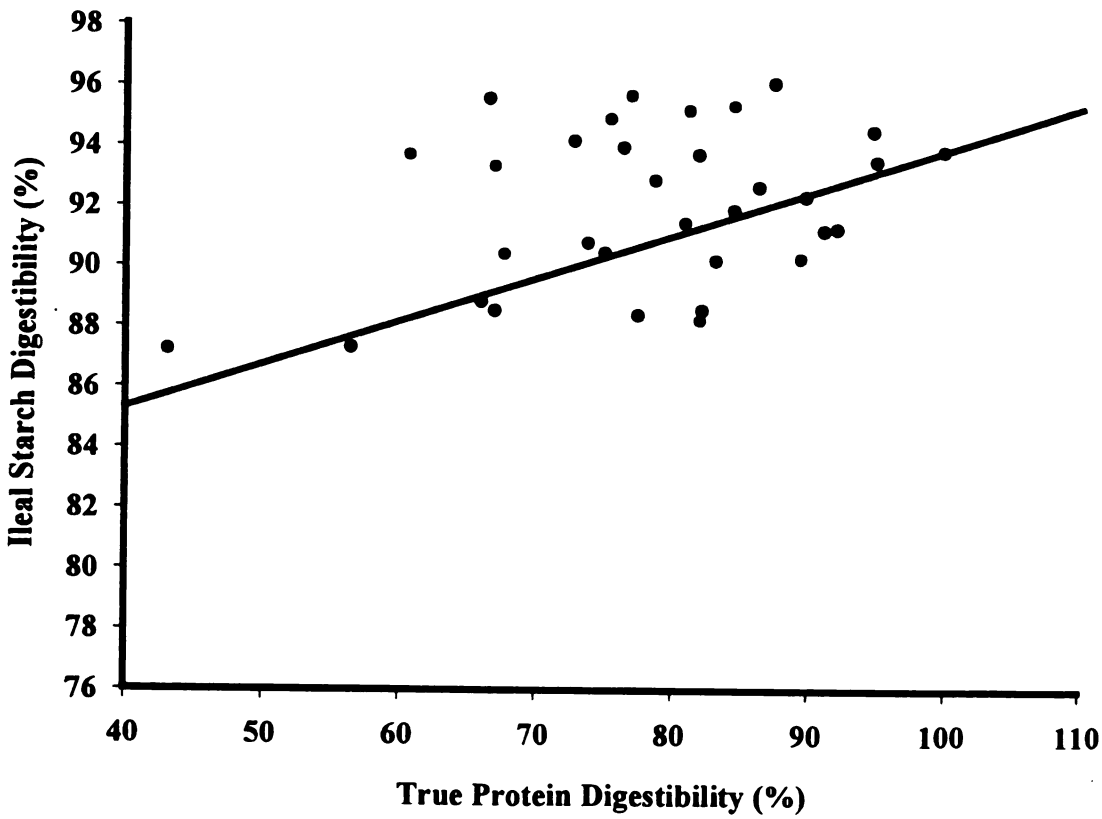
60
70
80
90
Apparent Protein Digestibility (%)


Ileal Starch Digestibility (%)
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70
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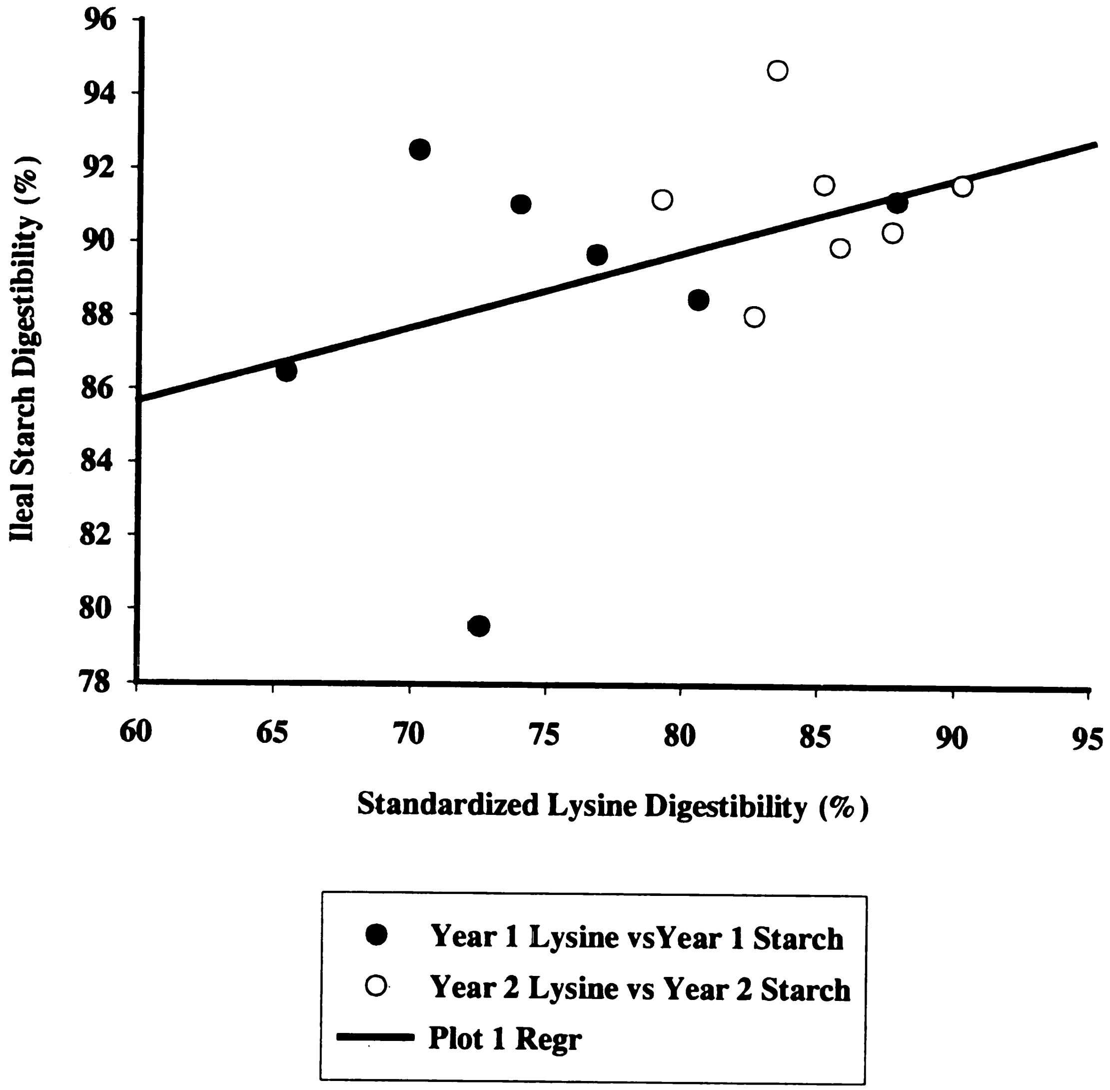
90
100
110
True Protein Digestibility (%)

Figure 3: Relationship between standardized lysine and ileal starch digestibility. $Y = 73.45 - 0.203X$. $r^2 = 0.179$, $P = .132$.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Ileal Starch Digestibility (%)
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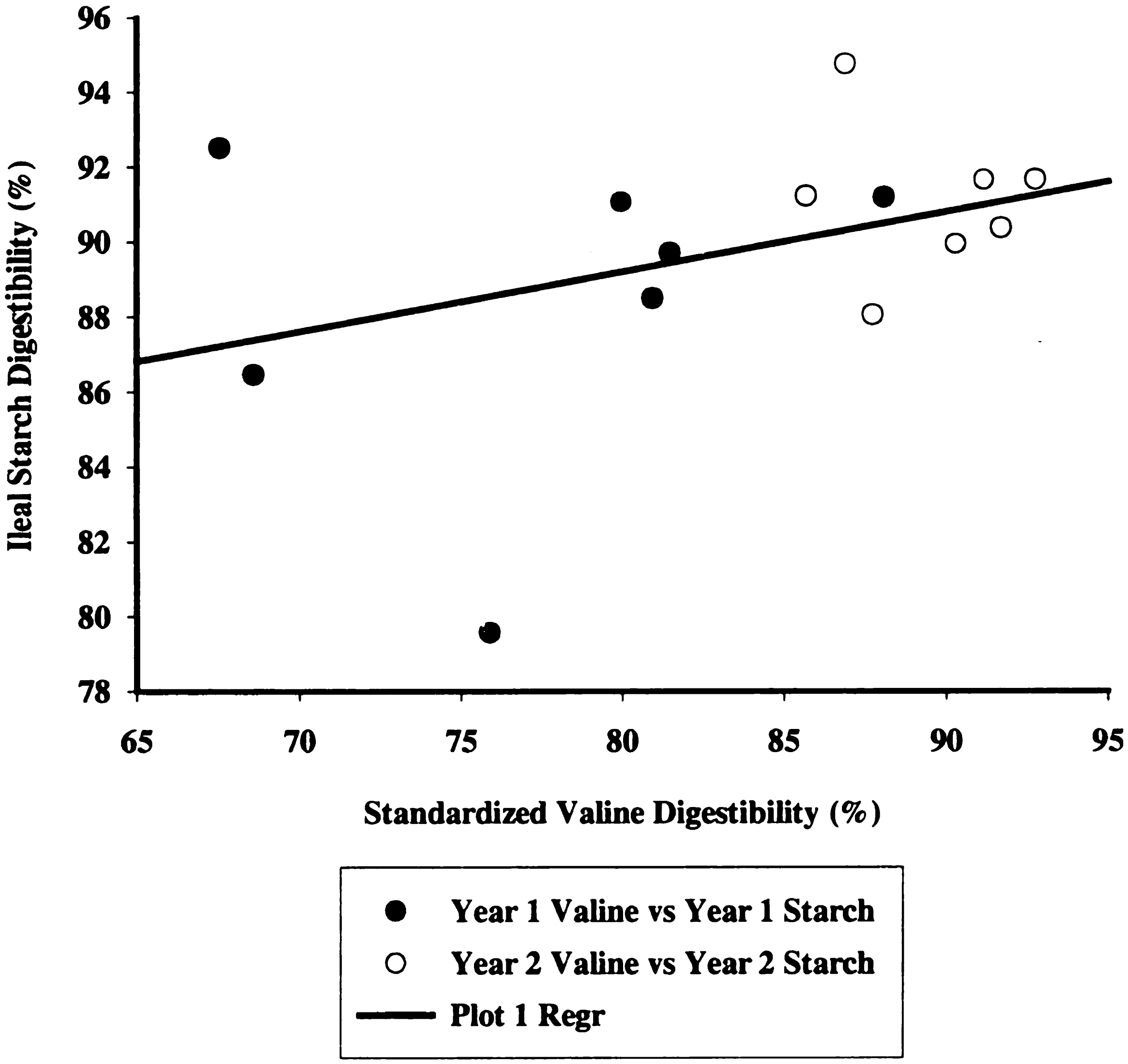
95
Standardized Lysine Digestibility (%)
Year 1 Lysine vsYear 1 Starch
Year 2 Lysine vs Year 2 Starch
Plot 1 Regr

