12-2008

Comparative evaluation of ethanol yield from HTF corn varieties in the whisky production process.

Kara Marie Zoeller
University of Louisville

Recommended Citation
Zoeller, Kara Marie, "Comparative evaluation of ethanol yield from HTF corn varieties in the whisky production process." (2008). *Electronic Theses and Dissertations.* Paper 1652.
https://doi.org/10.18297/etd/1652

COMPARATIVE EVALUATION OF ETHANOL YIELD FROM HTF CORN VARIETIES IN THE WHISKY PRODUCTION PROCESS

By

Kara Marie Zoeller

B.S., University of Louisville, 2008

A Thesis

Submitted to the Faculty of the

University of Louisville

Speed School of Engineering

As Partial Fulfillment of the Requirements

For the Professional Degree

MASTER OF ENGINEERING

Department of Chemical Engineering

December 2008

COMPARATIVE EVALUATION OF ETHANOL YIELD FROM HTF CORN VARIETIES IN THE WHISKY PRODUCTION PROCESS

Submitted by:___________________________________

Kara Marie Zoeller

A Thesis Approved on

____

December 10, 2008

By the Following Reading and Examination Committee:

____

Eric Berson, Thesis Director

____

Martin Klotz

____

Gerold Willing

ACKNOWLEDGMENTS

Many thanks are due to Charles Geisler, the project engineer who designed and directed this experiment. He provided much information about, and background of, the whisky production process. Thanks also to Eric Berson, the thesis advisor for this project, for guidance on technical writing and clarity.

ABSTRACT

In the whisky industry there is a balance between the desire to adhere to the traditional production process and the desire to increase profit margins. One solution that follows both stipulations is to increase the alcohol yield of a given batch of whisky. This can be achieved by utilizing high total fermentable corn which has a higher concentration of fermentable starches than other corn. HTF corn has the potential for a greater final ethanol yield. By simply using a higher quality of raw materials, the integrity of the process is maintained while allowing for an increase in output.

Ten strains of HTF corn (35D28, 35Y33, 34M94, 32K33, 34P88, 33A84, 34H31, 31G66, 33N56, and 34A15) and four strains of control corn (33N09, 32W86, 33M54, and 34D71) were tested for mash pH, sugar content by mass (balling), conversion of starch to sugar, conversion of sugar to ethanol, and alcohol content by volume (ABV). Ten trials were performed using HTF corn, yielding 60 fermentations; 18 trials were performed using control corn, yielding 158 fermentations. Each trial yielded five to nine fermentations depending on the size of the cooks. Due to contamination from an unknown source, only 44 HTF and 41 control fermentations were clean and, therefore, were used to establish the most significant trends.

For a 99% confidence level, a clean HTF fermentation yielded 9.69% ± 0.14% ABV and a clean control fermentation yielded 9.34% ± 0.08% ABV. From these values it was determined that the HTF corn provides a 3.6% increase in alcohol yield over

control corn. This indicates that the HTF corn may provide an advantage over the control corn when moved to an industrial scale.

When the strains of corn were compared on an individual basis, HTF strain 32K22 appeared to be the strain of choice for whisky production at this preliminary stage. Strain 32K22 provided for the highest levels of conversion of both starch and sugar, at 97.6% and 98.3% respectively, and it produced the highest alcohol content of any strain at 10.42% ABV. The 32K22 strain achieved an overall conversion of starch to ethanol of 95.9% which is significantly higher than the average overall conversion for the control corn, 88.5%.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The production of whisky is a practice that has been performed for hundreds of years. Because of this, there are multiple traditions and attitudes that have been culturally solidified, many of which have been carried over to the industrial scale. This traditionalist viewpoint that is prevalent in the industry can make it difficult to receive acceptance for alterations to the production process for fear of compromising the integrity of the product, especially since these improvements are typically made for the benefit of the profit margin and not the product itself. Therefore, it is vital to determine methods of enhancement that infringe as little as possible on the conventionally held sensibilities.

Between the necessities of preserving the integrity of a specific brand and the restriction of following federally regulated guidelines, the opportunities for the improvement of the production process for whisky is severely limited. Because whisky is diluted down to its saleable proof only immediately before bottling, the majority of these improvement methods have centered on the increase of the proof during the production process. For example, during recent years the whisky industry as a whole has begun to age whisky in barrels at a much higher poof than in the past, leading to a financial gain. Now, by law, whisky cannot be barreled at a proof greater than 125; this is significantly higher than was typically done, but it allows for fewer barrels and less warehouse space to be used (Alcohol and Tobacco Tax and Trade Bureau, 2008).

Another approach to making whisky production more economical is the use of hybrid corn to enhance the amount of ethanol produced per quantity of grain. The development of corn with a supposed higher level of fermentable starch has led to the possibility of achieving a greater proof per batch of whisky mash produced. This would, in turn, lead to a greater amount of product for the same amount of grain, which is monetarily advantageous. This is a particularly desirable route because it falls in line with the traditional method perfectly as it does not alter the actual production process, it relies solely on the use of higher quality raw materials.

The objectives of this experimentation were to determine how much more ethanol can be produced per batch using a hybrid species of corn specifically engineered to have a greater amount of high total fermentable (HTF) starch rather than the non-HTF species of corn currently used and whether the increase is significant enough to justify switching corn types in production on an industrial scale. In order to accomplish this, a number of trials were run with both control corn (non-HTF species) and experimental corn (HTF hybrids). Several strains of each type were used in order to make as comprehensive a comparison as possible. Four strains of non-HTF and ten strains of HTF corn were studied. For each trial, whole corn was milled and then cooked in a mashing process. The mash was then fermented and the resulting product distilled to determine the ethanol content. A comparison of the ethanol content was made in order to establish the statistical significance of any difference.

BACKGROUND

Distilled liquors have been produced for hundreds of years and, over that time, the process has become refined as well as highly regulated. Because of this, there are limited routes to advancement in the field that fall within the government guidelines while simultaneously following the traditional means of production that have become standard. In 2007 over six billion gallons of ethanol was generated, consuming 27% of the U.S. corn harvest (Pioneer, 2008).

A. Types of Liquor

Distilled liquors are differentiated on the basis of the raw materials used in their preparation. Alcoholic liquids, sugary substances, and starchy substances are the broad categories that are used to produce potable beverages. Of particular interest are starchy substances which include all types of cereals, including barley, barley-malt, corn, rye, oats, etc. as well as potatoes. Whisky is only one type of alcohol that can be made from these starchy substances and can, in fact, be delineated further on the basis of its grain bill. This term refers to the ratio of cereals that are used as raw materials. Different types of whiskies include bourbon whisky, rye whisky, malt whisky, and wheat whisky. Bourbon whisky, the most commonly produced variety, is separated into three distinct classes. Ordinary bourbon whisky is derived from a grain bill of 10% barley-malt, 10% rye, and 80% corn. In contrast, medium bourbon whisky is 12% barley-malt, 18-22%

rye, and 66-70% corn while good bourbon whisky is 15% barley-malt, 35% rye, and 50% corn (The Encyclopedia Americana, 1918).

The process for the production of whisky and other distilled liquors has been refined over hundreds of years to the highly regimented practice that is in use today. This constraint of the method allows not only for a more consistent product, but also for the ability to regulate the quality of product placed in the market.

B. Grain Preparation

The preparation of grain has long-reaching effects on the quality of liquor that is produced. Predominant among these preparatory steps is the proper method of malting the grain, typically barley. Malting is the process by which grain is soaked in water, allowing it to partially germinate and produce enzymes. This malted grain is the natural source of the enzymes that degrade starches into fermentable sugars. While malted barley is most commonly used, rye and wheat can also be malted. Distiller's malt is meant to achieve a maximum diastatic power, or enzymatic power, as opposed to brewer's malt which must also impart flavor to the resultant beer. Before the grain can sprout, it is slowly dried at low temperatures to preserve the enzymatic abilities at peak concentration. Distillers prefer "long malt" which is dried over a period of 20 days which, while leading to a decrease of starch in the grain, yields a significantly greater diastatic power. In contrast, brewers prefer "short malt" which is dried for 7 days and retains much more of its inherent starch content. Additionally, malt used by distillers typically has a greater content of nitrogenous matter as this allows for the production of more enzymes as well as providing supplementary sustenance for the yeast during fermentation (The Encyclopedia Americana, 1918).

There are a variety of methods by which grains can be milled including roller milling, impact milling, and wet milling. The first two types fall under the category of "dry milling," meaning the ground grain, or grist, is fed into a hopper or other receiving container rather than directly into the mashing tun where it is mixed with water as is the case in wet milling (Brewing: Science and Practice, 2004). Dry milling is predominantly used in industry, with 86% of ethanol produced in the U.S. in 2007 done so via dry milling (Pioneer, 2008). The performance of a dry mill can easily be calibrated and refined using sieve analysis. A sample of grist is loaded onto the top of a vertical stack of sieves with increasingly small pore sizes and shaken mechanically for a period of time. The percentage by weight of the grist on each sieve can be compared to ensure that the mill is operating properly and producing milled grain that falls within specifications (Brewing: Science and Practice, 2004).

The composition of the grain, such as starch and water, is dependent on the type and variety of grain as well as its handling. For corn, its moisture content is also affected by the season during which it is harvested and the humidity of the air.

C. Mashing

The actual process for the production of whisky can be broken down into roughly three steps: mashing, fermentation, and distillation. Mashing is the means by which the starch in the grains is converted into the fermentable sugar maltose. In the case of ordinary bourbon whisky, the corn component of the grain bill will provide the vast majority of the starch necessary. This process begins with the milled corn being mixed with hot water and then boiled to induce gelatinization (The Encyclopedia Americana, 1918). In some instances, an amount of malt is added to the corn in order to reduce the viscosity of the mash, which dramatically increases as the gelatinization takes place (The Biotechnology of Malting and Brewing, 1991).

