How does corn quality impact ethanol yield?

Novozymes North America Technical Service - Bioenergy

It is generally assumed that higher yielding corn has higher quality characteristics, including higher starch and oil. Variation in corn quality has shown to have observable impacts on ethanol yields. Studies have shown overall variability in ethanol production between low performing and high performing corn samples can range from 3% to 23%. This variability in corn can result in substantial loss of quantity and quality of dry grind ethanol products. In a 100 MGY ethanol plant, an average 3% loss of ethanol due to corn quality is equivalent to 3 million gallons per year.

How does corn yield and test weight impact ethanol yield?

Immature corn or corn with reduced grain fill can have lower corn yield ultimately leading to a reduction in ethanol yield. Corn yield is a measure of kernel weight and number and is related to the accumulation of dry matter in the kernel. The market standard weight of a bushel of corn is 56 lbs/bu at a 15.5% corn moisture content. It has been reported that since 2004 corn yield has increased an average of 2 bushels per acre per year. Increased corn yield does not necessarily mean increased ethanol yield.

Test weight is a measure of the bulk density or the weight of corn in pounds that fills a bushel (lb/bu). Test weight values for corn range from 45 lbs/bu to 60+ lbs/bu, and corn price can be affected by test weight (Table 1). Factors that impact test weight are those that affect how corn kernels fit or pack together, such as the kernel shape and size. If grain fill time is shortened or the corn has grown under drought conditions the seed size can be smaller resulting in a lower test weight. Lower test weight corn is also more susceptible to spoilage. Various physical characteristics can influence test weight. The most influential characteristic is corn moisture, which is inversely proportional to test weight. If corn moisture increases, test weight will decrease; therefore, more pounds of corn will be needed to equal one bushel. In seasons with extreme rainfall, loss of N can occur, which would lead to lower test weight too. Corn maturity is another important influencer of test weight. When corn is immature test weight will be lower because of the moisture content. Drying can increase test weight but depending on the maturity level test weight can go either up or down. The closer to maturity, the higher the test weigh. Higher test weight can be attributed to better filled corn kernels with a higher percentage of hard endosperm. Early planting dates, higher N availability, and moderate growth conditions can lead to higher corn test weight.

Table 1. Pounds of shelled corn needed to equal one bushel and change in test weight due to different corn moisture content.

Corn Moisture (%)	Pounds of shelled corn needed to equal one bushel (lbs)	Change in test weight (lbs/bu)
14	55.02	-0.98
15	55.67	-0.33
15.5	56	0
16	56.33	0.33
17	57.01	1.01
18	57.71	1.71
19	58.42	2.42
20	59.15	3.15

A common misconception is that corn yield and test weight are directly proportional. If corn yield is lower, it does not necessarily mean test weight will be lower. Unfortunately, corn yield and test weight do not change equally and currently there is no model to predict how they will be correlated. Although research literature is not clear, it is commonly believed that low test weight corn decreases processing efficiency.

What is the impact of corn moisture on ethanol yield?

Corn moisture content at the time of arrival to an ethanol plant is typically assumed to be 15%, but moisture content can often range between 13% and 18%. An increase of 1% moisture above 15% means 1% less solids, or 0.72% less starch in the bushel of corn. If a plant has a 2.82 ethanol yield, it will drop to 2.8 (2.82 * (1 – 0.0072)) if nothing changes except moisture content. This means if a plant receives corn that contains 18% moisture, an estimated ethanol yield loss of 2.16% is expected (Table 2).

Table 2. Estimated ethanol yields due to starch loss from higher corn moisture content.

Corn Moisture (%)	Starch Loss (%)	Estimated Ethanol Yield
15	0	2.82
16	0.72	2.8
17	1.44	2.76
18	2.16	2.7
19	2.88	2.62
20	3.6	2.53

In addition, even though moisture is discounted to 15% when corn is received by adjusting the net weight, plants must still process the additional water. A plant's energy costs are based upon the amount of water it must heat for either processing or removal. If water into the process increases 1% then energy costs will also increase 1%.

Flood soaked corn is not useable for animal feed or food, but it is often used in ethanol production. Flood damaged corn is considered adulterated because of the potential for considerable contamination from the toxins and pathogens in the water. Soaked corn will swell and can spoil within a few days at summer temperatures. Rain damaged corn can be dried, cleaned and immediately used without little concern, although it is recommended to test for mycotoxins.

What is the impact of drying on corn quality and ethanol yield?

Drying of corn is required to prevent spoilage. Storing wet corn without aeration will shorten the corn shelf life considerably. High harvest moisture means more forced drying by elevators and farmers. Drying air temperatures above 194°F can have a detrimental impact on ethanol yield. However, to get higher throughput producers and elevators will use higher drying temperatures. Removing a pound of water requires about 20% less energy at a drying air temperature of 200°F than at 150°F. Excessively high drying temperatures will result in a lower final test weight and as the drying time increases high-moisture corn becomes more susceptible to browning. Corn dried with low temperature drying will typically gain 0.25 lb/bu per percent of moisture removed.

It is well understood that increasing the drying temperature will result in increased breakage susceptibility and stress cracking. Kernel density and test weight significantly decrease with increased drying temperature. A recent study has revealed that forced dried corn has the least fermentability and the lowest enzyme accessible total carbohydrate content compared to damaged and normal corn. The forced dried corn also had the lowest normalized ethanol yield (ethanol/liquefaction Dry Solids). Interestingly, the residual starch at fermentation drop from the aggressively dried corn was not as high as expected. It was hypothesized that the residual starch could have been higher than what was measured if the starch structure changed during the forced drying process to a more resistant form making it no longer accessible to the enzymatic activity. This change in starch structure would not have been measured by the methodology utilized.