Figure 4: Relationship between standardized valine and ileal starch digestiblity.
$Y = 76.49 - 0.159X$. $r^2 = 0.133$, $P = .199$



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Ileal Starch Digestibility (%)
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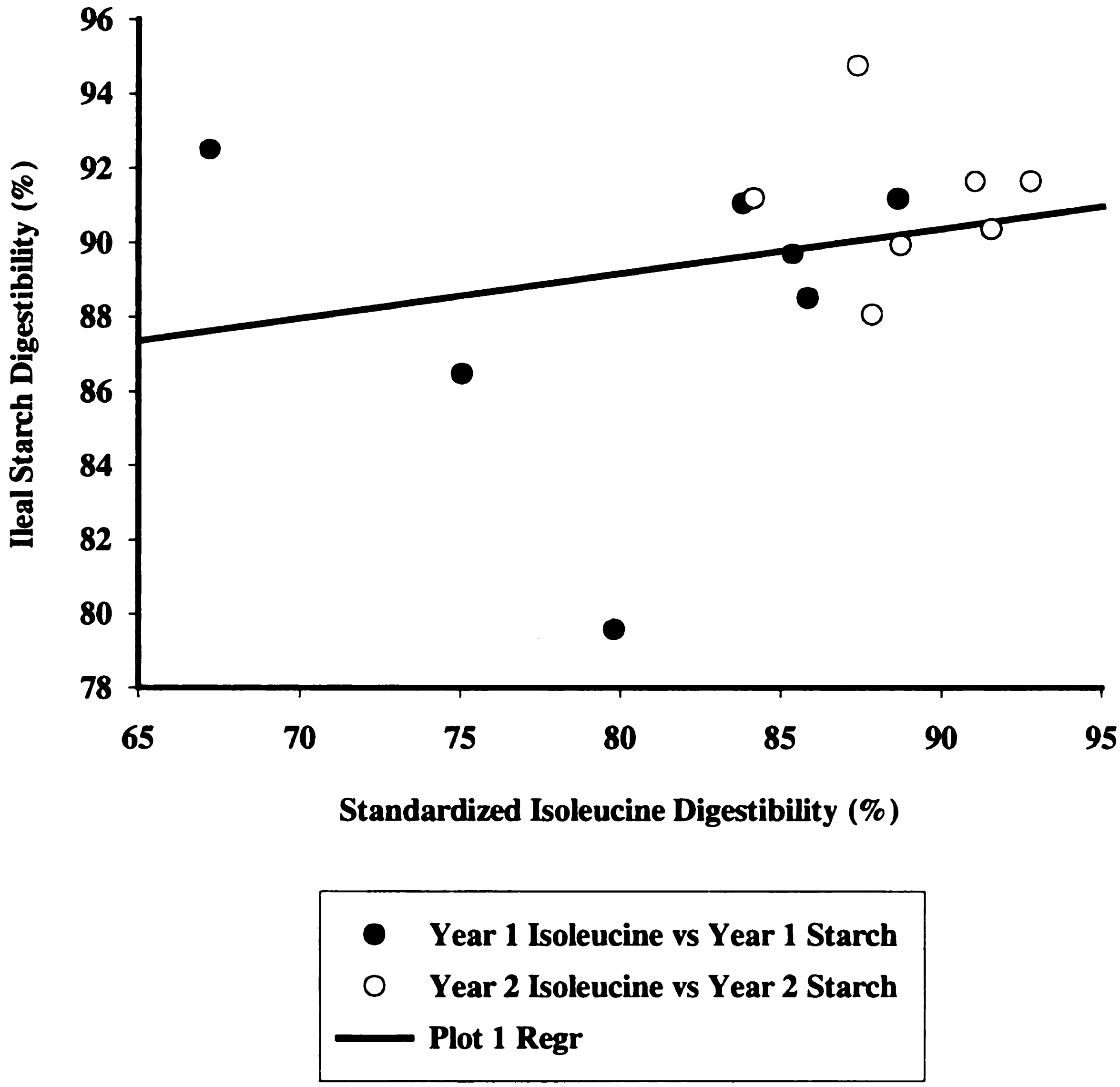
95
Standardized Valine Digestibility (%)
Year 1 Valine vs Year 1 Starch
Year 2 Valine vs Year 2 Starch
Plot 1 Regr

Figure 5: Relationship between isoleucine and ileal starch digestibility.
$Y = 79.57 - 0.120X$. $r^2 = 0.054$, $P = .422$.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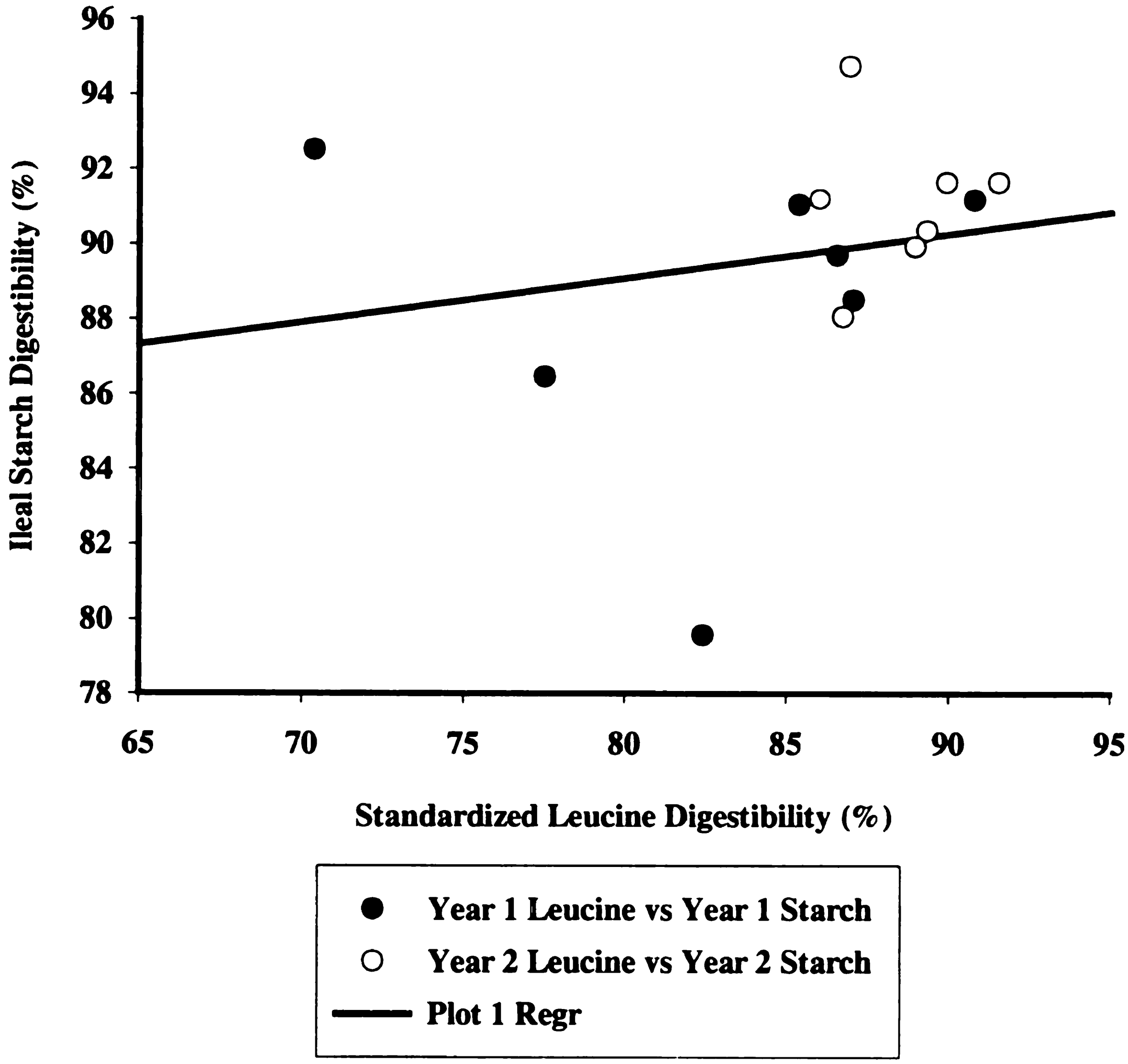
95
Ileal Starch Digestibility (%)
Standardized Isoleucine Digestibility (%)
Year 1 Isoleucine vs Year 1 Starch
Year 2 Isoleucine vs Year 2 Starch
Plot 1 Regr

