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Feeding value of corn grain from different origins

How homogeneous is corn or does it vary by country of origin? Join us this Thursday on Feedstuffs 365 for more on this topic.

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Corn is the cereal grain most widely used as an energy feedstuffs for livestock. It has been traditionally a quite homogeneous, energy-dense feed ingredient with carbohydrates having the largest impact on its digestible energy. The reduction on the dependence on foreign oil enacted through the Energy Policy Act of 2005 led to the development of new hybrids, changing corn yield and composition with more bushels per acre and more starch per bushel. Despite this, corn is still sold exclusively by weight and and/or volume. While some research has shown US corn to have more starch than that from other origins, it has not been quantified if these differences merit a differential price per ton. To assess this the nutrient composition of corn from three different origins was analyzed with special emphasis on energy.

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ports of Mexico, Colombia, Japan, Vietnam, and Taiwan. Five sub-samples were obtained from different locations of the container directly from augers or belt throwers. Sub-samples were then composited into one sample identifying date, vessel, country of origin, and destination. Samples were then analyzed for broken corn and foreign material (BCFM), and mycotoxins. Nutrient analyses included dry matter (DM), crude protein (CP), acid detergent insoluble crude protein (ADICP), soluble protein (SP), prolamin (PRO), vitreousness (VIT), acid detergent fiber (ADF), neutral detergent fiber (NDF), Starch (STA), ethanol soluble carbohydrates (ESC), water soluble carbohydrates (WSC), ether extract (EE), total fatty acids (TFA), non-fibrous carbohydrates (NFC), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), and total digestible nutrients (TDN), and net energies (NE) of lactation, maintenance, and gain (NE_L, NE_m, and NE_g, respectively). A total of 75 samples were analyzed, 25 from each of the three countries.

RESULTS AND DISCUSSION

Protein fractions

Corn composition is in table 1. The US had the lowest ($p<0.05$) CP concentration with 8.19% compared with Argentina (8.59%) and Brazil (8.68%), which did not differ with each other (Table 1). Protein was further partitioned analytically to determine soluble and insoluble protein. Corn protein is mainly constituted by zein, a highly hydrophobic and insoluble prolamin, which constitutes 45%–50% of all corn proteins. This protein has cross-linked bonds that make it highly hydrophobic and thus protects the starch granules from any external aggressors present in water solution. Zein is part of the so-called “storage proteins”, which protect the starch granules in the endosperm from enzymatic degradation. The more insoluble protein present, the harder it is to enzymatically digest the stored starch. Conversely, more soluble protein suggests starch will be more readily available for enzymatic digestion. The US had the highest ($p<0.05$) soluble CP with 20.01% compared with the other two countries.

Another aspect of importance with regards to protein availability in feedstuffs is the Maillard reaction. It occurs when feeds are subjected to high temperatures in the presence of moisture, where an amino group of one amino acid and the carbonyl group of a reducing sugar react rendering both undigestible to the animal. It is usually measured by the nitrogen or protein present in the acid detergent fiber of a feed, and labeled as ADIN or ADICP, respectively. Corn grain from the US had the lowest ADICP with 0.55% compared to Argentina (0.64%), and Brazil (0.65%) which did not differ with each other. One possible interpretation is that US underwent less heating due to drying compared to either the Argentinian or Brazilian grain.

Prolamin

Corn kernels are made up of three main parts pericarp, embryo, and endosperm. The endosperm is the major component of the kernel, representing 80 to 85% of its total dry weight. Corn starch is stored in this endosperm inside granules of variable size. These granules are imbedded in a protein matrix that protects the starch from enzymatic attack. To optimize starch digestion, it is necessary to disrupt this protein matrix (i.e., grinding, steam flaking, etc.). Prolamin proteins in corn are named zein and comprise 50-60 % of the total protein of the kernel. Floury or opaque endosperm corn types have lower prolamin compared to flint or normal dent corn hybrids. Prolamins define differences in the chemical composition between vitreous dry corn (glassy, translucent) and floury or opaque corns. Prolamin content of dry corn ranges between 2.5 and 5.5 % of the dry matter (Hoffman and Shaver. 2021). Corn grain with more than 4.5 % prolamin as % of the DM is likely more vitreous, whereas corn with lower prolamin (less than 3.0 %) may be opaque-floury hybrids. This report did not find any statistical differences in the prolamin content between countries, which was 2.78%, 2,65%, and 2,65% for Brazilian, Argentinian, and US corn, respectively.

