Factors affecting ileal digestible energy of corn in poultry diets

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Summary

Broiler diets were formulated for 93 different corn batches, each divided in half. One was supplemented with xylanase, amylase and protease enzymes (Avizyme™ 1502, Danisco Animal Nutrition) and fed to male broilers to 28 d, and body weights and feed intakes were recorded. Corn and digesta samples were analysed for starch, protein, oil, and gross energy content, and ileal digestible energy (IDE) was computed. Feed conversion ratio (FCR) ranged between 1.43 and 2.67 (mean and SD 1.81 ± 0.30). The 28 d weight ranged between 680 and 1301 g with mean 909 ± 114 g. Enzyme addition improved FCR to 1.73 (P<0.01) and significantly reduced its CV by 30%. The average corn IDE was 11.84 ± 2.03 MJ/kg. Using least–square estimators, digestibility coefficients for starch, protein, oil and other fractions (fibre etc.) were found to be 86%, 82%, 90% and 12%, respectively. With enzyme addition, IDE was raised by an average of 5% to 12.45 MJ/kg. Digestibility coefficients were raised to 91%, 83%, 91%, and 14% for starch (+5%), protein (+1%), oil (+1%) and other sources (+2%), respectively. Starch digestibility was related to *in vitro* starch digestion rate (P<0.01).

Keywords: poultry, ileal digestible energy, corn, maize, starch, enzymes, amylase, protease, xylanase

Introduction

Corn quality is affected by genetics, growing and harvesting conditions, drying process, and feed manufacturing. Variability in composition and quality affect the metabolizable energy content with consequential effects on poultry performance. Energy comes from the protein, oil, and carbohydrate sources in the corn; however, not all of this energy is metabolizable. Corn (see Figure 1) is comprised of a pericarp (P), which is the outer covering, or hull, that protects the kernel from the environment, insects and pathogens, although the tip cap (T) may provide access into the kernel. The kernel is comprised of the endosperm (E) and the germ (G). The endosperm is the source of energy for the seed, and this energy comes mainly from starch, and some protein. The germ is the living part of the kernel, and contains enzymes, vitamins, minerals and the genetic information for the kernel to grow into a corn plant. Depending on the genetic variety, approximately 25% of the germ is corn oil, high in linoleic acid. On average, the composition of corn dry matter is 68% starch, 8% protein, 4% oil, 2.5% cellulose, and trace amounts of vitamins and minerals.

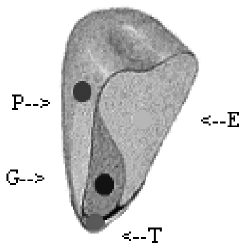

Figure 1 Corn kernel.

Starch as the major component of corn, and other grains, is the largest source of energy in the typical poultry corn–soy diet. Regardless of its source in the diet, starch is made up of glucose molecules amylose and amylopectin. The amylopectin molecule is nearly identical to amylose, except that amylopectin has an α 1–6 glucose linkage that causes it to form branches. The branching structure (A, B) of a starch granule (C) formed by the α 1–6 glucose linkage of amylopectin (D) is illustrated in Figure 2.

A global corn quality survey (D'Alfonso and McCracken 2002) provided data on the variability of corn composition. As shown in Figure 3, as starch level increases the protein and oil contents tend to decrease, especially oil; there is a less strong positive relationship between protein and oil contents. Gross energy values are relatively constant, 38.91, 17.36, and 22.97 MJ/kg for oil, starch, and protein, respectively (Noblet 2000), but these values could change if the corn is overheated and, for example, the starch is retrograded.

The rate of starch digestion was measured *in vitro* in a two–stage process in which each of 93 samples of corn from various sources was incubated with a solution of pepsin with HCl, followed by pancreatin digestion.

This process was designed to simulate digestion in the chicken (D'Alfonso and McCracken 2002). The extent of digestion after 7, 15, 22, 30, 45, 60 and 120 minutes of incubation was determined (Figure 4).

The purposes of this research are to quantify the sources of variation in corn quality, to predict the dietary energy of corn based on these factors, and to predict the improvement in dietary energy when appropriate enzymes are added to the feed. It is necessary to consider the proportion of corn in the diet which will determine the effect of corn quality on the performance of birds fed a corn–based diet. It is also necessary to use a method of measuring dietary energy that is closely related to poultry performance, namely the ileal digestible energy (IDE) of protein, oil and carbohydrates (starch and fibre) and the effect of enzyme supplementation on each value.