Figure 6: **Relationship** between leucine and ileal starch digestibility.
Y = 79.69– 0.117**X**. r^2 = 0.035, **P** = .522.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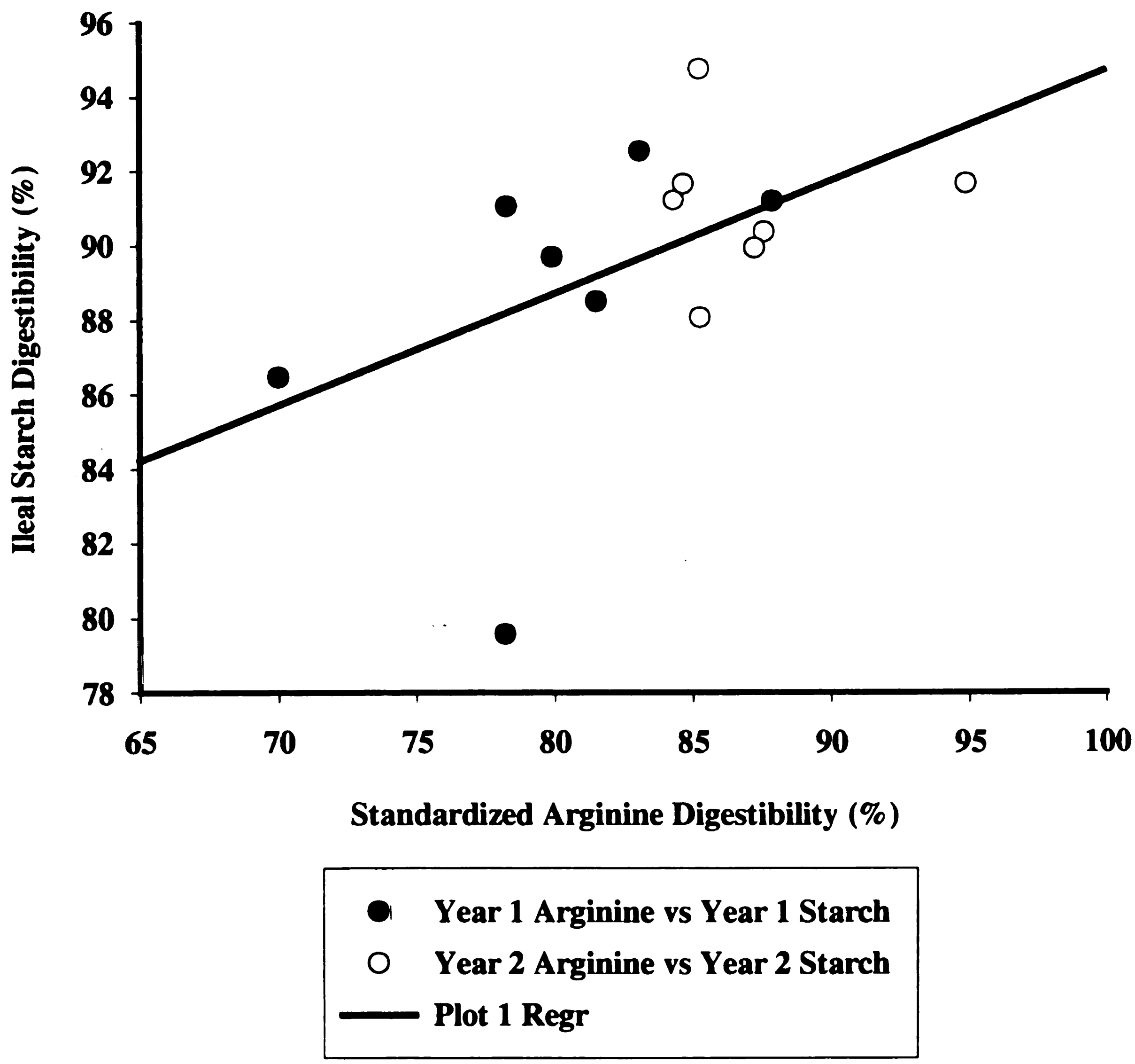
Ileal Starch Digestibility (%)
Standardized Leucine Digestibility (%)
Year 1 Leucine vs Year 1 Starch
Year 2 Leucine vs Year 2 Starch
Plot 1 Regr

Figure 7: Relationship between standardized arginine and ileal starch digestibility. $Y = 64.77 - 0.299X$. $r^2 = 0.243$, $P = .074$.



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Ileal Starch Digestibility (%)
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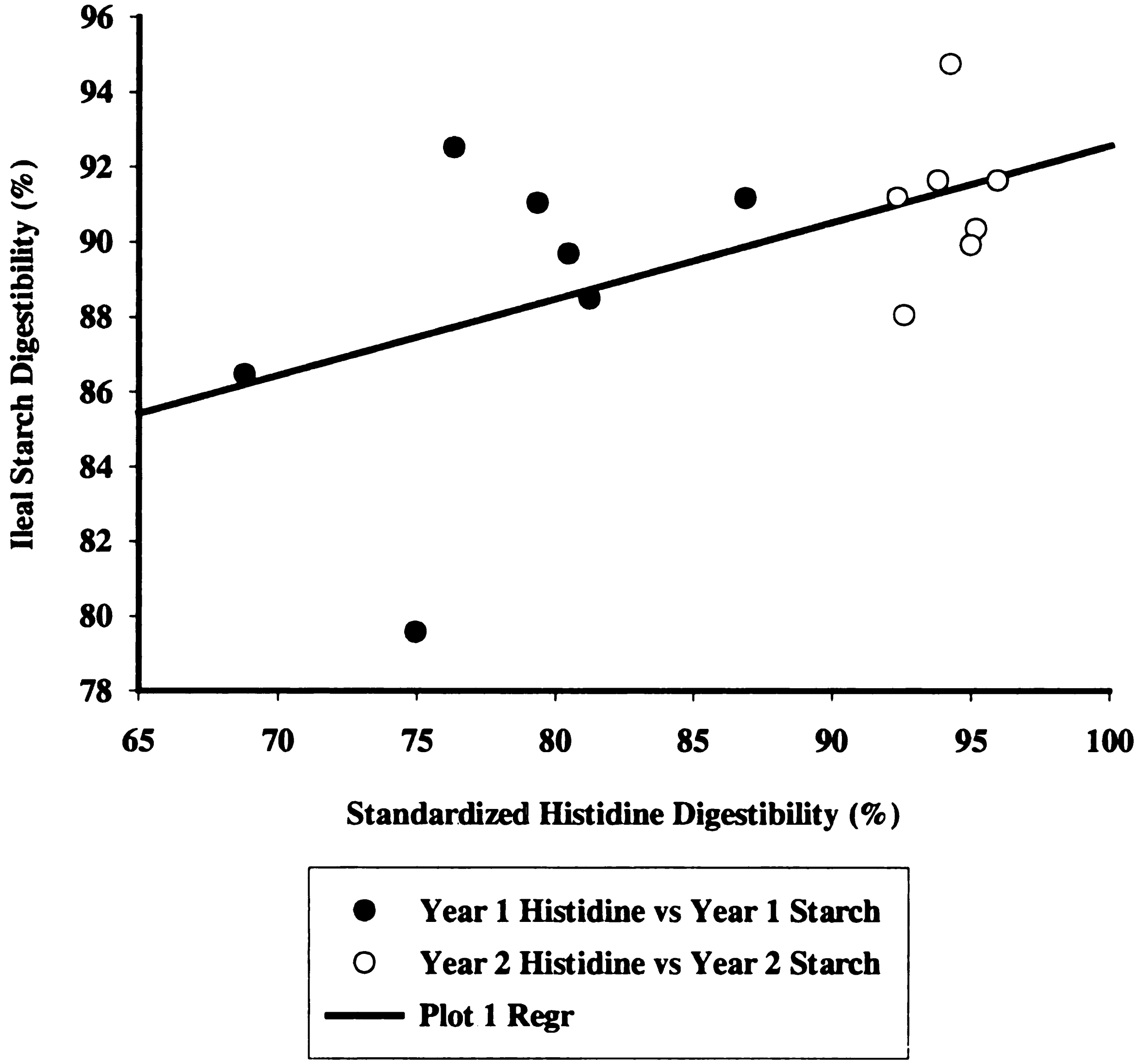
Standardized Arginine Digestibility (%)
Year 1 Arginine vs Year 1 Starch
Year 2 Arginine vs Year 2 Starch
Plot 1 Regr

Figure 8: Relationship between standardized histidine and ileal starch digestibility. $Y = 72.22 - 0.203X$. $r^2 = 0.272$, $P = .056$.