The combination of heat and water breaks down the intermolecular bonds of the starch molecules, exposing the hydrogen bonding sites and allowing the penetration of water. If the starch is not properly gelatinized, the enzymes cannot further degrade the starch into sugar. There are two types of starch found in grains: amylose and amylopectin. Amylose is a glucose polymer that contains 1,000-4,000 glucose units. Each unit is connected via an α1,4 bond creating a long, single chain. Amylose has only one functional reducing group which is located at the end of the molecule. Amylopectin is typically a larger glucose polymer that consists of over 250,000 units of glucose. While most of the units are connected with α1,4 bonds, some units are linked by α1,6 bonds which result in a branching chain. Although amylopectin tends to be degraded preferentially to amylose, it also only possesses one functional reducing group (The Biotechnology of Malting and Brewing, 1991).

Once the corn mash has been gelatinized, it is cooled to 156 to 160°F and any non-malted cereals are added. The mash is then further cooled to 150°F and the malt is added. In order to achieve full saccharification, the conversion of starch to sugar, the mash is held at this temperature for at least 30 minutes (The Encyclopedia Americana, 1918). This conversion is accomplished by the enzymes present in the malt added to the mash. At these temperatures, the only two enzymes that actively participate in the degradation of the starch are α-amylase and β-amylase. α-amylase is the more thermostable of the two and also performs most effectively at a more acidic environment with a pH of 5.3 as opposed to the optimal pH of 5.7 for β-amylase (The Biotechnology of Malting and Brewing, 1991). It is imperative that the malt not be added to the mash before it has cooled to the required temperature as the amylase enzymes are heat labile and will lose all catalytic ability if they become denatured. However, it is of note that both α and β-amylase do maintain some enzymatic activity when raised above their denaturation temperature until the enzyme is fully denatured (Brew Your Own, 2008). Theoretically, 96% of the starch in the grains can be converted into maltose, while the remaining 4% is converted into dextrin. Once the maltose has all been converted, the dextrin will then gradually be converted into maltose (The Encyclopedia Americana, 1918).

At the completion of the saccharification process, the mash is cooled to below 70°F and is then prepared to be moved to the fermenters. In industry, the mash is diluted with either water or slop, which is strained spent mash from a previous fermentation, to decrease the viscosity of the mash and produce sweet mash or sour mash, respectively. The sour mash is so named because the lactic acid, which can be a by-product of fermentation, in the slop lends a distinctively sour flavor to the finished product (The Encyclopedia Americana, 1918).

D. Fermentation

Once the mashing step has been completed, the next phase of whisky production is fermentation. Fermentation is the process by which the maltose produced during mashing is converted by yeast into ethanol. Contamination of the mash by bacteria can result in the conversion of glucose to lactic acid, resulting in an overly sour product. Carbon dioxide is a by-product of both the desired and undesired reactions (Geisler, 2006).

Four species of yeast that are used in the production of potable ethanol on the industrial level are *Saccharomyces cerevisiae, Saccharomyces uvarum, Schizosaccharomyces pombe,* and *Kluyveromyces sp* (Najafpour, 2002). *Saccharomyces cerevisiae* is the yeast type that is predominantly used in the production of whisky (The Encyclopedia Americana, 1918). Established brands of distilled liquor typically have a proprietary strain of a particular species that is carefully cultivated in order to maintain a consistent product (Geisler, 2006). Yeast operates under anaerobic conditions, utilizing the enzyme maltase to degrade maltose into glucose and then converting the glucose into ethanol via the Embden-Meyerhof pathway. This glycolysis reaction produces two molecules of ethanol per molecule of glucose; however, because some nutrients are required for the maintenance of the yeast cells, in actual fermentations the yield typically does not exceed 90% of the theoretical (Najafpour, 2002). The chemical reactions of the degradation of maltose and glucose, respectively, are illustrated below:

$$C_{12}H_{22}O_{11} \rightarrow 4CO_2 + 4C_2H_5OH$$

$$C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$$

Yeast are relatively delicate organisms so care must be taken in order to keep them alive so that total fermentation may be achieved. Due to the large amount of carbon dioxide that is produced as a by-product, the vessels in which fermentation is carried out must have some method of gas release because the increasing pressure caused by the generation of carbon dioxide could be great enough to destroy the yeast cells. In industry, fermentation is frequently carried out in open vessels in order to avoid this complication in spite of the increased risk of contamination. Like many other organisms, yeast is vulnerable to ethanol inhibition. Once the alcohol content of the fermenting mash has reached 15% by volume, the growth rate of the yeast will halt completely, ending the fermentation regardless of the amount of remaining glucose (Geisler, 2006).

In an industrial setting, once a yeast mash has thoroughly propagated, 10 to 14 hours after addition, it is then added to the grain mash. The greatest amount of fermentation activity takes place 24 hours after the yeast has been added to the mash and continues for 12 to 18 hours. It is important that during fermentation the mash maintains a temperature below 85°F both to prevent the alcohol generated from evaporating as well as maintaining an optimal operating temperature for the yeast. Sweet mash whiskies are typically fermented for 72 hours while sour mash whiskies require 76 hours (The Encyclopedia Americana, 1918).

E. Distillation

The final step in creating raw distilled spirits is the distillation of the fermented, or sour, mash. Distillation is the simple mechanical separation of substances based on their differing boiling points; water boils at 212°F while ethanol boils at 173.5°F. The distillation apparatus is comprised of a still, a condenser, and a receiver. With the best equipment, a highly concentrated alcoholic liquid of 192 proof, or 96% alcohol by volume, can be obtained. This is the highest concentration possible to achieve because at this composition ethanol and water form an azeotrope, making further purification via distillation infeasible. However, this is a much higher concentration than is needed in the potable beverage industry (The Encyclopedia Americana, 1918). Because distilled liquors are sold at a designated proof, fluctuations in ethanol content among batch fermentations do not adversely affect the final product. However, a greater ethanol content in the sour mash would result in an increase in saleable product once the resulting distillate is diluted, or cut, to its specified proof (Geisler, 2006).

F. Analysis

There are a variety of analysis methods that can be used to determine the degree of success of a given ethanol production trial, among these are near infra-red (NIR) spectroscopy, high performance liquid chromatography (HPLC), and standard gas chromatography (GC).

NIR can be used to analyze a range of grain types for a variety of properties. In particular, corn can be evaluated to determine levels of proteins, oils, moisture, and starch. While protein and oil content is of greater importance when establishing suitability of feedstock, verifying the moisture content as well as the starch content has profound importance in the production of alcohol. The level of moisture in corn dictates the handling and storage needs of the grain in addition to influencing the weight of the grain to such a degree that the calculation of grain bills could be impacted. NIR analysis can also be used to indicate the level of extractable starches present in the corn. This is presented with regards to fermentation as potential grams of carbon dioxide lost per 100 grams of corn (FOSS, 2008).

As an analysis technique, HPLC is advantageous for several reasons. It can be performed rapidly, has a high precision, and the required sample preparation is very simple. HPLC can be used to determine the content of sugars, organic and amino acids, glycerol, and a variety of alcohols of a liquid. In industry this is particularly beneficial as the presence of some substances may indicate an undesired process taking place during fermentation, possibly signifying contamination of the mash. HPLC is also invaluable in the arena of quality control (Nollet, 2000).

Standard GC analysis is particularly well suited to the analysis of alcohols in distilled liquor because they are thermostable, volatile substances. Gas chromatography operates by volatizing compounds in a liquid sample which then separate and can be quantified as they pass through a stationary column. This quantification is carried out with respect to an internal standard of the specific analysis apparatus used, typically benzyl alcohol, 3-pentanol, or n-butyl alcohol. GC is most commonly used for the detection of higher alcohols, such as n-propyl alcohol, isobutyl alcohol and isoamyl alcohol, which are collectively known as fusel oils. These alcohols have a considerable impact on the flavor profiles of the finished product, and in the U.S. and some other countries they have federally regulated allowable concentrations (Nielsen, 2003).

G. Hybrid Corn

In the alcohol production process, the amount of starch available in the grain, particularly the corn, is a dominant limiting factor. Because of this, agricultural companies have endeavored to develop hybrids of corn that contain greater levels of fermentable starches, denoted as high total fermentable (HTF) hybrids. Based on the dry grind ethanol yield potential, the company Pioneer claims a 2-4% ethanol yield gain for any of its 182 HTF corn hybrids as compared to non-HTF species. Pioneer asserts that each per cent increase in ethanol yield is worth \$0.05 per bushel of corn, leading to an increase of \$1.2-\$2.3 billion per year of the value of corn by the year 2010 (Pioneer, 2008). This increased ethanol yield potential of the hybrid corn creates an opportunity for large distilleries to decrease their overall cost should the increased yield be significant enough to offset the greater cost of hybrid corn (Geisler, 2006).

EQUIPMENT AND MATERIALS

The required equipment and instrumentation are described in order of the step in the process in which they are used: preparation, mashing, fermentation, distillation and analysis.

The preparation stage includes not only the preliminary sterilization that is necessary to reduce the possibility of contamination, but also the initial analysis of the corn and the milling of the grain. An autoclave (Alfa Medical, Westbury, NY) is used to sterilize the materials that come in contact with the mash via extreme temperature and pressure. This includes the yeast media and the graduated cylinder used to measure it, as well as the containers the mash is fermented in. The excess yeast not needed for backculturing at the end of each cook are killed in the autoclave before disposal.