Methodology

Ninety–three commercial corn samples were obtained from 15 countries around the world (D'Alfonso and McCracken 2002) and were ground, and one mash broiler diet was formulated with 55% corn for each corn batch, resulting in 93 diets that differed only in the batch of corn used. Diet formulation is shown in Table 1. Each diet was then separated into two portions and one was supplemented with a commercial enzyme blend of xylanase, amylase and protease (Avizyme™ 1502, Danisco Animal Nutrition). Each of these 186 diets was fed to 25 male broilers per pen from day 1 to day 28 and body weights and feed intake were measured. Digesta samples were collected at the terminal ileum from six birds per pen and digesta from each bird were analysed for energy content. Corn samples were analysed for starch, protein, oil and gross energy (GE). IDE was computed using the relative proportions of titanium dioxide marker in the feed and digesta.

GE of the corn was partitioned into that coming from starch, protein and oil, and subtracting these amounts and moisture from 100% determined the contribution of 'other' sources. The IDE of each source was calculated from its percent digestibility multiplied by the gross energy values of 38.91, 17.36, and 22.97 MJ/kg for oil, starch, and protein respectively. Improvements in IDE owing to the addition of the enzymes to the diets were portioned into improvements in the digestibility coefficients of starch, protein, oil and other sources.

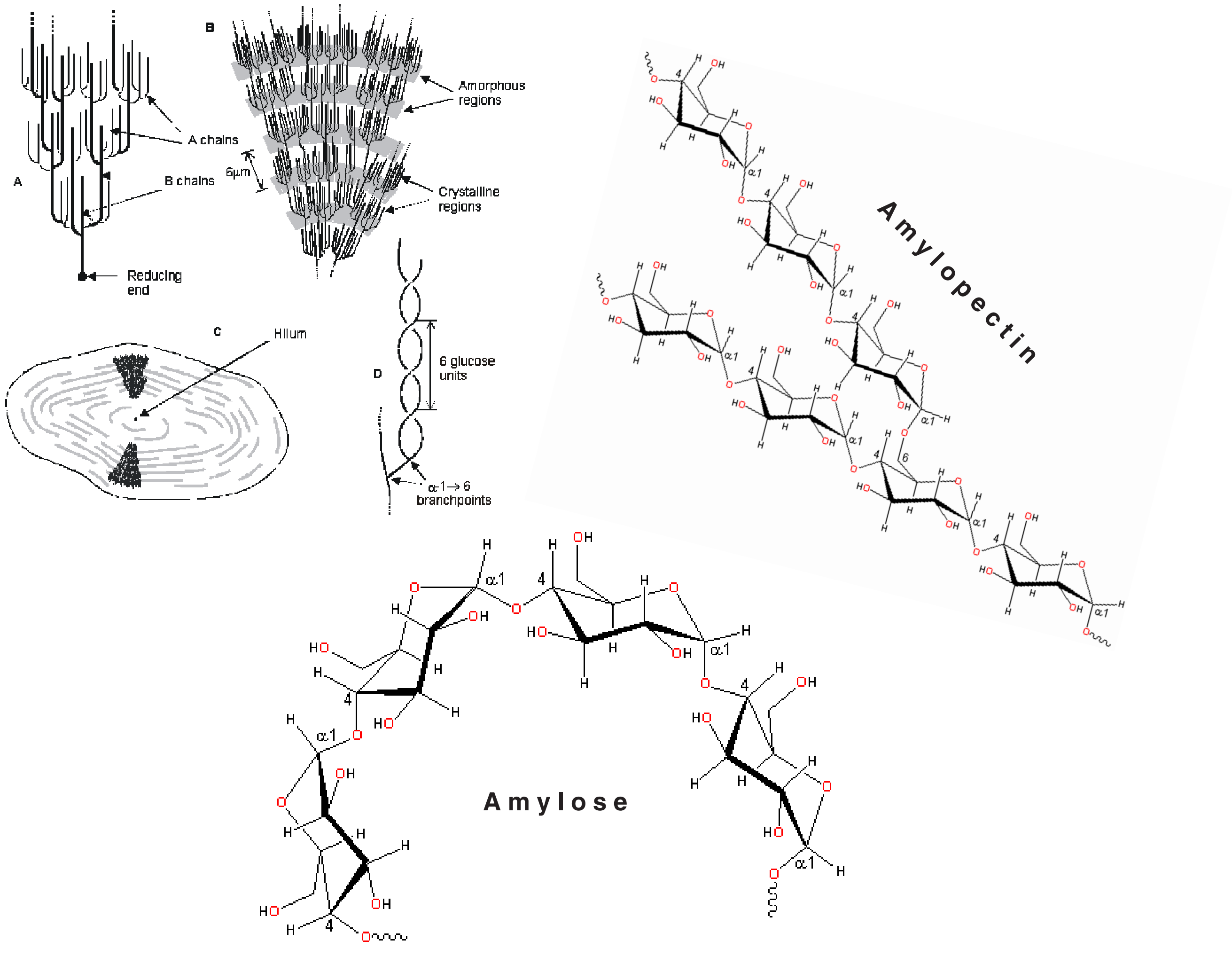

Figure 2 Starch structure (A–D) and amylose and amylopectin molecules.

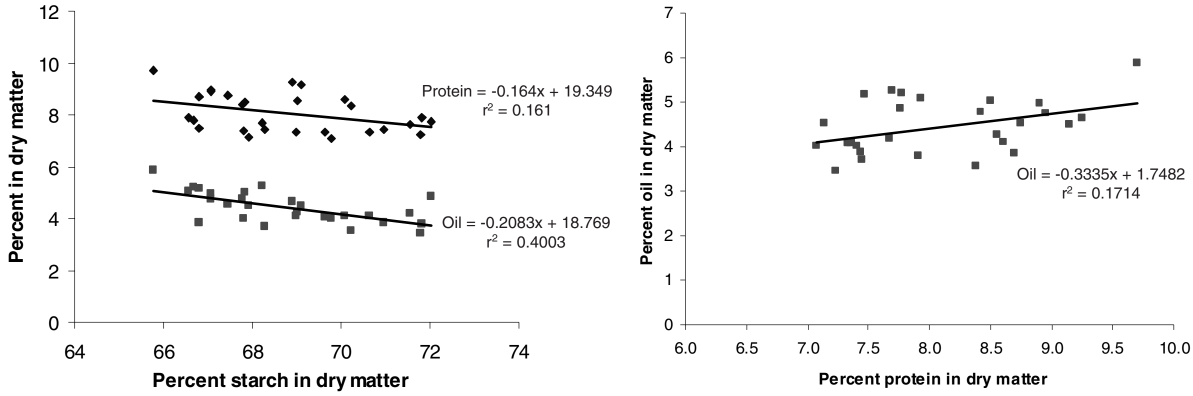

Figure 3 Relationships among starch, protein and oil contents of corn.

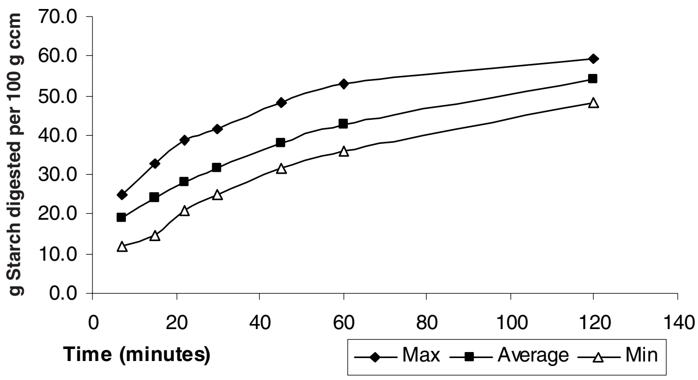

Figure 4 Rate of starch digestion determined *in–vitro* among 93 corn samples.

Table 1 Dietary composition and calculated nutrient levels.