96
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Ileal Starch Digestibility (%)
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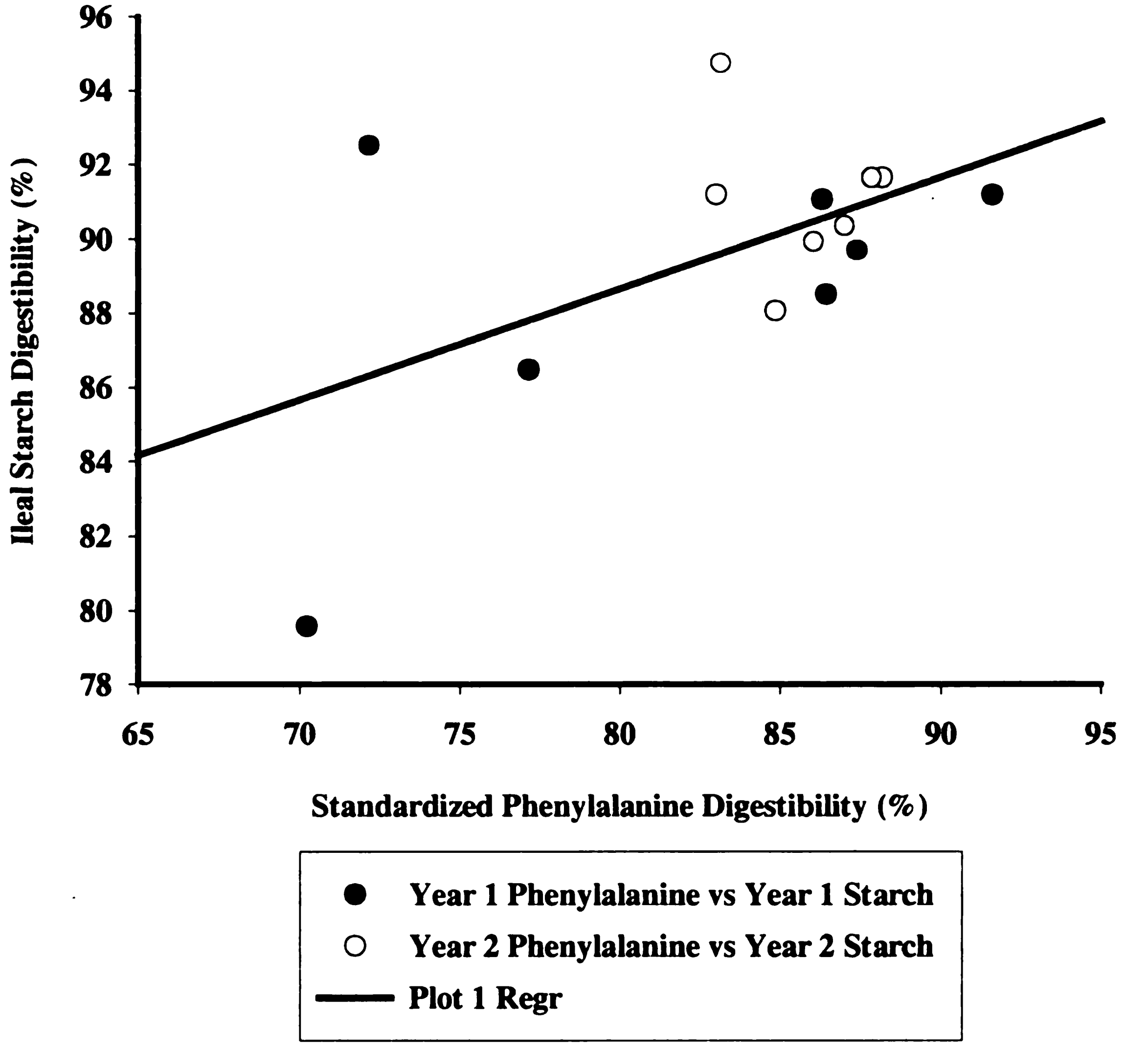
95
100
Standardized Histidine Digestibility (%)
Year 1 Histidine vs Year 1 Starch
Year 2 Histidine vs Year 2 Starch
Plot 1 Regr

Figure 9: **Relationship between standardized phenyialanine and ileal starch digestibility.** $Y = 64.73 - 0.299X$. $r^2 = 0.274$, $P = .055$.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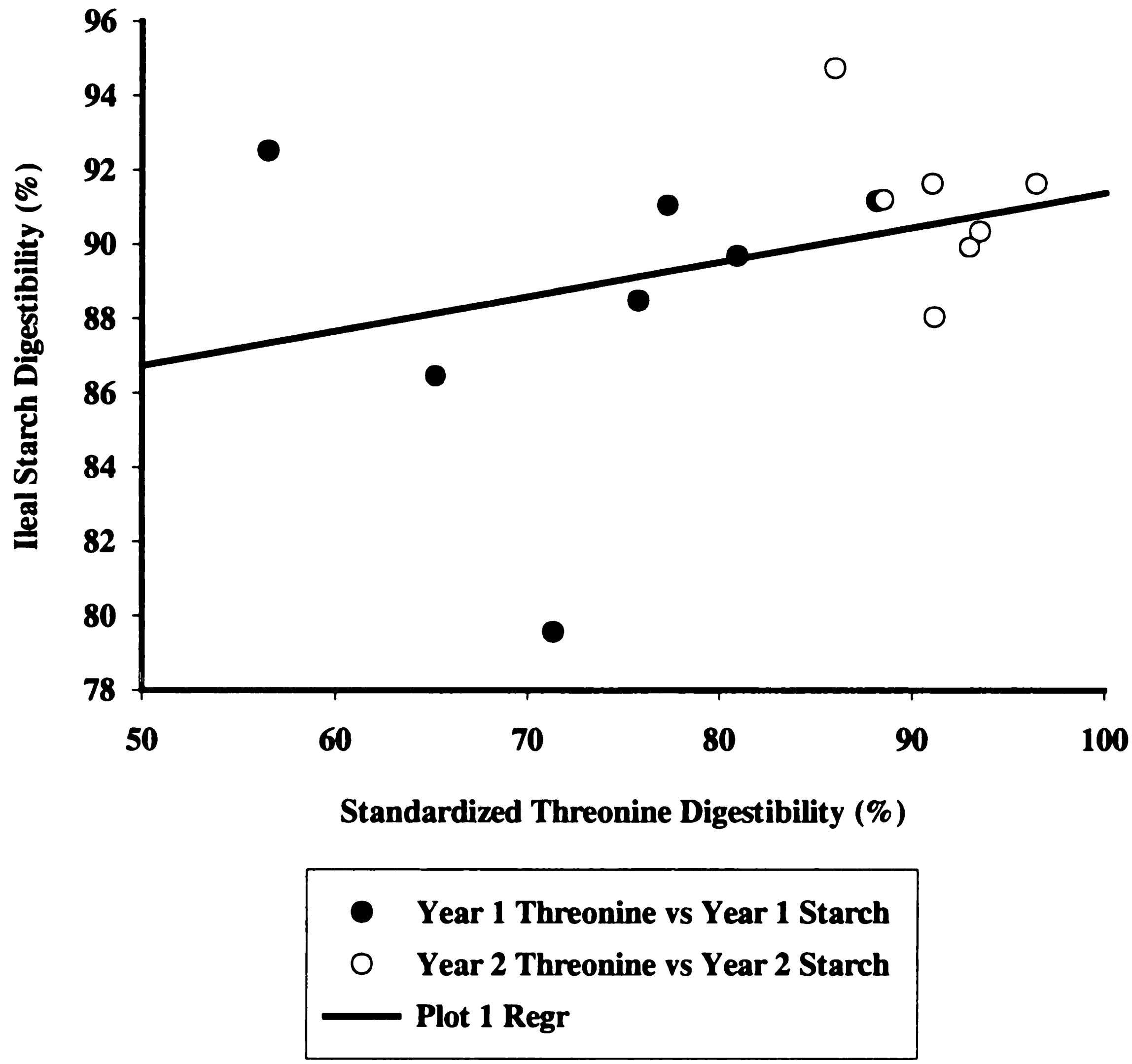
Ileal Starch Digestibility (%)
Standardized Phenylalanine Digestibility (%)
Year 1 Phenylalanine vs Year 1 Starch
Year 2 Phenylalanine vs Year 2 Starch
Plot 1 Regr

Figure 10: Relationship between standardized threonine and ileal starch digestibility. $Y = 82.06 - 0.093X$. $r^2 = 0.096$, $P = .281$.



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Ileal Starch Digestibility (%)
Standardized Threonine Digestibility (%)
Year 1 Threonine vs Year 1 Starch
Year 2 Threonine vs Year 2 Starch
Plot 1 Regr

CHAPTER 4: EFFECT OF NUTRIENT-DENSE CORN HYBRIDS FED TO GROWING PIGS ON NITROGEN METABOLISM AND UTILIZATION

Abstract

Six crossbred barrows (41.30 ± .49 kg, Yorkshire x Duroc) were used in a 6 x 6 Latin square experimental design to determine the effects of feeding different nutrient-dense corn hybrids on nitrogen metabolism and utilization. The corn hybrids used were: high-oil (HO), high-oil paired normal (HOPN), high-lysine (HL), waxy (WX), waxy paired normal (WXPN), and a yellow dent corn (NYD). Pigs were fed a diet consisting of 96.85% of one of the respective test corn hybrids. Vitamins, minerals, dicalcium phosphate, limestone, and salt were included at 3.15% of the diet to meet or exceed NRC (1988) requirements. Pigs were allowed a 5-day adjustment period to the test diets, followed by a 5-day total urine and fecal collection. Feces and urine were pooled at the end of each 5-day collection and analyzed for nitrogen content. Nitrogen intake was greater for NYD ($P < .05$) than HL. However, nitrogen intake for HL was higher ($P < .05$) than the average of the three control corns. Nitrogen excreted in urine was less in WX and HL ($P < .05$) than their respective paired normal corns, WXPN and NYD. In addition, N absorbed for WX and HL corn was less ($P < .05$) than their respective paired normals, WXPN and NYD. However, nitrogen retained, nitrogen digestibility, and nitrogen utilization was not different between HO vs HOPN, HL vs NYD, WX vs WXPN, HO vs the average of the three control corn hybrids (HOPN, WXPN, NYD), HL vs the average of the three control corn hybrids, and WX vs the average of the three control corn hybrids ($P > .05$).

Introduction

Every year, more producers feed nutrient-dense corn hybrids to their livestock (Bender and Hill, 2000). However, very little data is published on the nutritional value of feeding these corn hybrids to pigs. In the previous chapters, amino acid, protein, and ileal starch digestibility was determined to provide digestibility coefficients for the following corn hybrids: high-oil (HO), high-oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high-lysine (HL), high-lysine paired normal (HLPN), and a yellow dent corn (NYD). However, in order to fully understand the nutrient availability and utilization of these corn hybrids, the nitrogen retention and utilization must be investigated. Therefore, the objective of our research was to evaluate the N retention, digestibility, and utilization of high-oil, high-lysine, waxy, and their respective paired normal corn hybrids in growing pigs.