What is the impact of storage on starch, protein and ethanol yield?

Ethanol yields for incoming corn have been monitored daily for several years and seasonal variation in ethanol yields and residual starch content in DDGS has been observed. Typically, ethanol yields are low during the first few months after harvest of new crop. Freshly new corn is more difficult to process than stored corn. Ethanol yields are usually higher during the next 6 to 7 months and then yield starts dropping towards the end of the year. As previously stated, corn is typically harvested in October in the US Corn Belt. A loss of 6.8% ethanol yield has been measured between the 2nd quarter (January through March) and 4th quarter (July through September) after new corn crop has been harvested. Highest ethanol concentrations were observed in the month of January. Using more effective enzymes can increase overall ethanol production and ethanol plant profitability by leveling out feedstock variations. Unfortunately, the cause of the variation in ethanol yield is unclear, but it has been speculated that some intrinsic changes to the corn takes place during storage.

Storage of corn is required to provide a continuous supply of feedstock to support year-round operation of the ethanol industry. Changes in the chemical structures and functional properties that occur during storage are inevitable. The changes could be in the amylose/amylopectin ratio, amount of fermentable and resistant starch, digestibility of starch and protein matrix, protein solubility, and changes that are not measured by compositional analysis. The physiological changes during storage can have a significant effect on ethanol and corn oil yields, along with DDGS quantity and quality.

DDGS can contain more than 5% residual starch because of incomplete starch to ethanol conversion. The amount of residual starch depends on factors such as the type of raw starch in corn (amylose/amylopectin ratios), processing conditions (temperature, pH, duration of hydrolysis and enzyme activity) and amount of resistant starch. While starch quality is largely controlled by genetics and growth conditions, post-harvest practices (handling, storage and processing conditions) also affect starch composition and structure. Higher residual starch in DDGS can correspond to lower ethanol production. Therefore, the variation of residual starch content directly correlates to storage time.

A study has shown that initial FAN (Free Amino Nitrogen) content in corn liquefact increases with increased storage time, and FAN protein hydrolysis rates are also impacted by storage time. The highest FAN protein hydrolysis rate was observed after 5-months of storage. As with residual starch, storage temperature did not affect soluble protein content and initial FAN content. Ethanol yield also did not appear to be correlated to soluble protein and initial FAN content.

What are the impacts of storage conditions on corn quality and ethanol yield?

Moisture content is an important factor affecting corn deterioration in storage and can greatly impact corn quality. High moisture content of corn can occur because of improper moisture monitoring during harvest, moisture migration caused by in-storage air convection currents, moisture diffusion within the bulk pile, or entry of water into the storage bin. A study has reported differences in moisture content between corn stored outdoors and corn stored under refrigerated conditions during the first 10-weeks of storage. These differences in moisture were possibly due to temperature gradients causing moisture to migrate in the stored corn. Interestingly, another study has shown residual starch increase up to 8% after 20-weeks of storage, regardless of storage temperature. The rates of change in residual starch were similar for outdoor and refrigerated storage conditions.

Although storage temperature does not appear to have an impact on corn residual starch content, it is an important factor affecting corn deterioration in storage and can greatly impact corn quality. When corn contains excessive moisture, molds can grow and metabolize the corn reducing the corn quality. The heat of metabolism of the growing mold can cause spontaneous heating of the corn.

Seasonal changes in air temperature and solar radiation can create temperature gradients in the stored corn. These gradients produce air convection currents, which cause moisture to migrate from warm to cool regions of the bulk pile. To eliminate or minimize moisture migration, corn temperature should be equalized by aeration. Aeration can also cool the bulk-stored corn to a level where growth of molds and insects will be slowed or stopped.

In addition to moisture content and temperature, CO_2 evolution is another measure of corn deterioration. High levels of CO_2 have been shown to be related to the presence of respiring microorganisms and mold. As previously discussed, corn dry mass and quality can be decreased due to contamination by microorganisms and mold.

Test weight is a good indicator of corn storability. If corn test weight is below 54 lbs/bu it should not be stored in warm weather and should be dried to less than 15% moisture before storage.

What is the impact of kernel damage on corn quality and ethanol yield?

The type and severity of kernel damage can have a serious impact on ethanol yield. Corn kernels with damage starch contain undamaged granules and remnants of granules that have been partially damaged. In a mixed population of starch granules, the smaller granules are more susceptible to complete damage compared to the larger particles. Research has shown that kernel damage can affect the storability of the corn and increases breakage susceptibility. Cracked corn kernels and fines will spoil significantly faster than whole corn.

Breakage susceptibility is the potential for kernel fragmentation or breakage when subjected to impact force during handling and transport. Percentage of stress-cracked kernels, thickness of corneous endosperm, and temperature of drying are factors that can greatly affect breakage susceptibility. Stress cracking is associated with rapid drying of corn with high-temperature air followed by rapid cooling with ambient temperature air. When transporting and handling, kernels with stress cracks break more readily and generate considerable amounts of damaged corn and fine particles.

A recent study has shown that liquefact from damaged corn has higher dextrinization (higher DE and DI%) and starch solubility (higher SI%), most likely due to more short-chain dextrins (higher DP3) present compared to normal corn liquefact. Interestingly, higher dextrinization and starch solubility did not result in higher ethanol yield. The damaged corn had highly variable total carbohydrates, free sugars and starch, which led to highly variable ethanol yield and high residual starch remaining.

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