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Defining the physical properties of corn grown under drought-stressed conditions and the associated energy and nutrient content for swine

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Abstract

Historically high temperatures and low rainfall during the 2012 growing season resulted in drought-stressed conditions in much of the U.S. corn belt. The objective of this experiment was to investigate the impact of these conditions on the composition and energy content in corn and determine if relationships exist among corn quality measurements, chemical composition, and digestibility of energy. Twenty-eight samples of corn from the 2012 drought-stressed crop (DS), plus 2 samples from the 2011 crop to serve as controls (CNTRL), were collected in Iowa and Illinois using yield as an initial screen for drought impact. Yields ranged from 2.5 to 14.8 t/ha. Each sample was graded by an official of the U.S. grain inspection agency and analyzed for 1,000 kernel weight, kernel density, ether extract, starch, GE, NDF, and CP content. Diets were formulated using each of the 30 corn samples and were fed at 2.6 times the estimated maintenance energy requirement according to the NRC (2012). Sixty individually-housed barrows (PIC 359 X C29; initial BW = 34.2 ± 0.2 kg) were randomly allotted in an incomplete crossover design to 30 diets across 4 periods. Diet and fecal samples were analyzed in order to determine DE values. Both ME and NE values were then calculated from DE values using methods developed by Le Goff and Noblet (2001) and Noblet et al. (1994) respectively. Mean DE, ME, and NE values between the CNTRL and DS samples were not different (3.72 vs. 3.68 Mcal/kg respectively; 3.66 vs. 3.62 Mcal/kg respectively; and 2.92 vs 2.87 Mcal/kg respectively; P> 0.10). Comparing CNTRL with DS, there were no differences (P > 0.10) in ether extract (EE) (4.07% vs 3.96%), CP (8.56 vs 9.18%), or starch (70.5 vs 69.5%). However, ADF and NDF were higher in the DS samples (2.23 and 8.19%) when compared to CNTRL (1.89 and 6.92%); P < 0.001 and P = 0.015, respectively. Small but significant correlations were observed between DE and NDF (r = -0.51; P = 0.008), kernel density (r = 0.51; P = 0.007) and % damaged kernels (r = 0.41; P = 0.031). No statistically significant correlations were observed between DE and starch, or ADF content, nor between DE and test weight. We can conclude that corn grown in droughtstressed conditions has similar energy content to corn grown under more favorable conditions, and therefore can be successfully utilized in swine diets. Furthermore, NDF proved to be superior to fat, starch, and ADF content in explaining the variation in corn energy content.

Keywords

pig, corn, drought, digestibility, energy

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Comments

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Defining the physical properties of corn grown under drought-stressed conditions and the associated energy and nutrient content for swine [1]

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ABSTRACT

Historically high temperatures and low rainfall during the 2012 growing season resulted in drought-stressed conditions in much of the U.S. corn belt. The objective of this experiment was to investigate the impact of these conditions on the composition and energy content in corn and determine if relationships exist among corn quality measurements, chemical composition, and digestibility of energy. Twenty-eight samples of corn from the 2012 drought-stressed crop (DS), plus 2 samples from the 2011 crop to serve as controls (CNTRL), were collected in Iowa and Illinois using yield as an initial screen for drought impact. Yields ranged from 2.5 to 14.8 t/ha. Each sample was graded by an official of the U.S. grain inspection agency and analyzed for 1,000 kernel weight, kernel density, ether extract, starch, GE, NDF, and CP content. Diets were formulated using each of the 30 corn samples and were fed at 2.6 times the estimated maintenance energy requirement according to the NRC (2012). Sixty individually-housed barrows (PIC 359 X C29; initial BW = 34.2 ± 0.2 kg) were randomly allotted in an incomplete crossover design to 30 diets across 4 periods. Diet and fecal samples were analyzed in order to determine DE values. Both ME and NE values were then calculated from DE values using methods developed by Le Goff and Noblet (2001) and Noblet et al. (1994) respectively. Mean DE, ME, and NE values between the CNTRL and DS samples were not different (3.72 vs. 3.68 Mcal/kg respectively; 3.66 vs. 3.62 Mcal/kg respectively; and 2.92 vs 2.87 Mcal/kg respectively; $P > 0.10$). Comparing CNTRL with DS, there were no differences ($P > 0.10$) in ether extract (EE) (4.07% vs 3.96%), CP (8.56 vs 9.18%), or starch (70.5 vs 69.5%). However, ADF and NDF were higher in the DS samples (2.23 and 8.19%) when compared to CNTRL (1.89 and 6.92%); $P < 0.001$ and $P = 0.015$, respectively. Small but significant correlations were observed between DE and NDF ($r = -0.51$; $P = 0.008$), kernel density ($r = 0.51$; $P = 0.007$) and % damaged kernels ($r =$