Materials and Methods

All animals and experimental protocols were approved by Michigan State University All University Committee for Animal Use and Care. Six crossbred barrows (Yorkshire x Duroc) with an initial body weight of 41.3 ± .5 kg were used to determine nitrogen retention, digestion, and utilization of six corn hybrids: high oil (HO), high oil paired normal (HOPN), waxy (WX), waxy paired normal (WXPN), high lysine (HL), and a normal yellow dent corn (NYD). The HLPN hybrid that was used by Andersen (2001) became rancid and was tested positive for vomitoxins (4.8 ppm); therefore, it was not used in this study. Pigs were randomly assigned to treatments, which consisted of one of the test corn hybrids. The treatment assignments were the same as described by Andersen (2001). The respective test corn hybrids provided the only source of protein and energy at

96.85% of the total diet. Vitamins, minerals, dicalcium phosphate, limestone, and salt were included to meet or exceed NRC(1998) requirements.

The six barrows were randomly assigned to one of the six experimental corn diets and arranged in a 6 x 6 Latin square. Environmental temperatures ranged from 21.1 to 33.0°C with a mean temperature of 25.7°C. Pigs were individually housed in stainless steel metabolism cages (1.2 m x 0.75 m) containing low pressure nipple waters that allowed free access to water. The metabolism cages allowed for separate collection of urine and fecal matter.

Feed intake was adjusted to 4.5% of pig metabolic body weight and maintained at this level throughout the trial. Pigs were fed equal meals twice daily and allowed a 5-day adjustment period to the experimental diets. The diet adjustment period was followed by five days of separate fecal and urinary collection. During the 5-day adjustment period, an amino acid top dress was applied to the test diets during the first four days as described by Andersen (2001). Five grams of Ferric Oxide was mixed with 100 g of diet and used as an indigestible marker to signal the initiation and termination of the fecal collection. Feces and urine were collected once daily with weight and volume recorded. Urine was preserved by the addition of 100 mL of 6 N hydrochloric acid to each daily collection. Twenty percent of the daily urine samples were kept and pooled. At the end of the 5-day collection, 20% of the total urine volume was kept and frozen at -20°C. Daily fecal samples were also pooled and frozen at -20°C.

Chemical analysis

Fecal samples were thawed and homogenized in a Hobart mixer for 10 min and sub-sampled. A 2 g sample was taken from the sub-sampled fecal matter and dried in a vacuum oven for 16 h at 60°C for determination of dry matter content. The sub-sampled fecal matter was freeze-dried and ground through a 1 mm screen using a cyclone mill (Cyclotec Mill 1093, Tecator Co., Hoganas, Sweden). Diets, freeze-dried feces, and liquid urine were analyzed for nitrogen content using an automated LECO® elemental analysis istrument (AOAC # 990.03, crude protein and animal feeds) (LECO® FP-2000; LECO Co., St. Joseph, MI).

Statistical analysis

Data was analyzed using the Mixed procedure of SAS (1998) in a Latin square design. A linear model with main effects of period, diet, and pig were used in the statistical model. Contrasts were used to determine differences between the following preplanned comparisons: HO vs. HOPN, WX vs. WXPN, HL vs. NYD, HO vs. the average of the three control corn hybrids (HOPN, WXPN, and NYD), WX vs. the average of the three control corn hybrids, and HL vs the average of the three control corn hybrids at one level of significance ($P < .05$).

Results

The barrows had an average daily gain of 0.39 kg and an average daily feed intake of 2.08 kg. The chemically determined nutrient composition of the corn diets are shown in Table 15. The main difference between these diets and the diets described by Andersen (2001) is the exclusion of 0.25% chromic oxide. The nutrient composition of the corn hybrids (Table 15) were reported by Andersen (2001). Nitrogen digestibility, N retention, and DM digestibility are presented in Table 17. Nitrogen intake of the HL hybrid was lower ($P < .05$) than NYD and the three control corn hybrids (HOPN, WXPN, and NYD). Nitrogen in feces (g/d) was similar across all the experimental diets; however, NYD was numerically higher ($P > .05$) than the other corn hybrids. The N content in the urine for WX and HL was lower ($P < .05$) than the N content in the three control corns. Also, the N content in the urine for HL was lower (P < .05) as compared to its paired normal, NYD. Nitrogen absorbed (g/d) in the WX and HL hybrids was lower (P < .05) than for the three control corn hybrids. In addition, the N absorbed in the HL hybrid was less (P < .05) than as compared to its paired normal, NYD. No differences (P > .05) were detected across all the contrast investigated for N retained, DM intake, fecal DM output, N retention as a percent of intake and absorbed, and DM digestibility.

Discussion

Adeola and Bajjalieh (1997) conducted a study in 20 kg crossbred pigs to compare the N utilization of three high-oil corn varieties to regular corn, when fed as the sole source of protein and energy. The average N digestibility of the three high-oil corns was 76.3%. The published values for N retention as a percent of intake for the high-oil varieties ranged from 47.3 to 55.3% and N retention as a percent of absorbed ranged from 62.2 to 72.4%. Snow et al. (1998) also conducted a N balance trial using 20 kg pigs, and reported a high-oil corn N digestibility of 83.31 ± 2.13%, a N retention as a percent of intake of 49.74 ± 5.35%, and a N retention as a percent of absorbed of 59.73 ± 6.52%. The N digestibility and retention values published for high-oil corn in 20 kg pigs are higher than our reported values for 40 kg pigs of 67.80 ± 2.02% for N digestibility, 33.63 ± 6.75% retention as a percent of intake, and 49.19 ± 9.61% retention as a percent of absorbed. Furthermore, both Adeola and Bajjalieh (1997) and Snow et al. (1998) reported higher ether extracts (%) for high oil corn as compared to the high-oil corn tested in the present study. Our high-oil corn had a relatively low ether extract (3.52%). It is possible that weather conditions at time of planting the seed and at time of harvesting may have affected the oil content of our high-oil hybrid, which then may have contributed to the low digestibility and utilization values that we obtained in the present study.

Asche et al. (1986) reported N utilization values of dry, high-moisture, and reconstituted high-lysine corn diets in 35 kg pigs. The N digestibility values for the various high-lysine corn diets ranged from 79.35 to 83.29%. Total N retained (g/d) ranged from 11.46 to 13.06, and N retention as a percent of intake ranged from 42.92 to 45.84% for dry, high-moisture, and reconstituted high-lysine corn. Sachtleben (1975) reported a high-moisture, high-lysine N retention as a percent of intake of 59.1 ± 3.3 % and a N digestibility value of 82.9 ± 1.6% in growing-finishing pigs. Snow et al. (1998) also conducted a N balance with high-lysine corn and reported a N digestibility value of 81.06 ± 2.13%, 57.22 ± 5.35% nitrogen retained as a percent of intake, and 70.75 ± 6.52% nitrogen retained as a percent of absorbed. The value for total N retained in high-lysine corn (9.81 ± 2.05 g/d) in the present study was comparable to Asche's values for total N retained. However, the values for N digestibility (72.58 ± 2.02%), N retention as a percent of intake (33.54 ± 6.75%), and N retention as a percent of absorbed (43.58 ± 9.61%) were lower than other published values (Sachtleben, 1975; Asche et al., 1986; and Snow et al., 1998).

The only published values available for waxy corn to compare to this study came from Sachtleben (1975). Sachtleben conducted a N balance on 25 kg pigs to determine the value of high-moisture, waxy corn diets on growing swine performance. Sachtleben obtained a N retention as a percent of intake value of 68.5 ± 3.3% and N retention as a percent of absorbed value of 85.0 ± 1.6%. Once again, the values reported in this study for N retention as a percent of intake (30.77 ± 6.75%) and N retention as a percent of absorbed (42.62 ± 9.61%) for waxy corn diets were lower than published values reported by Sachtleben (1975). Values for N digestibility and retention as a percent of intake and as a percent of absorbed of normal yellow dent corn in the present study were 68.38 ± 2.02%, 19.39 ± 6.75%, and 24.22 ± 9.61%, respectively. Our N digestibility and retention values for normal dent corn were lower than other published values (Sachtleben, 1975; Asche et al., 1986; Adeola and Bajjalieh, 1997; and Snow et al., 1998). These differences may be due to the fact that our pigs were on a deficient diet compared to the studies discussed above, where pigs were fed complete diets. However, Snow et al. (1998) fed corn as a single feed ingredient and found N digestibility and N utilization to be higher than our reported values. Also, Snow et al. (1998) used 20 kg pigs as compared to 40 kg pigs in the present study. Also, the deficient diets in the present study caused the pigs to grow, retain N, and utilize N at a much less efficient rate as compared to those on a complete corn-soybean meal diet. However, dry matter digestibility values in this study ranged from 83.17 to 85.31%, which were within range of values reported by Asche (1986), but slightly lower than values reported by Snow et al. (1998) and Adeola and Bajjalieh (1997), and slightly higher than values reported by Sachtleben (1975).

Nitrogen digestibility was similar across all the corn hybrids, except for the WX hybrid, which tended to be lower ($P \leq .10$) as compared to the three control corns. Interestingly, N retention as a percent of intake and absorbed was also similar across all hybrids. However, the nutrient-dense hybrid performance of HO, WX, and HL was inferior to previously published values (Sachtleben, 1975; Asche, 1986; Adeola and Bajjalieh, 1997; and Snow et al., 1998). Reasons for the lower N digestibility and utilization performance from the present study may be due to several factors: the poor weather conditions at time of planting and harvesting the corn hybrids (Jones and Andersen, 1999), the time of year that the experiment was conducted, the size and age of the pigs, the type of diet fed (completely balanced or deficient), and environmental conditions in which the experiment was run.