The unmilled corn is analyzed for percent moisture and potential grams of CO_2 loss per 100 gram of corn using a near infra-red (NIR) spectrometer (FOSS, Ashland, VA) with a wavelength range of 570-1100 nm. The percent moisture indicates the proper storage of the corn as well as influencing the weight of the corn when used in later calculations. The grams of CO_2 loss per 100 grams of corn is indicative of the amount of fermentable starch present in the grain (Foss, 2008). The grain is milled in a lab-scale impact hammer mill (Raymond Mills, Zhengzhou, China). Swing hammers in the mill crush the grain as it is fed into the grinder. Once the corn has been milled, a sample is shaken through a series of sieve screens (H&C Sieving Systems, Columbia, MD) in order to ensure that the grain has been milled to a proper degree. Six screens are used to differentiate the array of grist sizes produced by the mill. The brass frame-stainless steel cloth sieves used are U.S. Standard #10, #20, #40, #80 and #100 having pore sizes of 2.0 mm, 1.7 mm, 425 µm, 180 µm and 150 µm respectively. Any grist passing through all screens is denoted as flour and is collected in a flour pan at the bottom of the stack of sieve screens (H&C Sieving Systems, 2008).

FIGURE 1 – Mashing Cookers. Mashes are cooked in 40 L steam-jacketed cookers.

The mashing process is carried out in three 40 L capacity agitated, jacketed kettle cookers, shown in FIGURE 1 (Roark Enterprises, Louisville, KY). These cookers were differentiated with the designations #9, #10, and #11 from left to right. The jacket of each stainless steel cooker is connected to both steam and water lines while the interior of the cooker is only directly piped for water. When heating, the water to the jacket is shut off and the steam line is open. The temperature of the mash is regulated by throttling the steam valve. If not properly controlled, the mash can boil and overflow out of the cooker. When cooling, water flows through a jacket that surrounds the tank. Agitation in the cooker is achieved by means of a triple bladed impeller that is submerged vertically into the mash. The mash must be well-mixed in order to eliminate hot spots and prevent scorching. Before dropping the mash at the end of a cook, the drain valve of the kettle is steamed for ten minutes to ensure sterilization.

The individual fermentations, three per cooker, are carried out by placing 3 L of mash and yeast in a 4 L Nalgene container with a screw-on lid (Thermo Fisher Scientific, Rochester, NY). The containers are translucent plastic so that the level of mash can be easily ascertained. During the fermentation, the lids of the Nalgenes are screwed on only slightly so that the carbon dioxide produced by the yeast can escape the container to avoid a build-up of pressure within that could damage or kill the yeast. The Nalgenes are placed in a fermentation bath so that the temperature of the mash can be regulated and kept at the optimum operating temperature of the yeast.

The temperature of the fermentation baths are controlled via a chiller bath and circulator, specifically, a NesLab RTE-111, as seen in FIGURE 2 (Thermo NesLab, Oak Park, IL). Each bath is large enough to fit nine 4 L Nalgenes and is filled so that the water level in the bath is just above that of the mash in the containers. The chiller is filled with a 50-50 water-glycol mixture which is circulated through copper coils submerged in the bath. Each chiller is controlled using its companion software program. This software can be programmed so that a specific regiment of temperatures and durations is carried out automatically. It also tracks the actual temperature of the water bath in graphical form along with the target temperature.

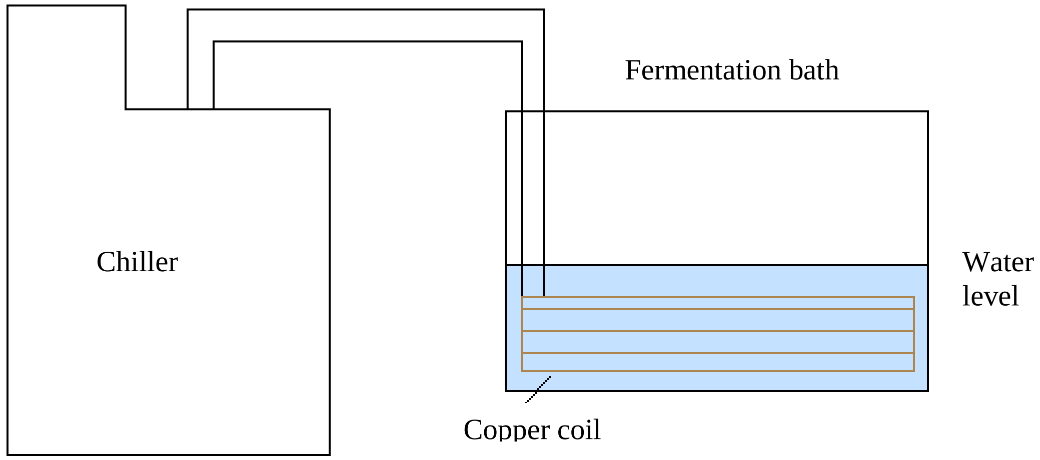

FIGURE 2 – Fermentation Bath Schematic

The mash is analyzed for a variety of properties. A hydrometer with thermometer for temperature adjustment (VWR Scientific, West Chester, PA) is used to determine the balling, or sugar content, of the mash both before and after fermentation. A comparison of the two values allows for an estimation of conversion. A pH meter (Techne, Burlington, NJ) was also used to analyze the mash pre- and post-fermentation. These values provided an indication of contamination as an increased presence of lactic acid signifies the existence of undesirable bacteria. The fermented mash is inspected via a high performance liquid chromatography (HPLC) machine (Waters, Milford, MA) for the concentration of acids, such as citric, succinic, lactic, and acetic, as well as sugars, including maltose, glucose, and fructose. HPLC can also be used to determine the ethanol content of the mash.

The analytical distillation is performed using Kjeldahl flasks (Kontes, Vineland, NJ) and burners (Precision Scientific, Arlington Heights, IL). As a 50/50 water-diluted mash sample is boiled in the bottom of the flask, the vapor travels through an upward sloping glass gooseneck tube to the vertical condenser column. The condenser is kept cool by a 50/50 glycol-water mixture that is chilled using the same sort of thermal bath as used in the fermentation set up. The distillate is collected in a volumetric flask until half the sample volume has been acquired.

The distillate obtained is also analyzed. Using a density meter (Anton Paar, Ashland, VA), the ethanol content, or percent alcohol by volume (ABV), can be determined. A more in-depth analysis of the distillate can be achieved through the use of a gas chromatography (GC) machine (Agilent Technologies, Santa Clara, CA). This method can breakdown the alcohol content of the sample, differentiating between methanol, n-propyl alcohol, isobutyl alcohol, and isoamyl alcohol, as well as indicating the concentration of substances such as acetaldehyde and ethyl acetate.

The materials used in this project are of vast importance as the basic goal of this project is the selection of the superior type of corn to use in the production of whisky. The corn used in the trials can be separated into two main categories: control and experimental. The control corn is comprised of non-HTF species and four distinct strains were utilized. The strain designated as 33N09 was grown in Newman, Illinois, strains 32W86 and 33M54 were grown in Toney, Alabama, and the strain 34D71 was grown in Mauzy, Indiana.

Ten strains of experimental HTF corn were used in the trials: 35D28, 35Y33, 34M94, 32K22, 34P88, 33A84, 34H31, 31G66, 33N56, and 34A15. All of the experimental corns were obtained in 10 lb samples from the Pioneer Research & Development Department. The malt and rye used in the mash cooks were obtained weekly from Froedtert grain suppliers to ensure freshness.

The species of yeast used in the fermentation process was *Saccharomyces cerevisiae*. The media used for storage, backculture, and inoculation was ½ malt made from Sigma-Aldrich M6409 Malt Extract Broth (St. Louis, MO).

When the analysis of a mash sample required the dilution of the mash sample, water stripped of its ions via reverse osmosis (RO water) was used in order to maintain the integrity of the sample.

PROCEDURE

I. Yeast Media Preparation (½ Malt)

1. Calculate the amount of ½ malt needed for one week's worth of cooks, including back cultures. Approximately 500 mL of ½ malt is needed per cooker; 250 mL is needed for every back culture. Use 1 L screw-cap flasks for the 500 mL portions and 500 mL flasks with metal caps for the 250 mL portions.
2. Sigma-Aldrich M6409 Malt Extract Broth is used to create the ½ malt. 15 g of dry powder media is needed per liter of water.
3. Add half of the total amount of water to a flask with a stir bar, then the powder, then the remainder of the water.
4. Bring the ½ malt to a boil using a stirring hot plate and then separate into the individual flasks. Place autoclave tape on flasks and label and date.
5. With caps on loosely, autoclave flasks to sterilize the ½ malt.
6. Place cooled, sterilized ½ malt in media cabinet.

II. Autoclave Nalgenes

1. Place clean 4 L Nalgene containers with caps on loosely in autoclave and sterilize. Three Nalgenes are needed per cooker.
2. An autoclaved 250 mL graduated cylinder will also be needed for each cook. Once sterilized, the dry cylinder should be covered with aluminum foil to prevent contamination.

III. Yeast Scale-up

1. Two days before the cook, transfer approximately 50 mL of media inoculated with *Saccharomyces cerevisiae* yeast to each 1 L flask. Label all flasks with dates of transfers.
2. Place flasks with yeast in incubator.

IV. Back culture

1. To keep the yeast strain alive, back culture every three or four days into a 500 mL flask of ½ malt unless a scale-up has been performed.

V. Grain Preparation

1. The grain bill is 80% corn, 8% rye and 12% malt, with 10% of the malt being used as pre-malt.
2. Cooks using experimental corn use two cookers at a time and are based on the amount of milled corn available. Cooks using control corn use three cookers and are 25 L cooks.
3. Calculate the amount of corn, malt, rye and water needed to carry out the cook. (Sample calculation of grain bill is in Appendix A.)
4. Malt and rye, either milled or unmilled, will be collected weekly to ensure freshness. Unmilled corn, both control and experimental, will be provided by Pioneer and will be milled in the hammer mill on the day of mashing.
5. Before milling the corn, analyze the whole kernels for potential CO_2 loss and percent moisture using the Foss NIR machine. Run the analysis three times and record the average.
6. To operate the hammer mill, wearing eye and ear protection, first turn on the grain grinder and then the grain feeder. Place a bucket under the mill to collect the

grain and pour the corn in the top of the mill. Ensure that the ground corn does not back up into the mill.