0.41; $P = 0.031$). No statistically significant correlations were observed between DE and starch, or ADF content, nor between DE and test weight. We can conclude that corn grown in drought-stressed conditions has similar energy content to corn grown under more favorable conditions, and therefore can be successfully utilized in swine diets. Furthermore, NDF proved to be superior to fat, starch, and ADF content in explaining the variation in corn energy content.
Key words: pig, corn, drought, digestibility, energy

INTRODUCTION

With ~712 million t produced annually (Markelz et al., 2011), corn is widely used in swine diets. When unusual cropping conditions occur, the industry logically asks if the nutritional value of corn is affected. For example, in 2009, wet growing and harvest conditions resulted in lower nutrient content (Pilcher et al., 2011) and mold infestation (Patience et al., 2014).

Much of the U.S. corn belt suffered drought conditions in 2012. Temperatures in Iowa averaged 3.8˚C above normal, making it the 4th warmest year on record since 1872. Rainfall was 22.2 cm (24.8%) below normal (Iowa Agriculture, 2012), making it one of the driest years on record. July 2012 was the hottest since 1936, with 21 days recording daily maximum temperatures above 32˚C. High temperatures combined with low rainfall place stress on the corn plant during the critical cob formation and milk stages of development, leading to reduced yields, decreased kernel mass, and lower kernel number (Claassen and Shaw, 1970; Mustek and Dusek, 1980; Çakir, 2004). Premature termination of kernel growth led to a decrease in final endosperm and embryo mass (Ouattar et al., 1987; Grant et al., 1989; Westgate, 1994).

Corn is added to swine diets primarily as a source of energy. Variation in energy content can lead to differences in growth performance and carcass composition (De La Llata et al., 2001; Beaulieu et al., 2009). Therefore, when the quality of a corn crop is questioned, energy is the topic of greatest and most immediate interest.

The objectives of this experiment were to evaluate the energy content of corn grown under drought-stressed growing conditions, and to determine if relationships exist among corn quality measurements, nutrient content, and digestibility of energy. We hypothesized that corn grown under drought-stressed conditions would have lower energy content than normal corn and that this would be correlated with yield as a crude proxy for the degree of drought stress experienced by the corn.

MATERIALS AND METHODS

All experimental procedures complied with the guidelines for the ethical and humane use of animals for research, and were approved by the Iowa State University Institutional Animal Care and Use Committee (#9-12-7441-S).

Animals, Housing and Experimental Design

Sixty barrows (PIC 359 × C29; initial BW = 34.2 ± 0.2 kg) were randomly allotted in an incomplete crossover design with 30 diets and 4 periods. The same pigs were used through the 4 periods, but no pig received the same diet twice. Each period consisted of 6 days of adaptation to test diets followed by 3 days of fecal collection. Pigs were fed a fully balanced grower diet for the 5 days between each period. Pigs were housed individually in 1.0 x 1.8 m pens. Each pen had a partially slatted concrete floor, individual feeder, and nipple drinker. Water was provided ad libitum throughout the experiment. Test diets were fed at 2.6 times the estimated energy required for maintenance (NRC, 2012) based upon the average weight of the pigs at the beginning of each collection period. The NRC (2012) ME value for corn was used to estimate the energy value of the experimental diets. Feed allowance was divided into equal rations that were provided twice daily.