Ingredient and percent in diet		**Composition of diets**			
		Nutrients		**Amino acids (%)**	
Corn	54.84	Protein %	23.0	Met	0.60
Soybean meal (49%)	36.34	ME MJ/kg	12.93	Cys	0.37
Fishmeal	1.07	Fat %	6.2	Me+Cys	0.98
Lysine	0.02	Fibre %	2.6	Lys	1.29
DL Methionine	0.24	Calcium %	1.04	His	0.62
Soy Oil	3.60	Total P %	0.78	Tryp	0.27
Dicalcium phosphate	1.82	Available P %	0.49	Thr	0.89
Limestone	1.22	Na %	0.16	Arg	1.55
Salt	0.32	Cl %	0.25	Iso	0.98
Sodium bicarbonate	0.10	K %	0.97	Leu	1.99
Vitamin/Mineral mix	0.27	Mg %	0.21	Phe	1.12
Choline chloride	0.04	S %	0.19	Tyr	0.83
Titanium dioxide	0.30	Choline ppm	1370	Val	1.08
		Linoleic acid %	2.53	Gly	0.95
				Ser	1.09

Results

The performance of broilers fed different sources of corn without enzymes was variable. Feed conversion ratio (FCR) ranged between 1.43 and 2.67 with a mean and SD of 1.81 ± 0.30 (Table 2). One outlier with an FCR of 3.36 was removed from the analysis, this being a corn sample from France with 25% moisture. The weight gain ranged between 680 and 1301 g with a mean of 909 ± 114 (an outlier of 375 g was removed). The addition of enzymes improved FCR ($P<0.01$) and reduced its CV by 30%. The variability in starch, protein, oil and gross energy composition among the samples on a dry matter basis is shown in Table 3.

The relationship between measured GE of the corn samples and values predicted from their chemical composition and energy of the components was highly significant ($P<0.0001$, $r^2 > 0.92$). The root mean square error of a predicted value was ± 0.10 MJ/kg (± 0.5% of the mean) An example of a predicted GE for a sample with a measured 18.97 MJ/kg is shown in Table 4.

Results from the analyses of many corn samples (Figure 5) show that starch contributes more than two–thirds of the GE in corn. Protein and oil each contribute approximately the same percentages, although this is different for high oil corn. Fibre and other sources contribute approximately 20% of the GE, but these are not very digestible as shown by the IDE values.

The mean of the measured IDE with SD was 13.58 ± 2.04 MJ/kg DM. Using least–square estimators, digestibility coefficients for starch, protein, oil and other fractions were found to be 86.3%, 81.6%, 90.2% and 11.4%, respectively. With the addition of enzymes, the IDE was raised by an average of 5% to 14.25 MJ/kg DM ($P<0.001$). Digestibility coefficients were found to be raised to 91.3%, 82.4%, 90.7% and 13% for starch (+5.0%), protein (+0.8%), oil (+0.5%) and other (+1.6%), respectively. The average increase in digestibility of starch was significant at $P<0.01$ and for protein, oil and the other sources of energy at $P<0.05$. Digestibility of starch *in vivo* ranged from 84 to 90% with an average of 86% and was significantly related

Table 2 Performance of 28–day broilers fed diets corn–based diets without or with enzymes.

	Enzymes	Mean	SD	CV %
Gain (g)	No	909	114	13
	Yes	915	114	12
Feed: Gain	No	1.81	0.30	16
	Yes	1.73	0.20	12

Table 3 Major chemical constituents in the dry matter and the measured gross energy of 93 samples of corn obtained from various locations.

	Dry Matter (%)	Starch (%)	Protein (%)	Oil (%)	Gross energy (MJ/kg DM)
Mean	89.1	68.8	8.1	4.4	18.9
SD	0.9	1.8	0.7	0.6	0.1
Minimum	87.4	65.8	7.1	3.5	18.7
Maximum	90.7	72.0	9.7	5.9	19.2
CV%	1	3	9	13	1

Table 4 The contributions of nutrients to the gross energy in a corn sample with measured 18.97 MJ per kg dry matter.

Nutrient	Percent in corn DM	GE MJ/kg DM	Calculated MJ/kg DM
Starch	71.6	17.36	12.43
Protein	7.7	22.97	1.77
Oil	4.2	38.91	1.63
Other	16.6	18.16	3.01
			Total: 18.84

(P<0.01, r^2 > 0.82) to the *in vitro* values for rate of starch digestion which ranged from 37 to 53% with an average of 42%. The addition of the enzymes increased starch digestion proportionately to the improvement in IDE. It is proposed that xylanase and protease act to increase accessibility of starch to digestion and that amylase increases the rate of digestion.