7. A sieve screening will be performed on 100 g of the milled corn to ensure it falls within the size specifications. Place each screen on sieve shaker and shake for 20 minutes. (Sieve specifications in Appendix B.)

VI. Mashing Procedure

1. Cooks will be performed in 40 L agitated, jacketed cookers. Drain jackets of residual water prior to using to prevent building up large amounts of pressure when heating.
2. Immediately prior to cooking, fill the cookers approximately half way with water and boil, with the agitators on, for 10 minutes to sterilize the cookers. Drain cookers after water has slightly cooled.
3. Turn on hose and allow water to run for 10-15 minutes to avoid using previously stagnant water in cooks.
4. Collect amount of water previously calculated that is needed for each cooker and pour into each cooker.
5. Heat water to 140°F and add pre-malt with approximately 20 g of corn.
6. Heat water to 150°F and add remainder of corn.
7. Heat to boiling and hold for 20 minutes.
8. Cool mash to 180°F, add rye and hold for 15 minutes.
9. Cool to 170°F, add post-malt and hold for 10 minutes.
10. Cool to 85°F.
11. Record the weights of all the Nalgenes that will be used.

12. Perform a sterile yeast transfer into the Nalgenes.
    a. In a sterile lab, place an autoclaved graduated cylinder, an autoclaved Nalgene and the prepared yeast in a fume hood. Ignite a small gas burner outside of the hood.
    b. Yeast is added in a 5% volume to volume ratio. Therefore, for the 3 L fermentations, approximately 150 mL of yeast should be placed in each Nalgene.
    c. Remove the foil from the cylinder while keeping it in the hood. Swirl the flask to suspend the yeast and remove the cap, placing it upside down in the hood.
    d. Flame the lip of the flask to sterilize it.
    e. Fill the cylinder with 150 mL of yeast without letting the flask and the cylinder touch, and immediately flame the lip of the flask, place it back in the hood and place the lid back on.
    f. Take the lid off the Nalgene, placing it upside down in the hood. Without allowing the cylinder and the Nalgene to touch, pour the yeast into the container.
    g. Screw the lid back onto the Nalgene and remove from the hood.
    h. Repeat until all of the Nalgenes contain yeast.
    i. Turn off burner and fume blower.
    j. Remove the extra yeast from the hood and return to incubator. If more than one flask remains, only one needs to be placed back in the incubator. The others may be wasted in the autoclave.

    k. Remove the graduated cylinder from the hood and rinse with water. Cover with fresh foil and a strip of autoclave tape and place on rack to be autoclaved.
    l. Clean hood and counter using isopropanol.

13. Record the weight of the Nalgenes with yeast.
14. Steam the bottom of the cookers for 15 minutes to sterilize.
15. Drain approximately 2 L of mash into a graduated 5 gallon bucket.
16. Collect a 500 mL sample of set mash for analysis.
17. Collect three 3 L samples in the prepared Nalgenes from each cooker.
18. Drain the remainder of the mash into the graduated bucket and record the volume.
19. Record the weights of the filled Nalgenes.

VII. Fermentation Bath

1. A water bath powered by a NesLab RTE-111 Bath is used to regulate temperature during fermentation. Fill the bath so that the mash in the Nalgenes are just below the water level.
2. Place baskets containing three Nalgenes with loosened lids each in the bath to prevent them from tipping over.
3. The five day fermentation consists of an increase in temperature from an initial 70°F to 84°F over a period of 72 hours, followed by a hold of 84°F for 24 hours, ending with a cooling to 78°F for 24 hours.
4. To initiate the program controlling the bath, open the desktop icon for NesLab. Set the appropriate program parameters and click “Start.”

5. Under View, select Chart. For the Parameter 2, select “Temperature 2” and begin chart. On the chart, click on the “Log File” button. Name the log file the using the date and click OK.

VIII. Set Analysis

1. Using the 500 mL sample taken from each cooker, determine the pH of the mash.
2. Strain the mash and determine the balling using a 2:1 ratio of water to mash. Mix 90 mL of strained mash in a 250 mL graduated cylinder with 180 mL RO water. Find the temperature adjusted balling of the mixture, and multiply that value by three to determine the actual balling of the mash.
3. Calculate the actual cook size by converting the gallons of mash in the graduated buckets to liters and adding to it approximately 9.5 liters.

IX. Cleaning

1. To clean the cookers, fill with water then drain to remove the largest portion of the residual mash.
2. Fill the cookers again and heat to 150°F. Add approximately 500 mL of 50% NaOH and allow to sit for 45 minutes.
3. Drain the cookers and fill with water to rinse. Drain again.
4. Fill the cookers approximately half way and bring to a boil.
5. Allow the water to cool and drain.
6. Remove the temperature gauges and plugs in the cookers to clean.
7. Wrap the gauges and plugs with Teflon tape and replace.
8. Rinse the cookers with water to remove any solids that may have fallen into the cooker.

9. Dispose of the remaining mash and wash the buckets.

X. Distillation

1. Once the five day fermentation is complete, remove the Nalgenes from the bath, dry them off and record their weights.
2. Tighten the lids and shake well before the distillation process.
3. Obtain a 500 mL sample and determine the drop pH and drop balling in the same manner that the set pH and balling were determined.
4. Place 30 mL of the strained mash into an HPLC vial containing 5 mL of 3M H_2SO_4, cap, label and shake well to halt any residual fermentation activity.
5. Using volumetric 100 mL flasks, obtain exactly 100 mL of mash and pour into a 500 mL Kjeldahl distillation flask. Using the same volumetric flask, obtain 100 mL of water and add it to the distillation flask.
6. Place the distillation flask on the burner and set the power to 50, placing the same volumetric flask underneath the condensation column.
7. Allow the distillation to continue until the volumetric flask is exactly full.
8. Once full, remove from under the column and remove the flask from heat.
9. Fill the GC vial to the 1.5 mL mark and cap and label.
10. Use the DMA to determine the alcohol by volume (ABV) of the distilled sample.
11. Send prepared HPLC and GC vials to an Analytical lab to be analyzed.
12. Once all analyses have been completed, dispose of the mash.
13. Wash the Nalgenes.

PLAN OF EXPERIMENTATION

Overall for this project, 28 trials, or cooks, were performed. Of these, 18 were done with control corn and yielded 158 fermentations; 10 were done with HTF experimental corn and yielded 60 fermentations. Only one strain was used for any particular trial. The HTF strains tested were 35D28, 35Y33, 34M94, 32K22, 34P88, 33A84, 34H31, 31G66, 33N54, and 34A15. All of these strains were developed by Pioneer. The control strains used were 33N09, 32W86, 33M54, and 34D71.

Initially, the whole corn used for a trial was analyzed for moisture content and maximum potential grams of CO_2 loss per 100 grams of corn. This measure of CO_2 loss is an indication of the fermentable starch content of the corn. The corn was then milled and a sample was analyzed using the sieve screens to determine whether the grist size fell within specifications.

The milled corn was cooked in 40 L jacketed cookers. At the completion of the cook, three 3 L samples of mash were collected in sterile Nalgene containers and inoculated with *Saccharomyces cerevisiae* yeast in a 5% volume to volume ratio. The inoculated mashes were placed in the water bath and the 5 day fermentation was begun. This is known as the set point. Samples of the mash remaining in each cooker, not inoculated with yeast, were collected and analyzed for pH and sugar content. The term "balling" is used to denote sugar content by mass. These measurements are the set data obtained for the fermentations.

At the end of the 5 day period, the fermentation process was stopped by removing the containers from the water bath. This is the drop point. A sample of the mash from each fermentation was analyzed for pH and balling as well as by HPLC. Two samples were taken from each fermentation and were distilled; these samples were analyzed using the DMA to determine alcohol content as well as by GC.

RESULTS & DISCUSSION

A total of twenty-eight mash cooks were performed, with 18 being control and 10 experimental, resulting in 158 and 60 fermentations respectively. When examined as a whole, the corn used in all trials was measured on the FOSS NIR spectrometer as having a potential 38.5 g of CO_2 loss per 100 g of corn at 100% conversion of starch and a moisture content of 13.1%. The balling decreased over the course of the fermentation from an average of 18.4% by mass at the set point to 1.0% when completed, or dropped. The overall average pH decreased from 5.93 to 4.29 from set to drop. The overall average alcohol by volume (ABV) achieved for all fermentations was 9.24%.

The GC analysis performed on the trials provided measurements of the amounts of various alcohols other than ethanol present in the distillate. These alcohols are collectively titled as fusel oils and, while closely monitored in an industrial setting, on an experimental scale are merely indicative of the integrity of the overall process. These other alcohols are present as the result of contamination of the mash by wild yeast or bacteria that produce other types of alcohols. The GC analysis was performed on the first 22 trials and indicated only trace amounts of fusel oils were present. It was, therefore, deemed unnecessary to carry out the analysis on the remaining trials. The data obtained by the GC analysis can be found in Appendix C.

Through the course of the project it was observed that a number of the cooks (trials 3, 6, 7, 8, 9, 13, 14, 15, 16, 18, 20, 21, 22, 23, and 24) showed signs of contamination. Of these, only trials 3, 14, and 15 were with experimental corn, and trial

15 only showed contamination in one cooker (#10). The reason for the large number of contaminated control trials is that due to the limited resources of experimental corn, cooks were only performed with the control corn, which was readily available, until the contamination disappeared from the cooks. In this way the number of clean experimental cooks was maximized. This contamination was initially noticed by the observation of a sulfur note in the odor of the ongoing fermentations. The sulfur note was strongest 24 hours after the fermentation was set and gradually faded over the next 48 hours.