Diets and Feeding

Corn samples (n = 38) were collected from across Iowa and parts of Illinois using yield as an initial screen for drought-stress. It was assumed that, in approximate terms, samples obtained from lower yielding fields were affected the most by drought. Corn samples were collected as evenly as possible within the following yield (t/ha) categories: < 6.28 (100 bu/acre), 6.29 to 7.85 (101 to 125 bu/acre), 7.86 to 9.42 (126 to 150 bu/acre), 9.43 to 10.98 (150 to 175 bu/acre) and > 10.99 (176 bu/acre). All samples were tested by the Iowa State University Veterinary Diagnostic Laboratory (Ames, IA 50011) for aflatoxin contamination, and any sample exceeding 20 ppb was discarded; only one sample surpassed this limit. Additionally, each sample was graded by an official U.S. grain inspection agent for moisture content, test weight, total damaged kernels, and broken kernels and foreign material. The samples were then tested at Iowa State University for 1,000 kernel weight and kernel density via NIR. Two representative corn samples from the 2011 crop (CNTRL) were obtained from the area surrounding Ames, IA to serve as controls. Twenty-eight of the 38 samples from the 2012 crop year (DS) were used in this experiment based on yield category and aflatoxin levels considered benign to the pig.

Thirty diets were formulated using one of each of the corn samples plus vitamins, minerals, and 0.4% titanium dioxide (Table 1) as an indigestible marker to determine the apparent total tract digestibility (ATTD) of GE and DM. Vitamins and minerals were supplied at levels formulated to meet or exceed the pigs' nutrient requirements (NRC, 2012). Thus, other than minor amounts supplied in the vitamin premix, the only source of energy in these diets would be corn, the ingredient of interest. The corn was ground to a mean particle size of 647 ± 70 microns.

Sample Collection and Analysis

Fresh fecal samples were collected on d 7, 8, and 9 via grab sampling and immediately frozen (- 20°C) for later assay. Pens were scraped on d 6 to ensure fresh sample collection. Representative corn and diet samples were collected at the time of feed mixing and stored at - 20°C until analyzed.

Fecal samples were thawed at room temperature, homogenized, dried in a forced air oven at 65°C (Yamato Mechanical Convection Oven DKN810, Yamato Scientific America, Inc., Santa Clara, CA), and ground through a 1.0 mm screen (Wiley Mill 3379-K35, Thomas Scientific, Swedesboro, NJ) prior to analysis. Dry matter of feed and feces was determined by drying at 105˚C to a constant weight (method 967.03; AOAC, 1990). The GE of feed and feces was determined using an isoperibolic bomb calorimeter (Model 6200, Parr Instrument, Moline, IL). Benzoic acid (6318 kcal GE/kg; Parr Instruments, Moline, IL) was used as the standard for calibration and was determined to contain 6320 ± 5 kcal GE/kg. Titanium dioxide content in both the feed and feces was determined according to Leone (1973).

Corn samples were processed and analyzed in the same manner as feed samples. They were additionally analyzed for nitrogen using a TruMac®N Nitrogen Analyzer (Leco Corporation, St. Joseph, MI) according to method 990.03 (AOAC, 2007). EDTA (9.586 % N;

LECO Corporation, St. Joseph, MI) was used as the standard for calibration and was determined to contain 9.584 ± 0.0067 % N. Total starch content was determined using a commercially available kit (Megazyme K-TSTA, Wicklow, Ireland) following modified method 996.11 (AOAC, 2007). Both ADF and NDF were quantified in the corn using an Ankom Fiber Analyzer (Model 2000, ANKOM Technology Method 9, Ankom Technology, Macedon, NY). Ether extract was determined following acid hydrolysis using ether extraction according to method 920.39 (AOAC, 2007).