Vitreousness

Vitreousness (glass-like) is determined by the ratio of vitreous and floury endosperm. The vitreous region is translucent, generally located in the periphery of the endosperm. The floury endosperm, usually located in the center of the endosperm is white, floury, and non-translucent. Vitreousness in kernels is determined by the composition of the starch–protein matrix and is responsible for the hardness of the kernels. The floury endosperm has a discontinuous protein matrix that results in soft kernels that break easily. The hardness difference between both types of endosperm can impact the nutritive value of corn, and its brittleness.

Results of this work showed that there were significant differences in vitreousness between countries. Brazilian corn vitreousness was the highest averaging 72.3%, followed by Argentinian with 65.5%, and then US corn with 47.2%, all statistically different from each other. These results indicate US corn had significantly more floury starch compared to the other two origins. Research has shown that with advancing maturity, kernel vitreousness and density increased while starch availability decreased (Correa et al. 20020). Since starch in vitreous dry corn is more extensively encapsulated by prolamins it is less degradable when compared to floury or opaque corns. These results suggest that while US corn can break more easily because of its greater content of floury starch, it can also have higher digestibility compared to the other two origins.

Non-fibrous carbohydrates

Starch constitutes by weight the largest individual chemical constituent of the corn kernel, and as a result has the greatest impact on its energy content. US corn had the highest ($p<0.05$) starch concentration with 72.67% followed by Brazil's 70.84%, and Argentina with 69.08% (table 1). Soluble carbohydrates do not greatly impact the energy density of the grain since their concentration is very low. The US had less soluble carbohydrates (1.77%) when compared to Argentina (2.30%) and Brazil (2.13%).

Table 1. Nutrient content in corn grain from three different origins

%	US	Argentina	Brazil
Moisture	13.08[a]	13.06[a]	12.38[b]
Crude Protein	8.19[a]	8.59[b]	8.68[b]
Insoluble CP	1.49	1.55	1.50
Soluble CP	20.01[a]	16.70[b]	15.80[b]
ADICP	0.55[a]	0.64[b]	0.65[b]
ADF	**2.39**	**3.17**	**2.60**
NDF	7.44[a]	9.21[b]	8.23[a]
WSC	1.77[a]	2.30[b]	2.13[b]
NFC	79.46[a]	76.74[b]	77.87[b]
TDN (from ADF)	88.55[a]	87.70[b]	88.23[b]
Starch	72.67[a]	69.08[b]	70.84[b]

EE	4.21[a]	4.81[b]	4.65[b]
TFA	3.82[a]	4.28[b]	4.17[b]
Ash	1.54[b]	1.73[a]	1.56[b]
Calcium	0.02[a]	0.03[b]	0.03[b]
Phosphorus	0.31[b]	0.33[a]	0.30[b]
Magnesium	0.13[b]	0.14[a]	0.13[b]
Potassium	0.43[b]	0.47[a]	0.42[b]

Superscripts in a same row with different letters differ ($p \leq 0.05$)**. ADICP = acid detergent insoluble crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; WSC = water soluble carbohydrates; NFC = non-fibrous carbohydrates; TDN = total digestible nutrients; EE = ether extract (lipids); TFA = total fatty acids.**

Other carbohydrate fractions of importance to assess the energy content of corn were also analyzed. Non-fiber carbohydrates (NFC) sometimes called nonstructural carbohydrates (NSC) are calculated by difference such that NFC = **[100- (%NDF + %CP + %Fat + Ash)]**. The Cornell Net Carbohydrate and Protein System defines NFC as [100 - ((%NDF - %NDFCP)+ %CP + %Fat + Ash)]. This latter equation is more correct because it doesn't double-count the protein that is contained in the NDF. Non fibrous carbohydrates greatly impact the energy value of cereal grains since they constitute their greatest portion by weight. The US had the highest ($p<0.05$) NFC concentration with 79.46% compared to both Argentina (76.74%), and Brazil (77.87%), which did not differ between them.

The structural carbohydrate or fiber portion dilutes the energy concentration of feedstuffs and can be used to estimate it. Both acid detergent fiber (ADF) and neutral detergent fiber have been used extensively, the former because it is negatively correlated with digestibility in ruminants, while the latter not only with digestibility but also feed intake. Argentina had the highest ($p<0.05$) ADF with 3.17% compared with Brazil (2.60%) and the US (2.39%). Argentina had also the highest ($p<0.05$)

NDF concentration with 9.21% while the US and Brazil had similar concentrations between them, with 7.44% and 8.23%, respectively. Since energy is oftentimes predicted from ADF, it was expected Argentinian corn would have less energy when compared to the other two countries.