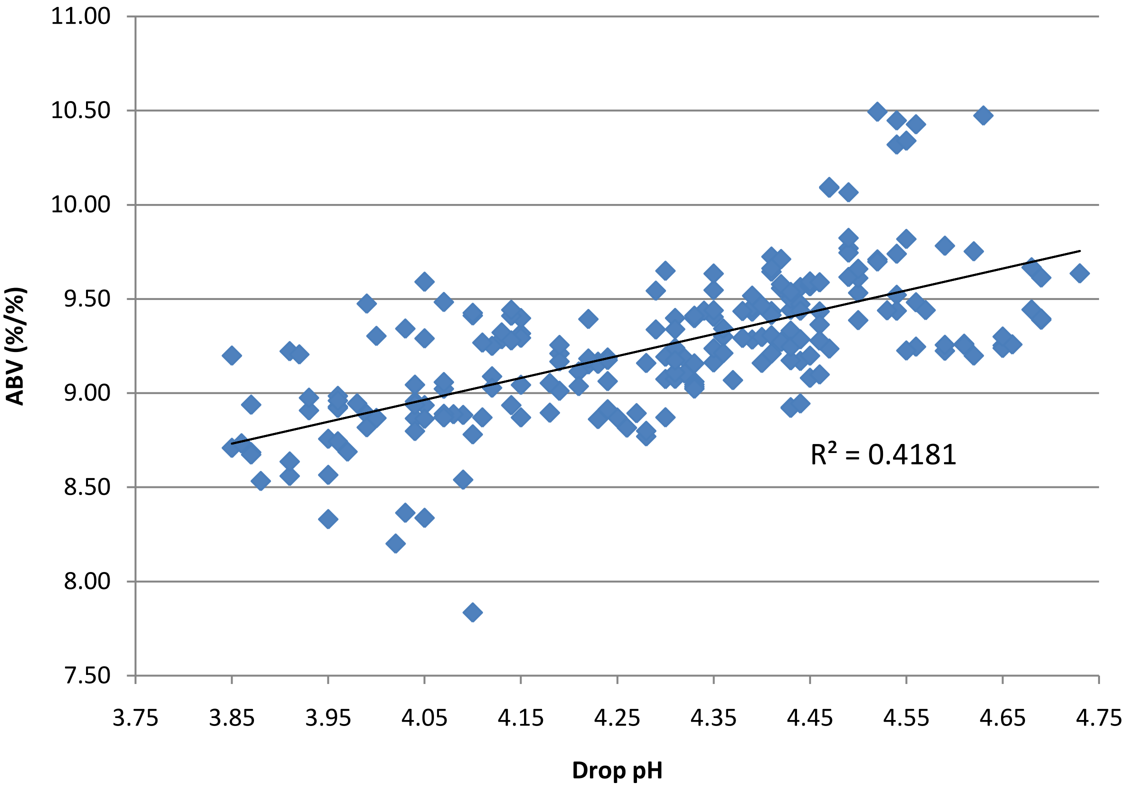

FIGURE 3 – ABV vs Drop pH for all Fermentations. Fermentations with a higher drop pH also have a higher yield of ABV, both of which correspond to a clean fermentation.

An additional indicator of contamination was the low drop in pH of the mash. The drop in pH of a sweet beer, which is what was created here, is typically 4.4 to 4.5 (Geisler, 2006). A pH lower than this range can indicate the presence of excess *lactobacillus*, a bacteria that produces lactic acid. The lactate not only increases the acidity of the mash, it also uses a significant portion of the sugar available to generate that acid, hindering the ethanol production potential of the yeast. This correlation is illustrated in FIGURE 3 above.

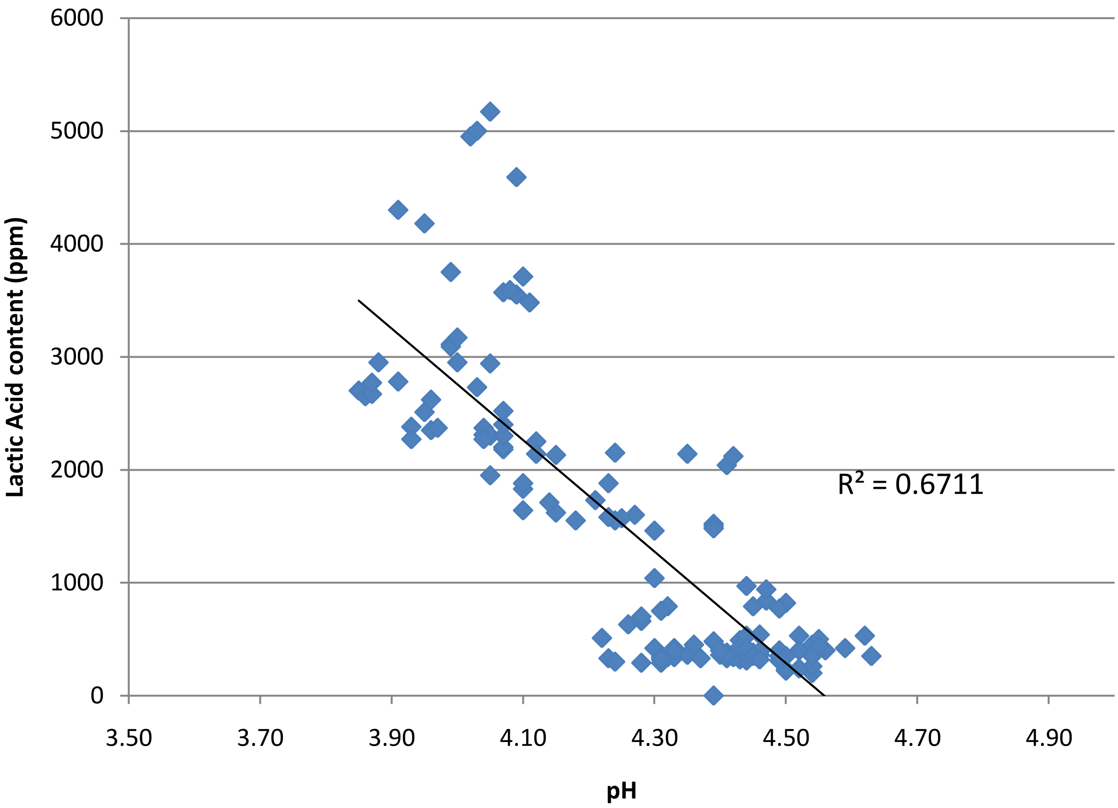

FIGURE 4 – Lactic Acid Content vs Drop pH of Fermentations. When the lactic acid content of the mash is graphed versus the pH, their inverse relationship can be clearly observed.

HPLC analysis was performed on the first 19 trials, yielding data for 137 fermentations, in order to establish a correlation between the pH of the mash and its lactic acid content. As can be seen in FIGURE 4, there is a definite trend that as the lactic acid in the mash increases, the pH of the sample decreases. This is illustrated via the R-squared value of 0.6711 for the data. Having thus been determined, the more in-depth

HPLC analysis can be eliminated for the remainder of the trials, relying instead on the pH analysis alone.

Since the pH is a sufficient indicator of the amount of lactic acid present in the mash, it can be used as the determinant for whether the mash has been contaminated. Based on the standard pH range for a sweet beer, all the fermentations with a pH below 4.40 will be considered contaminated while all those with a pH of 4.40 or greater will be deemed clean. By differentiating between clean and contaminated cooks, it is possible to eliminate those trials that would compromise the data when examined as a whole. While comparing clean control trials to clean experimental trials would produce the strongest correlation between the two types of corn, a comparison of the contaminated trials could provide supporting evidence. The differentiation of fermentations into the categories of clean and contaminated can be seen below in TABLE I.

TABLE I

DIVISION OF CLEAN AND CONTAMINATED COOKS

		# of Fermentations	Average Drop pH	Average ABV (%)
Overall	All	218	4.29	9.24
	Control	158	4.25	9.12
	HTF	60	4.41	9.58
Contaminated ($pH < 4.40$)	Control	117	4.15	9.04
	HTF	16	4.21	9.28
Clean ($pH \geq 4.40$)	Control	41	4.53	9.34
	HTF	44	4.48	9.69

From the table above it is easily shown that the vast majority of the contaminated fermentations were those done with control corn. The raw data for all trials can be found in Appendix C. TABLE IV contains the raw corn properties, TABLE V contains set data, and TABLE VI contains the drop data. HPLC data can be found in TABLE VII and

GC data can be found in TABLE VIII. It is worthy of note that while there may have been variation in pH and ABV among the three cookers for any given trial, the three separate fermentations from a single cooker were consistent among themselves. Because of this, it can be confidently stated that the origin of the contamination was not found in the fermenting process.

Due to the wide range of variables inherent in this project, it was difficult to determine the cause of contamination. The control corn acquired from Toney, Alabama (32W86 and 33M54) was used in trials 6-10, 13, 16, 18, and 20, all of which were contaminated, excluding trial 10. This may seem to indicate that this lot of corn was the contaminant; however, this is improbable for two reasons. There were three other strains of corn that showed contamination, two of which were HTF (34M94 and 31G66) and one of which was non-HTF (34D71). Also, in the mashing procedure, the corn is boiled for 20 minutes, which would effectively kill any bacteria present in the grain.

When the contamination first presented itself, it was noticed that the malt being used in the mash had a musty odor. Unlike the corn, the malt was never heated above 170°F while in the mash, making it a viable contamination source. A sample of the malt was analyzed for levels of bacteria present. A malt broth was made and plated on three different types of media. It was found that the bacteria levels in the malt were 5-10 times the allowable limits. However, as this malt had aged for several weeks between the time of its use and its testing, it could not be confidently concluded that the malt was the source of contamination. This suspect malt was used in trials 6-12 and 15-18. For the other trials, alternative lots of malt were utilized as available.

Following the fourth trial, the back culture of the yeast being used for fermentations had to be restarted when it was noticed that there was mold floating on top of the yeast media. While this may have contributed to the low yields seen in trial 3, it could not be responsible for any subsequent contaminated trials.