There was an additional increase in IDE of approximately 0.02 MJ/kg that was not attributable to corn. In the type of diet used it is assumed that the IDE of soybean meal may have been improved, perhaps due to the protease. Figure 6 illustrates the percentage of IDE coming from corn components and other ingredients in the diets.

Table 5 illustrates calculations of energy value for the corn sample with an estimated GE of 18.84 MJ/kg DM. The IDE of this sample was estimated to be 13.97 MJ/kg DM, and improved to 14.67 MJ/kg DM with the addition of enzymes (Table 5). In a diet containing 55% of this corn, the increase in IDE from the addition of enzymes due to corn alone is 0.38 MJ/kg DM (Table 6). Least square estimators were used to determine IDE of the other ingredients in the diet.

Conclusion

IDE and its improvement due to enzyme supplementation is predictable. A spreadsheet was developed to estimate:

- the IDE in corn based on starch, protein and oil composition;
- the IDE of a diet containing that corn and based on the inclusion level;

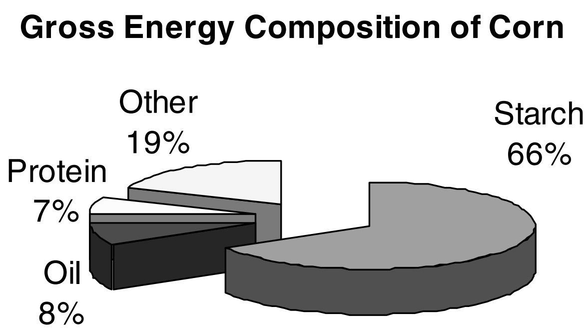

Figure 5 Sources of average gross energy in corn.

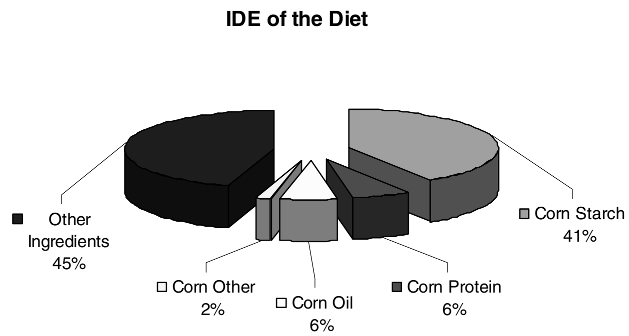

Figure 6 Sources of ileal digestible energy (IDE) of a corn–soy diet containing 55% corn.

Table 5 Calculated gross energy (GE) and ileal digestible energy (IDE) of a corn sample and the increase in IDE from the addition of enzymes.

	Energy digestibility (%)		Ileal digestible energy (MJ/kg)	
Nutrient	**–Enzymes**	**+Enzymes**	**–Enzymes**	**+Enzymes**
Starch	86.3	91.3	10.72	11.35
Protein	81.6	82.4	1.44	1.45
Oil	90.2	90.7	1.47	1.48
Other	11.4	13.0	0.34	0.39
Total	74.2	77.9	13.97	14.67

Table 6 Calculated gross energy (GE) and ileal digestible energy (IDE) of a diet containing a corn sample (Table 5) and the increase in IDE from the addition of enzymes.

	Energy digestibility (%)		Ileal digestible energy (MJ/kg)	
Ingredient	**–Enzymes**	**+Enzymes**	**–Enzymes**	**+Enzymes**
Corn (55%)	74.2	77.9	7.69	8.07
Others (45%)	65.8	65.9	6.09	6.11
Total	70.2	72.2	13.78	14.17

- the improvement in IDE due to supplementation with the blend of enzymes used in this study.

Practical benefits of this study include a more precise knowledge of corn energy for feed formulation, leading to reduced feed costs and reduced variability of dietary energy. The optimal formulation of the blend of xylanase, amylase, and protease enzymes may be determined. The results form a basis to monitor corn quality by harvest year and geographic region, giving more information on commodity value. *In vitro* measures of starch quality at critical points in the feed manufacturing process may be used to make recommendations on temperature, moisture and time of processing related to the effects on corn quality. These measurements may also be used as a tool to monitor the efficiency of feed manufacturing equipment and to predict when work on the equipment may be required.

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