Implications

The present study showed that feeding high-oil, waxy, and high-lysine hybrids to growing pigs results in similar nitrogen retention and utilization. Therefore, feeding nutrient-dense corn hybrids provides no nutritional advantage over most normal yellow dent corn hybrids.

Table 14: Composition of experimental diets on as-fed basis (%)

Ingredients	Experimental
Corn[a]	96.85
Dicalcium phosphate	0.50
Limestone	0.25
Vitamin premix[b]	0.30
Trace mineral premix[c]	1.25
Salt	0.85

[a] Corn varieties used were HO, HOPN, WX, WXPN, HL and NYD.
[b] Provided the following per kilogram of diet: 4,583 IU vitamin D_3, 55 IU vitamin E, 11 mg vitamin K, 3.66 mg menadione, 0.0275 mg vitamin B_{12}, 3.66 mg riboflavin, 14.67 mg d-pantothenic acid, 22 mg niacin, 0.913 mg thiamine, 0.825 mg pyridoxine.
[c] Provided the following per kilogram of diet: 335 g Ca, 5 g Fe, 5 g Zn, 5 mg Cu, 5 mg Mn, 150 µg Se and 75 µg I.

Table 15: Nutrient Composition of corn varieties (dry matter basis)

Items	HO	HOPN	WX	WXPN	HL	NYD
Dry matter, %	86.35	85.73	84.97	85.85	86.45	86.12
Crude protein, %	7.09	6.88	7.31	7.33	7.97	8.34
Gross energy, Mcal/kg	4.58	4.78	4.27	4.50	4.61	4.35
Ether Extract, %	3.52	5.54	4.24	4.01	4.50	4.00
Amino acids, %						
Indispensable						
Arg	0.43	0.41	0.40	0.39	0.53	0.40
His	0.30	0.29	0.29	0.30	0.37	0.34
Ile	0.23	0.24	0.26	0.23	0.26	0.33
Leu	0.74	0.70	0.71	0.73	0.60	1.00
Lys	0.19	0.20	0.21	0.21	0.30	0.20
Phe	0.32	0.31	0.32	0.32	0.31	0.42
Thr	0.23	0.27	0.26	0.24	0.26	0.31
Val	0.36	0.36	0.36	0.37	0.42	0.43
Dispensable						
Ala	0.50	0.49	0.49	0.50	0.48	0.62
Asp	0.36	0.45	0.39	0.48	0.66	0.28
Glu	1.05	1.11	1.09	1.13	1.15	0.92
Gly	0.27	0.28	0.28	0.27	0.34	0.29
Pro	0.57	0.51	0.56	0.54	0.58	0.71
Ser	0.38	0.34	0.35	0.35	0.36	0.42
Tyr	0.27	0.27	0.28	0.28	0.30	0.31
ΣAmino Acids	6.20	6.23	6.25	6.34	7.22	6.98

Table 16: Amino acid top dress composition[ab] (g/kg)

Amino acid	HO	HOPN	WX	WXPN	HL	NYD
Ile	1.86	1.76	1.65	1.80	1.63	.933
Leu	—	.150	—	—	1.06	—
Lys	6.89	6.71	6.57	6.57	5.48	6.66
Met	.070	.160	.010	—	.120	.050
Phe	1.18	1.34	1.20	1.19	1.30	.160
Thr	2.82	2.43	2.49	2.70	2.46	1.96
Trp	1.70	1.70	1.70	1.70	1.70	1.70
Val	1.60	1.57	1.56	1.50	.983	.908

[a] Amino acid top dress = amino acid requirement (NRC, 1988) for 50 to 80 kg pigs – amino acid content in the corn varieties.
[b] Added back to the test diets to meet the amino acid requirements.

Table 17: Nitrogen utilization and dry matter digestibility of the corn varieties[a]

Item	HO[c]	HOPN	WX	WXPN	HL	NYD	Pooled SEM[b]
N	6	6	6	6	6	6	
N intake, g/d	23.43	22.97	23.90	24.97	26.41*	31.67*	1.98
N in feces, g/d	7.63	8.02	8.79	7.53	6.96	9.69	1.05
N in urine, g/d	8.06	9.58	7.70*	9.52	9.64*	14.79*	1.89
N absorbed, g/d[c]	15.81	14.95	15.11*	17.45	19.45*	21.99*	1.83
N retained, g/d[d]	7.75	5.37	7.41	7.93	9.81	7.19	2.93
N digestibility, %[e]	67.80	65.19	63.42	70.21	72.58	68.38	3.47
N retention, % of intake	33.63	23.80	30.77	30.46	33.54	19.39	9.75
N retention, % absorbed	49.19	36.55	45.87	42.62	43.58	24.22	13.28
DM intake, g/d	2066.53	2086.17	2042 83	2130.90	2071.37	2374.40	151.49
Fecal DM, g/d	305.76	321.10	346.09	320.65	307.36	359.66	41.22
DM digestibility, %	85.31	84.62	83.17	85.13	84.95	84.37	1.50

[a] Values are least square means.
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c] If the superscript is on the paired normal corn, the comparison is between the hybrid and the respective paired normal corn. If the superscript is on the corn hybrid, the comparison is between the hybrid and the three control corns (HOPN, WXPN, NYD).Means in rows with different superscripts are different ($P<.05$).

SUMMARY AND GENERAL CONCLUSION

The goal of this thesis was to investigate protein, amino acid, and starch digestibility and the relationship between ileal starch and the following: protein and amino acid digestibility of high-oil, high-oil paired normal, waxy, waxy paired normal, high-lysine, high-lysine paired normal, and normal yellow dent corn in growing pigs.

Apparent and standardized amino acid digestibilities were determined for each of the corn hybrids. The apparent amino acid digestibility of the high-oil and high-lysine paired normals were superior to their hybrids, high-oil and high-lysine. Also, the high-oil hybrid was inferior to the average of the four control corn hybrids for apparent amino acid digestibility. A similar pattern was observed for standardized amino acid digestibility. The high-oil and high-lysine paired normal corns were superior to the high-oil and high-lysine hybrids for standardized amino acid digestibility. However, for both apparent and standardized indispensable amino acid digestibility, no differences were observed for the comparison of waxy vs. waxy paired normal and waxy vs. the average of the four control corns.

In the second experiment, ileal starch digestion and the relationship between ileal starch and protein and amino acid digestibility were investigated. The ileal starch digestibility of high-oil and high-lysine was superior to the four control corns for Year 2. Fecal starch digestibility (Year 2) for the high-lysine hybrid was superior to the high-lysine paired normal and the four control corns. In addition, a positive, linear correlation ($r = .175 - .176$, $P < .05$) was observed between ileal starch digestibility and apparent and true protein digestibility.

Nitrogen metabolism and utilization of the corn hybrids were investigated in the third experiment. The results showed that nitrogen retained, dry matter digestibility, and nitrogen as a percent of intake and absorbed were similar across all test corn diets.

In conclusion, this research suggests that the nutrient-dense corns provide similar performances for ileal starch and amino acid digestibility and nitrogen utilization as compare to the normal dent corns. Therefore, when formulating diets for nutrient-dense hybrids, we can currently use normal yellow dent hybrid digestibility coefficients until a more complete data set of nutrient-dense hybrid digestibility coefficients are available.

VITA

Lara L. Andersen was born and raised in the Upper Peninsula of Michigan. As a child she was interested in Arabian horses, and became an active competitor of long distance endurance racing. She was a five-year member of the U.P. Distance Riders Association and was active in many livestock activities throughout high school. After graduating from high school in 1993, she came to Michigan State University to pursue a career with animals. Upon graduating with a Bachelors degree in Animal Science in December of 1997, she was granted the opportunity to change direction and pursue a Masters degree in swine nutrition under the supervision of Dr. Nathalie L. Trottier.

APPENDICES

Appendix A

Calculations for digestibility:

Apparent ileal digestibility (AID):
Adapted from Snow et al. (1998)

AID = (100 – [(AAd/ AAf) x (CRf/ CRd)] x 100

Where:
AAd = Amino acid concentration in the digesta
AAf = Amino acid concentration in the feed
CRf = Chromium in the feed
CRd = Chromium in the digesta

Endogenous amino acid losses (EAL):
Adapted from Rademacher et al. (1999)

EAL = [AAd x (CRf/ CRd)]

Where:
EAL = Basal endogenous amino acid flow, mg/ kg DMI
AAd = Amino acid concentration in the digesta
CRf = Chromium in the feed
CRd = Chromium in the digesta

Standardized ileal digestibility (SID):
Adapted from Rademacher et al. (1999)

SID = [AID + (EAL/ AAf)] x 100

Where:
AID = Apparent ileal digestibility
EAL = Basal endogenous amino acid flow, mg/ kg DMI
AAf = Amino acid concentration in the feed

Appendix B

Apparent indispensable amino acid digestibility of corn hybrids based on growing pigs' age in weeks[a]

Age in weeks	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Pooled SEM[b]
Arg	82.15[c]	80.68	78.80	76.73	72.98	77.71	74.13	71.65[d]	2.14
His	88.51	89.21	88.35	87.24	85.83	87.92	86.42	86.19	1.06
Ile	75.21	77.26[c]	75.49	72.26	68.09[d]	73.73	71.56	70.07	1.77
Leu	82.98	84.55[c]	83.27	80.41	78.03[d]	82.15	80.74	78.72	1.40
Lys	66.69	69.26	67.51	64.67	60.15	63.82	60.76	61.89	2.04
Phe	81.04	83.11[c]	81.67	80.03	76.66[d]	80.90	79.06	78.32	1.36
Thr	65.44	68.92	68.15	69.89	61.79	67.49	66.04	62.62	2.33
Val	75.96	77.96[c]	76.29	73.83	70.17[d]	75.02	72.47	71.73	1.65

[a] Values are least square means.
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c,d] Means in rows with different superscripts are different ($P < .05$).