A mechanical possibility for the contamination is the cooling rate of the mash. If the mash is not cooled quickly enough after the addition of the post-malt, hot spots can form and cause the mash to partially solidify. This gelatinized mash allows the bacteria already present in the mash to thrive uninhibited since the added yeast cannot penetrate the solid portions of the mash. Since the cooling water used was simply city water, the temperature outside significantly affects the cooling ability. Because the trials took place from mid-August to mid-December, it could be argued that this is the reason the last four trials were clean. However, this disregards that trials 1, 2, 4, and 5 were all clean and took place during the hottest weather of the trial period.

In addition to performing analysis in an attempt to determine the contaminant, the cookers were also rigorously cleaned and sterilized before and after every trial. However, before the source of contamination could be firmly established, the contamination traits gradually declined and finally disappeared altogether over a series of trials without any percievable change in procedure.

Analysis of the clean cooks only yields the most significant data as it has not been compromised by contamination. The conversion of starch to sugar of the different strains of corn can be compared as seen in TABLE IX in Appendix D. The potential CO_2 loss is measured prior to milling by the Foss NIR while the actual CO_2 loss is calculated by determining the weight lost by the mash over the five day fermentation period. Thus it can be seen that, when examined overall, the HTF corn has a slightly better conversion of starch to sugar, at 93.7%, than the control corn, at 92.8%.

Below, FIGURE 5 displays the individual conversions achieved by the HTF and control strains. While the majority of the HTF strains reached over 92% conversion, two strains (31G66 and 33N54) performed substantially more poorly at about 88.5%. Since only one cook was conducted with each HTF strain, it cannot conclusively be stated that those strains are inferior to the others. Additional testing with corroborating data would be required. It is of note that four hybrid strains (33A84, 34P88, 32K22, and 35Y33) outperformed all of the control strains in the conversion of starch to sugar. The variability in the conversion of starch to sugar is the result of not only the amount of fermentable starch present, but also the accessability of that starch within the corn.

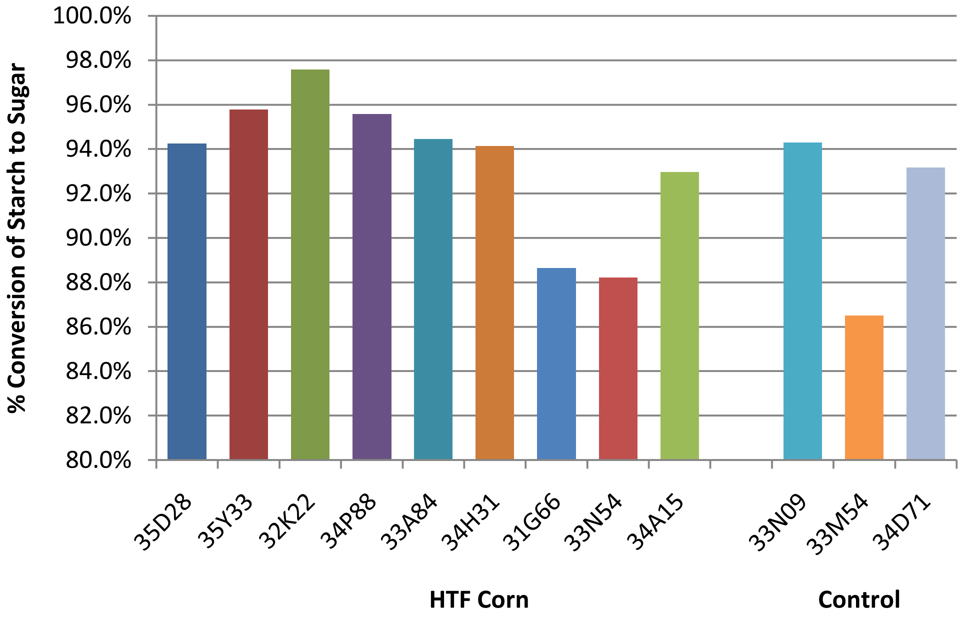

FIGURE 5 – Conversion of Starch to Sugar by Strain

Unlike the conversion from starch, the conversion of sugar to ethanol is, on average, the same for both types of corn. As can be seen from FIGURE 6, while there is some variation among the different strains of corn used (see Appendix D), both the control and the HTF corns have an average 95.4% conversion of sugar to ethanol in a clean fermentation.

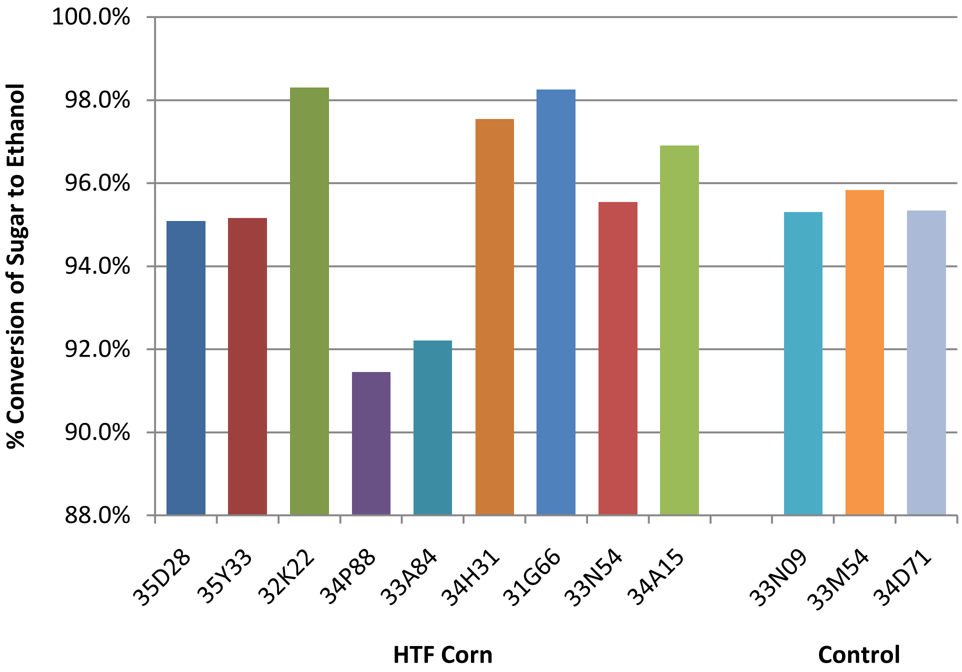

FIGURE 6 – Conversion of Sugar to Ethanol by Strain

In contrast to the conversion of starch, the conversion of sugar percentages achieved by the control strains were extremely consistent, all within 0.5% of each other. The HTF strains, however, showed considerably more deviation. Two strains (34P88 and 33A84) performed particularly poorly when compared to the other HTF strains, achieving only 92.2% and 91.5% conversion, respectively. It is interesting to note that both of these low-performance strains were two of the high-performing strains with regards to starch conversion to sugar. Once again, four of the HTF strains (32K22, 34H31, 31G66, and 34A15) outperformed all of the tested control strains. Of these, the only strain that demonstrated peak performance for both the conversion of starch to sugar as well as sugar to ethanol was 32K22. As mentioned earlier, the success or failure of a particular strain cannot be stated conclusively without additional testing.

TABLE II

STRAIN CONVERSION AND ETHANOL PRODUCTION

Corn Type	Strain	Conversion of Starch to Sugar	Conversion of Sugar to EtOH	Conversion of Starch to EtOH	Average ABV (%)
HTF	All	93.7%	95.4%	89.4%	9.69
	35D28	94.2%	95.1%	89.6%	9.52
	35Y33	95.8%	95.2%	91.1%	9.62
	32K22	97.6%	98.3%	95.9%	10.42
	34P88	95.6%	91.5%	87.4%	9.85
	33A84	94.4%	92.2%	87.1%	9.70
	34H31	94.1%	97.5%	91.8%	9.50
	31G66	88.6%	98.2%	87.1%	9.12
	33N54	88.2%	95.5%	84.3%	9.43
	34A15	92.9%	96.9%	90.1%	9.64
Control	All	92.8%	95.4%	88.5%	9.34
	33N09	94.3%	95.3%	89.9%	9.56
	33M54	86.5%	95.8%	82.9%	8.93
	34D71	93.2%	95.3%	88.8%	9.34

When the conversion capabilities of a strain are compiled in TABLE II along with the alcohol content achieved, it becomes apparent that the HTF strain 32K22 is indeed, for this set of trials, superior to the control strains as well as the other HTF strains. The 32K22 HTF strain achieved an average conversion of 97.6% of starch to sugar and 98.3% of sugar to ethanol, leading to an overall starch to ethanol conversion of 95.9% which is significantly higher than the average overall conversion, 89.4%, for all HTF strains. This enhanced performance can be seen even more clearly when the 32K22 HTF strain is held in contrast to the average overall conversion, 88.5%, for all of the control strains tested. When examined individually, four of the HTF strains (34A15, 34H31, 32K22, and 35Y33) achieved a greater overall conversion than all of the control strains tested.

While there was a great deal of variation among the different fermentations, the duplicate distillations performed for any given fermentation displayed excellent repeatability. Ninety-nine percent of the clean fermentations had distillation runs that differed by 0.031% or less from the average ABV for that particular fermentation.

Using statistical analysis (see Appendix E), it was calculated that, for a 99% confidence level, the average ABV produced by the HTF corn in a clean fermentation was 9.69% ± 0.14%. In contrast, the control corn produced an average of 9.34% ± 0.08% ABV for a clean fermentation at a 99% confidence level. This difference indicates a 3.6% increase in the alcohol yield of the HTF corn over the control, which corresponds with the 2-4% yield increase claimed by Pioneer. This increase of alcohol produced per fermentation would result in the ability to decrease the number of fermenations needed to maintain the current level of saleable product while at the same time reducing the energy and time needed in order to run those now-superfluous fermentations.