All analyses were carried out in duplicate, except ADF and NDF, which were assayed in triplicate. Assays were repeated when the intra-sample CV of any sample exceeded 3%. All assayed nutrient values for corn samples are presented on a DM basis.

Apparent total tract digestibility coefficients (ATTD) were calculated for GE and DM according to Oresanya et al. (2007). Both ME and NE values were calculated from DE using the equations of Le Goff and Noblet (2001) and Noblet et al. (1994), respectively.

Statistical Analysis

This experiment was designed as an incomplete crossover design with 30 treatments and 4 periods. The PROC UNIVARIATE procedure (Version 9.3, SAS Inst., Cary, NC) was used to verify normality and homogeneity of variances, and all data were analyzed using the PROC MIXED procedure of SAS. The individual animal and corn sample were the experimental units for analyzing the data from the digestibility trial and analysis of the chemical constituents, respectively. The model for ATTD of GE and DM included the fixed effect of treatment and the random effect of replicate period. Differences were considered significant if P was ≤ 0.05 and trends if P was > 0.05 and ≤ 0.10. Correlation coefficients were determined using the PROC

CORR procedure of SAS and are reported as Pearson coefficients. Correlations were considered significant if P was ≤ 0.05 and trends if P was > 0.05 and ≤ 0.10.

RESULTS AND DISCUSSION

A wide range in corn yield was represented in the 28 DS samples, from 2.45 kg/ha to 14.81 kg/ha. One of the immediate impacts of water stress in corn is a reduction in yield (Claassen and Shaw, 1970; Otegui et al., 1995); the well described impact of water stress on yield validated the use of yield as a proxy for the degree of drought stress experienced by the corn selected for use in this experiment. Depending on the timing of the drought, there can be a reduction in the number of cobs per plant (Çakir, 2004), in the number of kernels per cob (Zinselmeier et al., 1999) and/or the size or weight of the kernels (Grant et al., 1989). Drought also reduces plant height and leaf area index (Çakir, 2004). Carbohydrate reserves in the leaves and stalks, in addition to nitrogen reserves in the leaves, can be mobilized to aid in nutrient deposition in kernels during times of stress (Westgate, 1994). It is likely that due to drought-stress, the plant mobilized more carbohydrate and nitrogen stores from the leaves and stalk to aid in kernel growth than it would under normal conditions. Additionally, the total N needed to produce a given concentration in the corn would be less for low yields. These factors could explain how plants were able to maintain normal nutrient concentrations, in spite of small kernel size and severe drought.

A comparison of CNTRL corn samples with DS samples provides some basis for yr-to-yr differences, especially since all samples were handled identically and evaluated under the same experimental conditions. However, with only 2 samples included from the former yr, conclusions drawn from the comparison must be interpreted with great care. The selection of samples from

2012 was based on the study objective, which was to characterize corn grown under drought-stressed conditions, not to compare the two yr directly. Nonetheless, it was useful to include 2 prior year samples in the study, as a basis for evaluating the nutrient and chemical composition and digestibility of drought-stressed corn compared with that grown under less stressful conditions.

There were few differences between CNTRL and DS corn samples in terms of physical characteristics (Table 2). Density and test weight were virtually identical between years, which agree with field observations made throughout the 2012 crop year that test weights did not appear to be affected by the drought. There was a tendency for the proportion of damaged kernels to be higher in the DS corn ($P = 0.068$) and there certainly was a very wide range among samples. Kernel weight was highly variable, and although the 2012 crop appeared to be lower than that of the 2011 crop, the difference was not significant ($P > 0.10$). The 1,000 kernel weight for 2011 appeared to be typical for corn grown under optimal conditions and the 2012 samples reflected the range expected in severely stressed conditions (Al-Naggar et al., 2015).