Lipid fractions

The needs of the US ethanol industry have focused corn hybrid genetic selection on higher starch, at the expense of other nutrients. Since there is 2.25 times more energy in fat compared to carbohydrates one would intuitively tend to think there would be more energy in corn with higher fat. This is not usually the case since slight increases in NFC concentration have greater effect on the energy content of the grain. An increase in fat of 5% (e.g., 4 to 4.2%) would add only 2 grams of fat per kg of corn, while a similar concentration increase in NFC would add approximately 39 grams of this carbohydrate fraction. Since fat, protein, and carbohydrate **are typically estimated to provide respectively 9, 4, and 4 kcal/g,** similar changes in concentration of NFC will add more gross energy per kg of grain than fat. Both Argentinian and Brazilian corn had similar total fat and fatty acid concentrations, which were higher ($p<0.01$) than in US corn (Table 1).

Minerals

Since corn is fed for energy and the minerals contained in the ash do not supply any, the greater the ash content, the lower the energy. Ash was significantly lower ($p<0.01$) for the US (1.54%) and Brazil (1.56%) compared to Argentina (1.73%). As mentioned above for fat, since ash concentration is small compared to NFC concentration, small changes in the latter will have greater impact on energy concentration than ash content. There were differences in the mineral concentration between countries with calcium lower ($p<0.01$) for the US (0.02%) compared to Argentina and Brazil (both with 0.03%). Phosphorus was higher for Argentina ($p<0.05$) with 0.33% compared to Brazil (0.30%) and the US (0.31%) which did not differ between them. Magnesium was higher ($p<0.05$) for Argentina with 0.14% compared with Brazil and the US both with 0.13%. Potassium was higher ($p<0.05$) for Argentina with 0.47% when compared to the US (0.43%) and Brazil (0.42%).

Energy content in corn grain

Corn's energy can vary depending on the hybrid, the region, and the growth conditions. Total digestible nutrients, digestible energy, metabolizable energy, and net energy of lactation (NE_L) for dairy cattle were predicted using equations available in the literature. Total digestible nutrients (TDN) report the percentage of digestible material in a feedstuff and as such it can be used to assess its energy density. They can be calculated from the nutrient composition using summative equations or predicted with regression equations from structural carbohydrates (usually ADF). Corn TDN were predicted from its composition using summative equations and NEL from TDN using the regression equation by Weiss (1998). Argentinian corn had the lowest ($p<0.05$) TDN concentration at 87.7% compared with the US (88.55%) and Brazil (88.23%), which did not differ with each other.

The NE_L content (Mcal/kg) was calculated using the equation 0.0245*TDN - .12 (Weiss. 1998)

Table 2. Dairy cows net energy of lactation (3X maintenance) of corn from 3 origins			
	US	**Brazil**	**Argentina**
NE_L, **Mcal/kg**	**2.05**	**2.04**	**2.04**

Swine

The regression equations proposed by Li at al. (2014) were used to predict digestible and metabolizable energy in swine. The gross energy content of corn was calculated from total protein, carbohydrate and fat concentration in each country's sample using the Atwater factors (4, 4, and 9 calories/g, respectively).

Table 3. Total carbohydrates by country (NFC + NDF)			
	US	**Brazil**	**Argentina**
%	**86.9**	**86.1**	**86.0**

Gross energy in calories per g = (carbohydrates x 4) + (Protein x 4) + (fat x 9)

US 795 x 4 + 81.9 x 4 + 42.1 x 9 = **3,887 Kcal/kg**

Argentina 767 x 4 + 85.9 x 4 + 48.1 x 9 = **3,845 Kcal/kg**

Brazil 779 x 4 + 81.9 x 4 + 42.1 x 9 = **3,823 Kcal/kg**

There were no statistical differences of the gross energy of corn, with the US showing the highest numerical value at 3,887 Kcal/kg.