TABLE III

AVERAGE VALUES OF TRIAL DATA

		#	CO_2 loss (g)	Set Balling (%)	Drop Balling (%)	Set pH	Drop pH	Average ABV (%)
Overall	All	218	38.5	18.4	1.0	5.93	4.29	9.24
	Control	158	38.5	18.3	1.0	5.96	4.25	9.12
	HTF	60	38.6	18.6	0.9	5.84	4.41	9.58
Contaminated (pH < 4.40)	Control	117	38.4	18.3	1.1	5.96	4.15	9.04
	HTF	16	38.6	18.5	1.1	5.89	4.21	9.28
Clean (pH ≥ 4.40)	Control	41	38.5	18.6	0.9	5.98	4.53	9.34
	HTF	44	38.6	18.6	0.9	5.82	4.48	9.69

When an identical analysis was performed on the contaminated trials, it was found that the trends between the HTF and control corns were similar to those observed in the clean fermentations. In TABLE III, the results are compared both overall as well as between contaminated and clean fermentations.

When the contaminated fermentations were analyzed statistically (Appendix E), it was found that for a 99% confidence level HTF and control corn yielded 9.28% ± 0.11% ABV and 9.04% ± 0.07% ABV respectively. From this it can be seen that even when contaminated, the HTF corn managed to provide a 2.6% increase in the alcohol yield over that produced by the control corn. While this trend is not as strongly significant as the data obtained from the clean fermentations due to being compromised by contamination, it can be looked upon as supporting evidence of the claim that HTF corn produces a higher ethanol yield than the non-HTF control corn. This outcome is not entirely unexpected since the suspected contaminant was a lactic acid-producing bacteria. The bacteria used the sugar created during the mashing process to create lactic acid, simultaneously depriving the yeast of needed nutrients and creating an environment where the pH was below the optimum operating conditions of the yeast. However, if the contamination was present to roughly the same degree in the different fermentations, the ethanol producing capabilities of the HTF and control strains would be decreased by the same amount. This, of course, varies with respect to the initial amount of starch present in the corn as well as the conversion of that starch to sugar achieved by that particular strain.

While the increase in the clean fermentations of 3.6% does not seem to be greatly significant, when moved to an industrial scale, it becomes much more noteworthy. Not only is this a simple means of enhancing the process, it also enhances the profit margin without incurring large, if any, expenses.

CONCLUSIONS

There are several conclusions that can be reached based on the findings of this experimentation. These findings are valid only for the procedure followed and the strains of corn utilized, both control (33N09, 32W86, 33M54, and 34D71) and HTF (35D28, 35Y33, 34M94, 32K22, 34P88, 33A84, 34H31, 31G66, 33N56, and 34A15).

- There is a directly proportional trend between the pH of a fermentation and its lactic acid content, thus allowing it to be used as a means of determining contamination.
- For clean fermentations, HTF corn reaches an average 93.7% conversion of starch to sugar and control corn reaches 92.8%; however, both HTF and control corn achieve an average 95.4% conversion of sugar to ethanol for clean fermentations.
- From a preliminary standpoint, the HTF strain 32K22 is the most successful of the strains with 97.6% conversion of starch to sugar, 98.3% conversion of sugar to ethanol, 95.9% conversion of starch to ethanol, and a final alcohol content of 10.42% ABV.
- Under a 99% confidence level, a clean HTF fermentation yields 9.69% ± 0.14% ABV and a clean control fermentation yields 9.34% ± 0.08% ABV; a contaminated HTF fermentation yields 9.28% ± 0.11% ABV and a contaminated control fermentation yields 9.04% ± 0.08% ABV.
- A clean HTF fermentation produces, on average, 3.6% more ethanol than a clean control fermentation, falling in the range advertised by Pioneer of 2-4%. A

contaminated HTF fermentation produces an average of 2.6% more ethanol than a contaminated fermentation, also falling within Pioneer’s range.

- The optimum HTF strain, 32K22, achieves a 11.6% increase in ethanol content over the average produced by the clean control fermentations.

RECOMMENDATIONS

The primary recommendation that can be made at the close of this experimentation is that the HTF corn, particularly 32K22, be utilized in the production of whisky in conjunction with, if not in lieu of, non-HTF corn. By using a superior raw material, the process can be upgraded at a minimal cost and simultaneously preserve the integrity with which the whisky industry regards the tradition of whisky production.

In order to determine the best strains to blend together for the optimal alcohol production, additional trials should be done with the HTF strains in order to determine conclusively which have the best conversion capabilities and produce the most alcohol.

The improvement of the process could potentially be advanced through additional enhancement of the grains used in the mashing process. Perhaps the best candidate for this would be the development of malt with an increased amount of amylase enzymes. This could allow for a more complete conversion of starch to sugar during the mashing process, providing more ample resources for the yeast when converting sugar to ethanol.

REFERENCES CITED

Alcohol and Tobacco Tax and Trade Bureau. “Distilled Spirits: Laws and Regulations.” 2008. http://www.ttb.gov/spirits/spirits_regs.shtml. Accessed 16 October, 2008.

Briggs, D., Boulton, C. A., Brookes, P. A., and Stevens, R. 2004. Brewing: Science and Practice. Cambridge, England: Woodhead Publishing.

“Fermentability and mashing out.” *Brew Your Own: The How-to Homebrew Beer Magazine*. (November 2005).

Ferris, R. “Distilled liquors,” *The Encyclopedia Americana*, 1918 ed.

FOSS. “Dedicated Analytical Systems.” 2008. http://www.foss.dk/Solutions/ProductsDirect/Infratec1241GrainAnalyzer.aspx. Accessed 25 September, 2008.

Geisler, C. 2006. Private communication.

H&C Sieving Systems. “12 Inch Diameter Sieves.” 2008. http://www.affordablesieves.com/12_inch_sieves.htm. Accessed 2 October, 2008.

Hough, J. S. 1991. The Biotechnology of Malting and Brewing. Cambridge, England: Cambridge University Press.

Najafpour, G.D. and Lim, J.K. 2002. Evaluation and Isolation of Ethanol Producer Strain SMP-6. Regional Symposium on Chemical Engineering (Malaysia).

Nielsen, S. 2003. Food Analysis Laboratory Manual. New York: Springer.

Nollet, L. 2000. Food Analysis by HPLC. New York: CRC Press.

Pioneer Hi-Bred International, Inc. “Increased Ethanol Production.” 2008. http://www.pioneer.com/CMRoot/pioneer/research/pipeline/spec_sheets/Ethanol.pdf. Accessed 10 September, 2008.

APPENDIX A

SAMPLE CALCULATION OF GRAIN BILL

$$\frac{25.liters.mash}{3.785\,\frac{L}{gal}} \text{ x } \frac{56\,\frac{lb}{bushel.grain}}{28.beer.gallonage.\left(\frac{gal.mash}{bushel.grain}\right)} \text{ x } 0.454\,\frac{kg}{lb} = 6.0 \text{ kg of grain}$$

$$25 \text{ L of mash - } \frac{0.637L}{kg} \text{ x } 6.0 \text{ kg of grain} = 21.2 \text{ L of water}$$

Grain	Volume
Corn	4,800 g
Malt	72 g as pre-malt 648 g as post-malt
Rye	480 g

APPENDIX B

MILLED CORN SIZE SPECIFICATIONS

Sieve	Specs Max %	Specs Min %	Specs Goal %
#10	5	0	< 3
#20	46	20	< 35
#40	31	18	< 27
#60	16	9	< 10
#80	8	4	> 5
#100	7	1	> 3
Flour	28	5	> 13

APPENDIX C

RAW DATA

TABLE IV

RAW CORN PROPERTIES

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
8/17/2006	35D28	HTF	1A9	38.4	14.4%	9	22.2
8/17/2006	35D28	HTF	1B9	38.4	14.4%	9	22.2
8/17/2006	35D28	HTF	1C9	38.4	14.4%	9	22.2
8/17/2006	35D28	HTF	1A10	38.4	14.4%	10	22.2
8/17/2006	35D28	HTF	1B10	38.4	14.4%	10	22.2
8/17/2006	35D28	HTF	1C10	38.4	14.4%	10	22.2
8/18/2006	35Y33	HTF	2A9	38.1	12.8%	9	24.5
8/18/2006	35Y33	HTF	2B9	38.1	12.8%	9	24.5
8/18/2006	35Y33	HTF	2C9	38.1	12.8%	9	24.5
8/18/2006	35Y33	HTF	2A10	38.1	12.8%	10	24.5
8/18/2006	35Y33	HTF	2B10	38.1	12.8%	10	24.5
8/18/2006	35Y33	HTF	2C10	38.1	12.8%	10	24.5
8/24/2006	34M94	HTF	3A9	38.8	13.0%	9	22.1
8/24/2006	34M94	HTF	3B9	38.8	13.0%	9	22.1
8/24/2006	34M94	HTF	3C9	38.8	13.0%	9	22.1
8/24/2006	34M94	HTF	3A10	38.8	13.0%	10	22.1
8/24/2006	34M94	HTF	3B10	38.8	13.0%	10	22.1
8/24/2006	34M94	HTF	3C10	38.8	13.0%	10	22.1
8/25/2006	33N09	Control	4A9	38.4	13.0%	9	23.4
8/25/2006	33N09	Control	4B9	38.4	13.0%	9	23.4
8/25/2006	33N09	Control	4C9	38.4	13.0%	9	23.4
8/25/2006	33N09	Control	4A10	38.4	13.0%	10	23.4
8/25/2006	33N09	Control	4B10	38.4	13.0%	10	23.4
9/8/2006	32K22	HTF	5A9	38.5	13.6%	9	23.1
9/8/2006	32K22	HTF	5B9	38.5	13.6%	9	23.1
9/8/2006	32K22	HTF	5C9	38.5	13.6%	9	23.1
9/8/2006	32K22	HTF	5A10	38.5	13.6%	10	23.1
9/8/2006	32K22	HTF	5B10	38.5	13.6%	10	23.1
9/8/2006	32K22	HTF	5C10	38.5	13.6%	10	23.1
9/11/2006	32W86	Control	6A9	38.5	13.5%	9	25.0
9/11/2006	32W86	Control	6B9	38.5	13.5%	9	25.0
9/11/2006	32W86	Control	6C9	38.5	13.5%	9	25.0
9/11/2006	32W86	Control	6A10	38.5	13.5%	10	25.0
9/11/2006	32W86	Control	6B10	38.5	13.5%	10	25.0
9/11/2006	32W86	Control	6C10	38.5	13.5%	10	25.0
9/11/2006	32W86	Control	6A11	38.5	13.5%	11	25.0
9/11/2006	32W86	Control	6B11	38.5	13.5%	11	25.0
9/11/2006	32W86	Control	6C11	38.5	13.5%	11	25.0

TABLE IV

RAW CORN PROPERTIES CONT.