Appendix C

Apparent dispensable amino acid digestibility of corn hybrids based on growing pigs' age in weeks[a]

Age in weeks	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Pooled SEM[b]
Ala	76.90[c]	78.07[c]	76.12[c]	72.55	65.80[d]	72.59	71.77	70.39	1.83
Asp	72.32	75.95	75.41	73.51	68.36	74.30	72.63	69.84	3.74
Glu	79.04	80.62[c]	79.11	77.53	72.63[d]	78.21	77.36	74.45	1.54
Gly	48.24	41.09	39.15	35.73	27.37	38.80	37.58	26.71	4.76
Pro	58.16[c]	17.59	13.14	-13.17[d]	-3.53[d]	12.66	2.74	-18.85[d]	14.15
Ser	75.11	76.93	75.95	76.08	70.43	76.53	73.72	72.18	1.54
Tyr	82.28	84.06[c]	81.61	79.30	76.22[d]	82.29	80.61	79.45	1.46

[a] Values are least square means.
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c,d] Means in rows with different superscripts are different ($P < .05$).

Appendix D

Standardized indispensable amino acid digestibility of corn hybrids based on growing pigs' age in weeks[a]

Age in weeks	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Pooled SEM[b]
Arg	93.43[c]	91.36	89.32	87.94	83.35	87.74	84.00	81.81[d]	2.23
His	92.78	93.15	92.33	91.39	89.75	91.68	90.14	89.99	1.08
Ile	84.25	85.29[c]	83.87	80.75	76.44[d]	81.45	79.52	77.94	1.79
Leu	87.75	88.80[c]	87.56	84.95	82.54[d]	86.30	84.92	82.97	1.38
Lys	77.30	79.25	77.60	75.21	69.98	73.29	70.03	71.35	2.09
Phe	87.23	88.57	87.34	85.82	82.39	86.18	84.48	83.71	1.36
Thr	79.88	81.85	81.56	83.48	75.27	79.98	78.86	75.16	2.33
Val	84.37	85.60[c]	84.10	81.90	77.94[d]	82.35	79.83	79.14	1.67

[a] Values are least square means.
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c,d] Means in rows with different superscripts are different ($P < .05$).

Appendix E

Standardized dispensable amino acid digestibility of corn hybrids based on growing pigs' age in weeks[a]

Age in weeks	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Pooled SEM[b]
Ala	86.02[c]	86.18[c]	84.48[c]	81.13	74.27[d]	80.43	79.78	78.35	1.86
Asp	79.18	83.04	82.09	80.97	74.96	80.89	78.74	76.42	3.73
Glu	84.80	86.12[c]	84.48	83.31	78.10[d]	83.39	82.47	79.65	1.56
Gly	88.38[c]	78.30	76.63	74.89	64.43[d]	74.12	72.78	62.34[d]	5.25
Pro	141.58[c]	88.78	87.45	61.90[d]	72.08[d]	82.38	74.31[d]	49.12	14.98
Ser	85.32	86.15	85.32	85.86	79.84	85.32	82.64	81.20	1.55
Tyr	88.60	89.79[c]	87.46	85.37	82.08[d]	87.77	86.14	85.01	1.47

[a] Values are least square means.
[b] Pooled SEM represents the square root of the mean standard error divided by n.
[c,d] Means in rows with different superscripts are different ($P < .05$).

LITERATURE CITED

Literature Cited

Adeola, O. and Bajjalieh, N. L. 1997 Energy concentration of high-oil corn varieties for pigs. J. Anim. Sci. 75: 430-436.

AOAC. 1990. Official Methods of Analysis (15 Ed.). Association of Analytical Chemists, Arlington, VA.

Asche, G. L., Crenshaw, J. D., Lewis, A. J., and Peo, J. E. R. 1986. Effect of dry, high moisture and reconstituted normal and high-lysine corn diets and particle size on energy and nitrogen metabolism in growing swine. J. Anim. Sci. 63: 131-138.

Bender, K., and Hill, L. 2000. Producer alternatives in growing specialty corn, soybeans explored. Feedstuffs. February 28, 2000. 72(9):16-21.

Boyer, C. D. and Hannah, C 1994. Kernel Mutants of Corns. In A. R. Hallauer (Ed.) Specialty Corns.CRC Press Inc., Boca Raton.

Burgoon, K. G., Hansen, J. A., Knabe, D. A., and Bockholt, A. J. 1992. Nutritional value of quality protein maize for starter and finisher swine. J. Anim. Sci. 70:811-817.

Carr, S. N . 1994. Energy metabolism and amino acid digestion by growing-finishing pigs fed various high-oil corn lines. M. S. Thesis. University of Illinois, Urbana-Champaign.

Cone, J. W. and Marcella Vlot. 1989. Comparison of degradability of starch in concentrates by enzymes and rumen fluid. J. Anim. Physiol. a. Anim. Nutr. 63:142-148.

Cromwell, G. L., Pickett, R. A., and Beeson, W. M. 1967. Nutritional value of opaque-2 corn for swine. J. Anim. Sci. 26:1325-1331.

Cromwell, G. L., Stahly, T. S., and Monegue, H. J. 1984. Effects of processing (grinding versus rolling) of normal and mutant corn hybrids on performance of growing pigs. J. Anim. Sci. 59:875-882.

Cunningham, H. M. 1959. Digestion of starch and some of its degradation products by newborn pigs. J. Anim. Sci. 18:964-974.

Dekker, R. A., Smits, B., and Cone, J. W. 1996. Digestion of maize starch and native pea starch in the small intestine of pigs. The Proc. Nutr. Soc. 55(1A):59A.

de Lange, C. F. M., Sauer, W. C., Mosenthin, R., and Souffrant, W. B. 1989. The effect of feeding different protein-free diets on the recovery and amino acid composition of endogenous protein collected from the distal ileum and feces in pigs. J. Anim. Sci. 67:746-754.

de Lange, C. F. M., Sauer, W. C., and Souffrant, W. B. 1989. The effect of protein status of the pig on the recovery and amino acid composition of endogenous protein in digesta collected from the distal ileum. J. Anim. Sci. 67:755-762.

de Lange, C. F. M., Souffrant, W. B., and Sauer, W. C. 1990. Real ileal protein and amino acid digestibilities in feedstuffs for growing pigs as determined with the ^{15}N-isotope dilution technique. J. Anim. Sci. 68:409-418.

den Hartog, L. A., Verstengen, M. W. A., and Huisman, J. 1989. Amino acid digestibility in pigs as affected by diet composition. In M. Friedman (Ed.) Absorption and Utilization of Amino Acids. Vol. 3. CRC Press, Inc., Boca Raton.

Donkoh, A. and Moughan, P. J. 1994. The effect of dietary crude protein content on apparent and true ileal nitrogen and amino acid digestibilities. Br. J. Nutr. 72:59-68.

Easter, R. A. and Tanksley, J., T. D. 1973. A technique for re-entrant ileocecal cannulation of swine. J. Anim. Sci. 36:1099-1103.

Eggum, B. O., Thorbek, G., Beames, R. M., Chwalibog, A., and Henckel, S. 1982. Influence of diet and microbial activity in the digestive tract on digestbility, and nitrogen and energy metabolism in rats and pigs. Br. J. Nutr. 48:161-175.

Eggum, B. O., Dumanovic, J., Misevic, D., and Denic, M. 1985. Nutritive quality and energy yield of high oil, opaque-2 and waxy maize hybrids compared to normal maize hybrids. Qual. Plant Foods Hum. Nutr. 35:165-174.

Everts, H., Dekker, R. A., Smits, B., and Cone, J. W. 1996. Digestion of maize starch and native pea starch in the small intestine of pigs. The Proc. of Nutr. Soc. 55:59A.

Fan, M. Z. and Sauer, W. C. 1994. Determination of the apparent ileal amino acid digestibilities in barley for pigs with the direct, difference and regression methods. J. Anim. Sci. 77:99.

Fan, M. Z., Sauer, W. C., Hardin, R. T., and Lien, K. A. 1994. Determination of apparent ileal amino acid digestibility in pigs: Effect of dietary amino acid levels. J. Anim. Sci. 72:2851-2859.

Fan, M. Z., Sauer, W. C., and McBurney, M. I. 1995. Estimation by regression analysis of endogenous amino acid levels in digesta collected from the distal ileum of pigs. J. Anim. Sci. 73:2319-2328.

Fergason, V. 1994. High amylose and waxy corns. In A. R. Hallauer (Ed.) Specialty Corns. CRC Press, Inc., Boca Raton.

Freese, B. and Fee, R. 1996. Feeding specialty corns: Does it pay? What's available? Who's using it? Successful Farming. 94(4):38-40.

Furuya, S. and Kaji, Y. 1989. Estimation of the true ileal digestibility of amino acids and nitrgen from their apparent values for growing pigs. Anim. Feed Sci. Tech. 26:271-285.

Goihl, J. 1997. Nutrients from high-oil corn used as efficiently as normal varieties. Feedstuffs. April 28, 1997. Vol. 69 (17): 12.

Graham, H., Lowgren, W., and Aman, P. 1989. An in vitro method for studying digestion in the pig. 2. Comparison with in vivo ileal and faecal digestibilities. Br. J. Nutr. 61:689-698.

Grala, W., Verstegen, M. W. A., van Leeuwen, P., Huisman, J., Jansman, A. J. M., and Tamminga, S. 1997. Nitrogen balance of pigs as affected by feedstuffs causing different endogenous nitrogen flow at the terminal ileum. Livest. Pro. Sci. 48:143-155.

Grala, W., Verstengen, M. W. A., Jansman, A. J. M., Huisman, J. and van Leeusen, P. 1998. Ileal apparent protein and amino acid digestibilities and endogenous nitrogen losses in pigs fed soybean and rapeseed products. J. Anim. Sci. 76:557-568.