A highly variable characteristic of the corn used in this experiment was 1,000 kernel weight (Table 2). Water deprivation has been shown to cause premature termination of the grain fill period, thus causing decreased kernel weight and overall yield (Prasad et al., 2008). Expected differences in the degree of drought-stress among samples would likely cause variation in length of the grain fill period, and therefore would explain the range observed in kernel sizes. Despite this wide variation in kernel weight, the variation in average kernel density among samples only ranged from 1.26 to 1.30 g/cc with a mean of 1.27 g/cc.

The DS corn samples had higher NDF concentrations compared to CNTRL samples (8.2 vs. 6.9%, $P = 0.015$; Table 3). INRA (2002) and NRC (2012) reported somewhat higher average

NDF content of corn at 12.0% and 10.3%, respectively, suggesting that the fiber content of corn grown in the DS crop yr was not abnormally high. Additionally, DS samples had higher ADF concentrations than CNTRL samples (2.2 vs. 1.9%, $P < 0.001$). No other differences in chemical constituents of the corn samples were detected, despite a numerical increase in CP (9.2 vs 8.6%) and a numerical decrease in starch (69.5 vs 70.5%) in DS versus CNTRL ($P > 0.10$). Elevated levels of CP would be expected in corn grown under drought-stress conditions (Oktem, 2008).

The mean CP level observed in DS was similar to the values reported by the NRC (9.3%; 2012), Feedstuffs (8.7%; 2014) and INRA (9.4%; 2002) for yellow dent corn. Cromwell et al. (1999) reported variation in the mean composition of 45 corn samples collected over 3 yr. They reported mean CP values of 9.6, 9.2, and 8.9% for 1989, 1990 and 1992, respectively, further suggesting that the DS corn samples used in this experiment were not unusual in their protein content. The 4.0% ether extract reported in Table 3 is also similar to the 4.3, 4.2, and 4.1% reported by INRA (2002), NRC (2012) and Feedstuffs (2014), respectively. Finally, the starch content of the DS corn (69.5%) was less than the 74.2% reported by INRA (2002) but only slightly less than the 70.8% reported by NRC (2012). Overall, the data on chemical composition suggest that DS corn was not very different compared with typical corn.

The GE of corn would not be expected to differ among yr, unless the fat content also varied. Since ether extract values were virtually identical in CNTRL and DS samples, no differences in GE were expected or observed ($P > 0.10$; Table 4). The ATTD of DM was greater in CNTRL (84.4%) compared with DS corn (83.4%; $P < 0.001$). This differed from the results reported by Jones et al. (2015) who suggested that ATTD of DM did not differ between normal or drought-stressed corn. This could be explained by the fact that they compared only 1 sample each of normal and drought-stressed corn. Furthermore, the ATTD of DM reported by Jones et al. (2015) was considerably higher than reported in this study (85.3 vs 83.9%), despite having corn samples with greater NDF content (9.8 vs 7.6%). There was no difference in ATTD of GE (84.3 and 83.1% for CNTRL and DS, respectively; $P > 0.10$). The fact that differences in ATTD of DM was observed but not of GE can be explained by the difference in the SEMs: 0.20 for ATTD of DM and 0.81 for ATTD of GE. Typically, ATTD of DM and GE of ingredients and complete feeds is very similar within samples (Gutierrez et al., 2013; Pilcher et al., 2013), unless they are rich in lipids.

Similarly, there were no differences between the CNTRL and DS corn samples for DE, ME or NE content (Table 4; $P > 0.10$). The ME and NE values were calculated from DE using generally accepted equations: Le Goff and Noblet (2001) for ME and Noblet et al. (1994) for NE. The observed range in DE values, at about 8%, is typical of measurements of DE and ME observed in swine studies (Jacobs et al., 2013).