Digestible and metabolizable energy for swine were then calculated from:

1. DE = 1062.68 + (49.72 x EE) – (24.89 x NDF) + (0.54 x corn gross energy) + (9.11 x starch)
2. ME = 671.58 + (0.89 x DE) – (5.59 x NDF) – (191.39 x Ash)

Substituting the values for EE, NDF, Starch, ash, and gross energy for each country in 1 and 2 above

Table 4. Swine digestible and metabolizable energy by country

	US	**Brazil**	**Argentina**
DE**, Kcal/kg**	**3,847**	**3,799**	**3,778**
ME, **Kcal/kg**	**3,759**	**3,708**	**3,651**

Poultry

The equation used to predict apparent ME in poultry was the one validated by Losada et al. (2015):

AME = 2,299.1 − 41.6 × NDF + 0.394 × GE

Table 5. Poultry apparent metabolizable energy by country

	US	**Brazil**	**Argentina**

AME**, Kcal/kg**	**3,521**	**3,463**	**3,431**

The energy of US corn was numerically higher regardless of the livestock species.

BROKEN CORN AND FOREIGN MATERIAL (BCFM)

Kernels break upon impact when the stress required for breaking to occur is exceeded (brittleness). Harvesting and drying are the major contributors to breakage potential of any corn hybrid regardless of their original “brittleness”. Combines for example can inflict variable damage to the kernels that can be apparent and/or small cracks. During transport and auger loading/unloading, damaged kernels suffer additional physical stresses that expand any fissures. In addition, drying at higher temperatures and shorter times to speed-up the process, result in kernel stress-cracks allowing for further grain deterioration and increased BCFMs. Because of the importance of this fraction during corn commercialization, it was decided to also analyze its nutritional composition to determine its feeding value. The same equations used to predict the energy in corn grain were also used for BCFM. The analytical values suggest starch is reduced by approximately the same proportion as the other nutrients increase at 8-10% (table 6). As a result, the energy content of the BCFM was only slightly affected resulting in 96-98% of the value of corn for all livestock species.

Table 6. BCFM Nutrient composition average for all three countries						
DM	**CP**	**ADF**	**NDF**	**Starch**	**Fat**	**Ash**
87.92	9.15	4.72	11.39	64.87	4.79	2.04

Ruminants

NE_L Mcal/kg= 2.139-(0.0376*ADF)

NE_L Mcal/kg= 2.139-(0.0376*4.72) = 1.96 Mcal/kg

Swine

1. DE = 1062.68 + (49.72 x EE) – (24.89 x NDF) + 0.54 x Gross energy) + (9.11 x starch) (Li et al.)

Average GE for corn = 3,840 kcal/kg.

2. DE = 1062.68 + (49.72 x 4.79) – (24.89 x 11.39) + 0.54 x 4,053) + (9.11 x 64.87)
3. **DE = 3,797 Kcal/kg**
4. ME = 671.58 + (0.89 x DE) – (5.59 x NDF) – (191.39 x Ash)
5. ME = 671.58 + (0.89 x 3768) – (5.59 x 11.39) – (191.39 x 2.04)
6. **ME = 3,597 Kcal/kg**

Poultry

AME = 2299.1 – 41.6 x NDF + 0.394 x GE

AME = 2299.1 – 41.6 x 11.39 + 0.394 x 4,053

AME = 3,422 Kcal/kg

Mycotoxins

There were no significant differences in mycotoxins between countries (table 7). Concentrations of aflatoxins were very low in all three countries (and well below the 20 ppb FDA action level), with the US showing non-detectable levels. (table 7).

Table 7. Mycotoxin concentration in corn grain from three different origins

%	US	Argentina	Brazil
Aflatoxin, ppb	**0.000**	**0.444**	**0.800**
Fumonisin, ppm	**0.948**	**5.680**	**3.328**
Vomitoxin, ppm	0.536	0.804	0.500

Zearalenone, ppb	36.12	125.62	27.46

In summary, nutrient composition in corn differed between countries. The most noticeable variations were for starch and non-fibrous carbohydrates, with the US having the highest concentration compared to Argentinian and Brazilian corn. The opposite was also true for fat concentration, with the US showing a lower concentration compared to both Argentina and Brazil. As a result of the greater incidence of total carbohydrates, US had more total digestible nutrients compared to the other two countries. The energy prediction for dairy cattle, swine, and poultry showed the US had numerically higher values for net, digestible, and metabolizable energy, although they were not enough to show statistically significant differences. The lower vitreousness detected in US corn suggests that the kernels are not that hard and can break during transport. It also suggests that the starch protected by the prolamin matrix is likely more easily digestible by mammalian and microbial enzymes. In the present study the energy value of BCFM was 96 to 98% of the value for corn suggesting it has similar nutritional value. Further research with corn fed to livestock is warranted to confirm if these differences have an impact on animal performance.

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