Grala, W., Verstengen, M. W. A., Jansman, A. J. M., Huisman, J. and Wasilewko, J. 1998. Nitrogen utilization in pigs fed diets with soybean and rapeseed products leading to different ileal endogenous nitrogen losses. J. Anim. Sci. 76:569-577.

Gray, G. M. 1992. Starch digestion and absorption in nonruminants. J. Nutr. 122:172 177.

Han, Y., Parsons, C. M., and Alexander, D. E. 1987. Nutritive value of high oil corn for poultry. Poultry Science. 66:103-111.

Hanson, L. E. 1946. Waxy corn versus non-waxy corn for growing fattening pigs fed in dry lot. J. Anim. Sci. 5:36-41.

Hopkins, C. G., Smith, L. H., and East, E. M. 1974. The structure of the corn kernel and the composition of its different parts. Seventy Generations of Selection for oil and protein in maize. Crop Sci. Soc. America, Inc. Madison, WI.

Johnson, L. R. 1997. Pancreatic Enzymes. In Gastrointestinal Physiology (5th Ed.). Mosby-YearBook, Inc. St. Louis, MO.

Johnston, L. 1991. Effect of waxy corn on performance of nursery pigs. Recent Advances in Swine Production and Health. 1:41.

Jondreville, C., Van den Broecke, J., Gatel, F., and Van Cauwenberghe, S. 1995. Ileal digestibility of amino acids in feedstuffs for pigs. Eurolysine/ Technical Institute for Cereals and forages.

Jones, Marcus and Andersen, Jeff. Delayed maturity in 1997 – Potential for frost damage and other effects in corn. [Online] http://www.msu.edu/ipm/harvest.htm. 1996 and 1997 Harvest Alerts. March 17, 1999.

Karkalas, J. 1985. An improved enzymic method for the determination of native and modified starch. J. Sci. Food Agric. 36:1019-1027.

Knabe, D. A., LaRue, D. C., Gregg, E. J., Martinez, G. M., and Tanksley, Jr., T. D. 1989. Apparent digestibility of nitrogen and amino acids in protein feedstuffs by growing pigs. J. Anim. Sci. 67:441-458.

Lambert, R. J. 1994. High-oil corn hybrids. In A. R. Halluer (Ed.) Specialty Corns. CRC Press Inc., Boca Raton.

Laplace, J. P., Darcy-Vrillon, B., Perez, J. M., Henry, Y., Giger, S., and Sauvant, D. 1989. Associative effects between two fibre sources on ileal and overall digestibilities of amino acids, energy and cell-wall components in growing pigs. Br. J. Nutr. 61:75-87.

Leterne, P., Pirard, L., and Thewis, A. 1991. A note on the comparison of methods for estimating the ileal digestibility of amino acids in pigs. Anim. Prod. 52:404-406.

Lin, F. D., Knabe, D. A., and Tanksley, J., T. D. 1987. Apparent digestibility of amino acids, gross energy and starch in corn, sorghum, wheat, barley, oat groats, and wheat middlings for growing pigs. J. Anim. Sci. 64:1655-1663.

Maner, J. H. 1975.Quality protein maize in swine nutrition. In High Quality Protein Maize. Halsted Press. Stroudburg, Pennsylvania.

Marroquin, C. R., Cromwell, G. L., and Hays, V. W. 1973. Nutritive value of several varieties of opaque-2 corn and normal corn for growing swine. J. Anim. Sci. 35(2):253-257.

Mertz, E. T., and Bates, L. S. 1964. Mutant gene that changes protein composition and increases lysine content of maize endosperm. Science. 145:279-280.

Moran, Jr., E. T. 1982. Starch digestion in fowl. Poultry Sci. 61:1257-1267.

Nordstrom, J. W., Behrends, B. R., Meade, R. J., and Thompson, E. H. 1972. Effects of feeding high oil corns to growing-finishing swine. J. Anim. Sci. 35:357-361.

NRC. 1988. Nutrient requirements of swine (9th Ed.). National Academy Press, Washington, D. C.

NRC. 1988. Nutrient requirements of swine (9th Ed.). National Academy Press, Washington, D. C.

NRC. 1998. Nutrient requirements of swine (10th Ed.). National Academy Press, Washington, D. C.

Nyachoti, C. M., de Lange, C. F. M., McBride, B. W., and Schulze, H. 1997. Significance of endogenous gut nitrogen losses in the nutrition of growing pigs: A review. Can. J. Anim. Sci. 77:149-163.

Orskov, E. R. 1986. Starch digestion and utilization in ruminants. J. Anim. Sci. 63:1624 1633.

Owens, F. N., Zinn, R. A., and Kim, Y. K. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634-1648.

Parsons, C. M., Zhang, Ye, and Araba, Miloud. 1998. Availability of amino acids in high-oil corn. Poultry Sci. 77:1016-1019.

Philippeau, C., Landry, J., and Michalet-Doreau, B. 2000. Influence of the protein distribution of maize endosperm on ruminal starch degradability. J Sci. Food Agr. 80:404-408.

Pond, W. G. and Maner, J. H. 1984. Swine Production and Nutrition. Pond and Maner, Eds. West Port, CT.

Ragland, D., Thomas, C. R., Harmon, B. G., Miller, R., and Adeola, O. 1998. Nutritional evaluation of two agroidustrial by-products for ducks and pigs. J. Anim. Sci. 76:2845-2852.

Rademacher, M., Sauer, W. C., and Jans,an, A. J. M. 1999. Standardized ileal digestible amino acids for pigs. Degussa-Huls.

Risley, C. R., Bajjalieh, N. L. 1996. Apparent digestibility of high oil corn in weanling pig and growth performance of grow-finisher pigs fed high oil corn. J. Anim. Sci. 74(Suppl.1): 176.

Rooney, L. W. and Pflugfelder, R. L. 1986. Factors affecting starch digestibility with special emphasis on sorghum and corn. J. Anim. Sci. 63:1607-1623.

Sachtleben, S. S. 1975. High moisture, acid-treated opaque-2, waxy and dent corn rations for growing-finishing pigs. Michigan State Univ. Swine Res. Rep. 81.

SAS. 1998. SAS/STAT. Users Guide (Fifth Ed.). SAS Inst. Inc., Cary, NC.

Sauer, W. C., Stothers, S. C., and Phillips, G. D. 1977. Apparent availabilities of amino acids in corn, wheat and barley for growing pigs. Can. J. Anim. Sci. 57:585-597.

Sauer, W. C. and Ozimek, L. 1986. Digestibility of amino acids in swine: results and their practical applications. A review. Livest. Prod. Sci. 15:367-388.

Sauer, W. C., Dugan, M., de Lange, K., Imbeah, M., and Mosenthin, R. 1989. Considerations in methodology for the determination of amino acid digestibilities in feedstuffs for pigs. In Absorption and Utilization of Amino Acids. CRC Press Inc., Boca Raton.

Sauer, W. C., Mosenthin, R., Ahrens, F., and deh Hartog, L. A. 1991. The effect of source of fiber on ileal and fecal amino acid digestibility and bacterial nitrogen excretion in growing pigs. J. Anim. Sci. 69:4070-4077.

Shulze, H., van Leeuwen, P., Verstengen, M. W. A., and van den Berg, J. W. O. 1995. Dietary level and source of neutral detergent fiber and ileal endogenous nitrogen flow in pigs. J. Anim. Sci. 73:441-448.

Snow, J. L.1998. Amino acid digestibility and nitrogen utilization of corn hybrids fed to growing pigs. M. S. Thesis. Michigan State University, East Lansing.

Soltwedel, K. T. 1996. Digestibility of various constituents in normal, high-oil and waxy corns. M. S. Thesis. University of Illinois, Urbana-Champaign.

Stein, H. H. 1998. Comparative amino acid digestibilities in growing pigs and sows. PhD Dissertation. University of Illinois, Urbana-Champaign.

Stein, H. H., Shipley, C. F., and Easter, R. A. 1998. A technique for inserting simple T cannula in the terminal ileum of pregnant sows. J. Anim. Sci. 76:1433-1436.

Taverner, M. R., and Farrell, D. J. 1981. Availability to pigs of amino acids in cereal grains. 3. A comparison of ileal availability values with faecal, chemical and enzymic estimates. Br. J. Nutr. 46:173-180.

Taverner, M. R., Hume, I. D., and Farrell, D. J. 1981. Availability to pigs of amino acids in cereal grains. 1. Endogenous levels of amino acids in ileal digesta and faeces of pigs given cereal diets. Br. J. Nutr. 46:149-158.

Vasal, S. K. 1994. High quality protein corn. In A. R. Hallauer (Ed.) Specialty Corns. CRC Press Inc., Boca Raton.

Van der Meulen, J., Bakker, J. G. M., Smits, B., and de Visser, H. 1997. Effect of source of starch on net portal flux of glucose, lactate, volatile fatty acids and amino acids in the pig. Br. J. Nutr. 78: 533-544.

van der Poel, A. F. B., Gravendeel, S., van Kleef, D. J., Jansman, A. J. M., and Kemp, B. 1992. Tannin-containing faba beans (*Vicia faba* L.): effects of methods of processing on ileal digestibility of protein and starch for growing pigs. Anim. Feed Sci. Technol. 36:205-214.

Walker, J. A., Harmon, D. L., Gross, K. L., and Collings, G. 1993. Effect of carbohydrates on starch digestibility in the dog. J. Anim. Sci. 71 (Suppl. 1):276.

West, D. R. and Kincer, H. C. 1985. A comparison of near-isogenic high lysine and normal endosperm corn hybrids. Tennessee Farm and Home Science. 136:3-5.

White, P. J. 1994. Properties of corn starch. In A. R. Hallauer (Ed.) Specialty Corns. CRC Press Inc., Boca Raton.