The DE content of CNTRL (3.72 Mcal/kg DM) and DS samples (3.68 Mcal/kg DM) were below the 3.91 Mcal/kg DM reported by NRC (2012), the 3.93 Mcal/kg DM reported by INRA (2002) and the 3.90 Mcal/kg DM reported by Feedstuffs (2014). The ME content of CNTRL (3.66 Mcal/kg DM) and DS samples (3.62 Mcal/kg DM) were below the 3.84 Mcal/kg DM reported by the NRC (2012), 3.85 Mcal/kg DM reported by INRA (2002), and 3.90 Mcal/kg DM reported in Feedstuffs (2014). The NE content of CNTRL (2.92 Mcal/kg DM) and DS samples (2.87 Mcal/kg DM) were also lower than the 3.03 Mcal/kg DM reported by the NRC (2012) and the 3.07 Mcal/kg DM reported by INRA (2002). Nothing in the chemical composition of the CNTRL or DS corn samples explains the lower energy content in this experiment, compared to these common databases. It can only be concluded that energy concentration measured on specific ingredients varies among experiments, and that the data reported herein fall within the range of previously published values (all expressed on a DM basis): 4.11 Mcal DE/kg (Smith et al., 2015), 4.03 Mcal/kg (Rojas et al., 2014), 3.77 Mcal/kg (Adeola and Bajjalieh, 1997), 3.77 Mcal/kg (Carr et al., 1995) and 3.27 Mcal DE/kg (Park et al., 2015).

No relationships were observed between any single physical or chemical corn quality measurement, and DE content of the 28 DS corn samples (Table 5). It was surprising that no relationship was apparent between corn yield and DE content, thus rejecting our hypothesis that the energy content of the corn would be negatively impacted by drought stress. If one can accept our assertion that corn yielding less than 6.28 kg/hL was severely affected by drought and that corn yielding greater than 10.99 kg/hL was much less affected by drought, if at all, then clearly drought affecting yield did not affect DE content of the grain. Personal communications with pork producers suggested that problems with pig performance were not observed with the 2012 corn crop, certainly not in the way that widespread complaints were reported with the 2009 crop which was exposed to excess moisture during harvest (Pilcher et al., 2011). It is possible that yield was not a suitable proxy for drought stress, but this is unlikely, since yield is the most consistent consequence of water stress (Claassen and Shaw, 1970; Çakir, 2004). Alternatively, modern hybrids may be more tolerant of drought or perhaps modern hybrids are capable of maintaining nutritive value in spite of severe water inadequacy. Indeed, the only characteristics of the corn which were correlated with DE content were percent damaged kernels, NDF content, and kernel density.

It was not expected that test weight would correlate with corn DE (Table 5). This has been observed in other crops, such as barley (Fairbairn et al., 1999) and wheat (Zijlstra et al., 1999). This agrees with the observations of Leeson et al. (1993) in poultry, although Dale (1994) concluded in poultry that test weight was not a useful indicator of the feeding value of corn, unless it falls below 64 kg/hL. In the present study, no such threshold was apparent in swine, possibly because the lowest test weight recorded among the samples was 69 kg/hL.

A positive correlation was observed between kernel density and DE; as density increased, so too did DE (r = 0.51; *P* = 0.007; Table 5). This seems intuitive because more dense kernels should contain more nutrients. However, like other volumetric measures which are influenced not only by kernel density but also by kernel size and shape, we believe this measure should be employed with care, unless additional research supports its value. In this instance, kernel density explained about one quarter of the variation in DE content, similar to that reported for NDF. What is most interesting about this outcome is that kernel density varied so little among samples, and yet it explained a substantial portion of the variation in DE content.

There was also a positive correlation between total damaged kernels and DE (Table 5; r = 0.41; *P* = 0.031). This relationship does not make biological sense. There are a variety of factors that could result in a kernel being officially classified as damaged, including dryer-damage, cob rot, surface mold, insect-bore damage, sprout-damage and heat-damage. This high variability in the cause of kernel damage makes it nearly impossible to predict the impact of total damaged kernel on the nutritional value of a given corn sample. Furthermore, the majority of samples in this dataset contain less than 1% total damaged kernels and a much smaller portion had less than 2% damaged kernels. Only very few samples had more than 2% damaged kernels, and these are disproportionately influencing the correlation.

There was an expected negative correlation between NDF and DE, such that as fiber increased, DE decreased (r = -0.51; *P* = 0.008; Table 5). This relationship makes biological sense, since higher fiber levels would be associated with lower digestibility of GE (Gutierrez et al., 2013). Indeed, Gutierrez et al. (2014) reported that a very small constituent of dietary fiber – xylose – could explain more than 60% of the variation in the DE content among 9 highly diverse corn coproducts. However, there was no relationship between ADF and DE, further emphasizing the importance of the hemicellulose component of the fiber in corn (Gutierrez et al., 2014).

Surprisingly, no relationship existed between fat content of the corn and DE. However, the majority of the samples were very similar in fat content, making it difficult to establish a correlation, if one exists biologically. Smith et al. (2015) used a much larger corn dataset (n = 83) and reported a correlation of 0.86 between ether extract and DE. However, their samples varied in fat content from 3.11 to 10.8, suggesting that so-called "high fat" corn samples were used in this study. The highest fat content in the samples used herein was only 4.83%. Whether a relationship exists between the fat content of normal corn samples and DE remains uncertain at this time.

Neither was there a relationship between the starch content of corn and its DE content. One would expect a positive correlation, since starch is the major source of energy in the corn kernel. Yet, Smith et al. (2015) reported a significant negative correlation between starch and DE; but once again, their samples varied in starch content from 58 to 69%, whereas the samples used herein ranged from only 67 to 72% with a measurement error of just over 1%. Why they observed a negative correlation between starch and DE is difficult to explain.

In conclusion, our hypothesis that drought-stressed corn would be inferior to corn grown under more favorable conditions was not supported. Corn grown in drought-stressed conditions was comparable in available energy concentration to corn grown in a "normal" yr. Despite some lower quality measurements, such as kernel density and damaged kernels, energy values remained unaffected. Therefore, corn grown under drought-stressed conditions can be successfully utilized in swine diets. This study also reaffirmed the superiority of NDF over ADF as a predictor of available energy content in corn for swine, and that within the range of nutrient content experienced in this study, compositional measures such as ether extract and starch are not related to available energy content. Finally, variation is a feature of all biological populations, and while corn is surprisingly uniform compared to other grains, evaluation of each new crop year is recommended. While drought was not shown to be a factor related to energy content in this study, the fact that other environmental variables have been shown to impact energy values justifies caution.

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Table 1. Ingredient composition of test diets, % as-fed basis

Item	
Corn	96.54
Limestone	1.23
Monocalcium phosphate	1.19
Salt	0.40
Vitamin premix[1]	0.14
Trace mineral premix[2]	0.10
Titanium dioxide	0.40

[1]Provided per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D, 827 IU; vitamin E, 26 IU; vitamin K, 2.6 mg; niacin, 29.8 mg; pantothenic acid, 16.5 mg; riboflavin, 5.0 mg; vitamin B_{12}, 0.023 mg.

[2]Provided per kilogram of diet: Zn, 165 mg as zinc sulfate; Fe, 165 mg as iron sulfate; Mn, 39 mg as manganese sulfate; Cu, 17 mg as copper sulfate; I, 0.3 mg as calcium iodate; and Se, 0.3 mg as sodium selenite.

Table 2. Physical measurements of corn samples used in diet formulation[1]

Item	CNTRL[2]	DS[3]	DS Range	SEM	*P*-value
n	2	28	--	--	--
Kernel density, g/cc	1.27	1.27	1.26 – 1.30	0.024	0.904
1000 kernel weight, g	337	284	176 – 386	55.8	0.344
Test weight, kg/hL	73.9	73.1	69.0 – 76.0	1.87	0.653
Total damaged kernels, %	0.9	1.7	0.2 – 7.9	0.40	0.068
Broken kernels and foreign material, %	0.8	0.7	0.2 – 2.0	0.66	0.953
Yield, t/ha	--	7.97	2.45 – 14.81	--	--
Particle size, microns	625	647	525 – 844	59.5	0.718

[1]All values presented on an as-is basis

[2]CNTRL = control samples from 2011 crop; collected from Ames, IA

[3]DS = samples grown in drought-stressed conditions from 2012 crop from Iowa and Illinois

Table 3. Chemical composition of corn samples used in diet formulation[1]

Item	CNTRL[2]	DS[3]	DS range	SEM	*P*-value
n	2	28	--	--	--
CP, %	8.56	9.18	7.98 – 11.07	0.379	0.108
Ether extract, %	4.07	3.96	2.91 – 4.83	0.183	0.579
ADF, %	1.89	2.23	1.82 – 3.14	0.073	<0.001
NDF, %	6.92	8.19	7.02 – 10.14	0.489	0.015
Starch, %	70.5	69.5	67.4 – 71.6	1.21	0.419

[1]All values presented on a dry-matter basis

[2]CNTRL = control samples from 2011 crop; collected from Ames, IA

[3]DS = samples grown in drought-stressed conditions from 2012 crop from Iowa and Illinois

Table 4. Digestibility and energy content of corn samples used in diet formulation[1]

Item	CNTRL[2]	DS[3]	DS Range	SEM	*P*-value
n	2	28	--	--	--
DM	89.41	89.79	86.3 – 92.3	0.352	0.280
GE	4.42	4.43	4.40 – 4.49	0.007	0.116
ATTD of DM	84.4	83.4	81.4 – 85.0	0.20	<0.001
ATTD of GE	84.3	83.1	80.6 – 85.6	0.81	0.150
DE, Mcal/kg	3.72	3.68	3.54 – 3.82	0.042	0.359
ME, Mcal/kg[4]	3.66	3.62	3.48 – 3.75	0.041	0.299
NE, Mcal/kg[5]	2.92	2.87	2.76 – 2.97	0.031	0.160

[1]All values reported on a dry-matter basis

[2]CNTRL = control samples from 2011 crop; collected from Ames, IA

[3]DS = samples grown in drought-stressed conditions from 2012 crop from Iowa and Illinois

[4]Calculated as: ME = DE x [100.3 – (0.021 x CP)]; where DE is expressed as Mcal/kg DM; CP is expressed as g/kg DM (Le Goff and Noblet, 2001)

[5]Calculated as: NE = (0.700 x DE) + (1.61 x EE) + (0.48 x Starch) – (0.91 x CP) – (0.87 x ADF); where DE is expressed as Mcal/kg DM; chemical components are all expressed in g/kg DM; (Noblet et al., 1994)

Table 5. Relationship between DE concentration and yield, physical and chemical characteristics of the corn grown under drought-stressed conditions[1,2]

Item	P- value	Correlation coefficient, r	Coefficient of determination, R^2
Yield, t/ha	0.516	-0.13	0.02
Test weight, kg/hL	0.294	0.21	0.04
1,000 kernel weight, g	0.377	0.17	0.03
Damaged kernels, %	0.031	0.41	0.17
Broken kernels and foreign material, %	0.454	0.14	0.02
Kernel density, g/cc	0.007	0.51	0.26
CP, %	0.242	0.22	0.05
Ether extract, %	0.525	0.14	0.02
Starch, %	0.151	-0.28	0.08
NDF, %	0.008	-0.51	0.26
ADF, %	0.607	-0.10	0.01

[1] DE expressed in Mcal/kg DM; range in values of all parameters are presented in Tables 2, 3 and 4

[2] Data from 28 corn samples selected for diversity of yield as a proxy for degree of drought stress