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
9/14/2006	32W86	Control	7A9	38.6	15.0%	9	25.0
9/14/2006	32W86	Control	7B9	38.6	15.0%	9	25.0
9/14/2006	32W86	Control	7C9	38.6	15.0%	9	25.0
9/14/2006	32W86	Control	7A10	38.6	15.0%	10	25.0
9/14/2006	32W86	Control	7B10	38.6	15.0%	10	25.0
9/14/2006	32W86	Control	7C10	38.6	15.0%	10	25.0
9/14/2006	32W86	Control	7A11	38.6	15.0%	11	25.0
9/14/2006	32W86	Control	7B11	38.6	15.0%	11	25.0
9/14/2006	32W86	Control	7C11	38.6	15.0%	11	25.0
9/15/2006	33M54	Control	8A9	38.2	15.1%	9	25.0
9/15/2006	33M54	Control	8B9	38.2	15.1%	9	25.0
9/15/2006	33M54	Control	8C9	38.2	15.1%	9	25.0
9/15/2006	33M54	Control	8A10	38.2	15.1%	10	25.0
9/15/2006	33M54	Control	8B10	38.2	15.1%	10	25.0
9/15/2006	33M54	Control	8C10	38.2	15.1%	10	25.0
9/15/2006	33M54	Control	8A11	38.2	15.1%	11	25.0
9/15/2006	33M54	Control	8B11	38.2	15.1%	11	25.0
9/15/2006	33M54	Control	8C11	38.2	15.1%	11	25.0
9/21/2006	32W86	Control	9A9	38.4	15.3%	9	25.0
9/21/2006	32W86	Control	9B9	38.4	15.3%	9	25.0
9/21/2006	32W86	Control	9C9	38.4	15.3%	9	25.0
9/21/2006	32W86	Control	9A10	38.4	15.3%	10	25.0
9/21/2006	32W86	Control	9B10	38.4	15.3%	10	25.0
9/21/2006	32W86	Control	9C10	38.4	15.3%	10	25.0
9/21/2006	32W86	Control	9A11	38.4	15.3%	11	25.0
9/21/2006	32W86	Control	9B11	38.4	15.3%	11	25.0
9/21/2006	32W86	Control	9C11	38.4	15.3%	11	25.0
9/22/2006	32W86	Control	10A9	38.4	14.8%	9	25.0
9/22/2006	32W86	Control	10B9	38.4	14.8%	9	25.0
9/22/2006	32W86	Control	10C9	38.4	14.8%	9	25.0
9/22/2006	32W86	Control	10A10	38.4	14.8%	10	25.0
9/22/2006	32W86	Control	10B10	38.4	14.8%	10	25.0
9/22/2006	32W86	Control	10C10	38.4	14.8%	10	25.0
9/22/2006	32W86	Control	10A11	38.4	14.8%	11	25.0
9/22/2006	32W86	Control	10B11	38.4	14.8%	11	25.0
9/22/2006	32W86	Control	10C11	38.4	14.8%	11	25.0
10/5/2006	34P88	HTF	11A9	38.4	13.8%	9	20.8
10/5/2006	34P88	HTF	11B9	38.4	13.8%	9	20.8
10/5/2006	34P88	HTF	11C9	38.4	13.8%	9	20.8
10/5/2006	34P88	HTF	11A10	38.4	13.8%	10	20.8
10/5/2006	34P88	HTF	11B10	38.4	13.8%	10	20.8
10/5/2006	34P88	HTF	11C10	38.4	13.8%	10	20.8

TABLE IV

RAW CORN PROPERTIES CONT.

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
10/6/2006	33A84	HTF	12A9	38.7	13.5%	9	20.8
10/6/2006	33A84	HTF	12B9	38.7	13.5%	9	20.8
10/6/2006	33A84	HTF	12C9	38.7	13.5%	9	20.8
10/6/2006	33A84	HTF	12A10	38.7	13.5%	10	20.8
10/6/2006	33A84	HTF	12B10	38.7	13.5%	10	20.8
10/6/2006	33A84	HTF	12C10	38.7	13.5%	10	20.8
10/12/2006	33M54	Control	13A9	38.1	13.8%	9	25.0
10/12/2006	33M54	Control	13B9	38.1	13.8%	9	25.0
10/12/2006	33M54	Control	13C9	38.1	13.8%	9	25.0
10/12/2006	33M54	Control	13A10	38.1	13.8%	10	25.0
10/12/2006	33M54	Control	13B10	38.1	13.8%	10	25.0
10/12/2006	33M54	Control	13C10	38.1	13.8%	10	25.0
10/12/2006	33M54	Control	13A11	38.1	13.8%	11	25.0
10/12/2006	33M54	Control	13B11	38.1	13.8%	11	25.0
10/12/2006	33M54	Control	13C11	38.1	13.8%	11	25.0
10/13/2006	34H31	HTF	14A9	38.5	12.5%	9	23.4
10/13/2006	34H31	HTF	14B9	38.5	12.5%	9	23.4
10/13/2006	34H31	HTF	14C9	38.5	12.5%	9	23.4
10/13/2006	34H31	HTF	14A10	38.5	12.5%	10	23.4
10/13/2006	34H31	HTF	14B10	38.5	12.5%	10	23.4
10/13/2006	34H31	HTF	14C10	38.5	12.5%	10	23.4
10/19/2006	31G66	HTF	15A9	38.7	13.5%	9	19.3
10/19/2006	31G66	HTF	15B9	38.7	13.5%	9	19.3
10/19/2006	31G66	HTF	15C9	38.7	13.5%	9	19.3
10/19/2006	31G66	HTF	15A10	38.7	13.5%	10	19.3
10/19/2006	31G66	HTF	15B10	38.7	13.5%	10	19.3
10/19/2006	31G66	HTF	15C10	38.7	13.5%	10	19.3
10/20/2006	33M54	Control	16A9	38.3	12.5%	9	25.0
10/20/2006	33M54	Control	16B9	38.3	12.5%	9	25.0
10/20/2006	33M54	Control	16C9	38.3	12.5%	9	25.0
10/20/2006	33M54	Control	16A10	38.3	12.5%	10	25.0
10/20/2006	33M54	Control	16B10	38.3	12.5%	10	25.0
10/20/2006	33M54	Control	16C10	38.3	12.5%	10	25.0
10/20/2006	33M54	Control	16A11	38.3	12.5%	11	25.0
10/20/2006	33M54	Control	16B11	38.3	12.5%	11	25.0
10/20/2006	33M54	Control	16C11	38.3	12.5%	11	25.0
10/26/2006	33N56	HTF	17A9	38.9	15.3%	9	22.4
10/26/2006	33N56	HTF	17B9	38.9	15.3%	9	22.4
10/26/2006	33N56	HTF	17C9	38.9	15.3%	9	22.4
10/26/2006	33N56	HTF	17A10	38.9	15.3%	10	22.4
10/26/2006	33N56	HTF	17B10	38.9	15.3%	10	22.4
10/26/2006	33N56	HTF	17C10	38.9	15.3%	10	22.4

TABLE IV

RAW CORN PROPERTIES CONT.

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
10/27/2006	32W86	Control	18A9	38.5	12.3%	9	25.0
10/27/2006	32W86	Control	18B9	38.5	12.3%	9	25.0
10/27/2006	32W86	Control	18C9	38.5	12.3%	9	25.0
10/27/2006	32W86	Control	18A10	38.5	12.3%	10	25.0
10/27/2006	32W86	Control	18B10	38.5	12.3%	10	25.0
10/27/2006	32W86	Control	18C10	38.5	12.3%	10	25.0
10/27/2006	32W86	Control	18A11	38.5	12.3%	11	25.0
10/27/2006	32W86	Control	18B11	38.5	12.3%	11	25.0
10/27/2006	32W86	Control	18C11	38.5	12.3%	11	25.0
11/3/2006	34A15	HTF	19A9	38.9	13.6%	9	20.8
11/3/2006	34A15	HTF	19B9	38.9	13.6%	9	20.8
11/3/2006	34A15	HTF	19C9	38.9	13.6%	9	20.8
11/3/2006	34A15	HTF	19A10	38.9	13.6%	10	20.8
11/3/2006	34A15	HTF	19B10	38.9	13.6%	10	20.8
11/3/2006	34A15	HTF	19C10	38.9	13.6%	10	20.8
11/10/2006	33M54	Control	20A9	38.1	12.3%	9	25.0
11/10/2006	33M54	Control	20B9	38.1	12.3%	9	25.0
11/10/2006	33M54	Control	20C9	38.1	12.3%	9	25.0
11/10/2006	33M54	Control	20A10	38.1	12.3%	10	25.0
11/10/2006	33M54	Control	20B10	38.1	12.3%	10	25.0
11/10/2006	33M54	Control	20C10	38.1	12.3%	10	25.0
11/10/2006	33M54	Control	20A11	38.1	12.3%	11	25.0
11/10/2006	33M54	Control	20B11	38.1	12.3%	11	25.0
11/10/2006	33M54	Control	20C11	38.1	12.3%	11	25.0
11/16/2006	34D71	Control	21A9	38.6	11.8%	9	25.0
11/16/2006	34D71	Control	21B9	38.6	11.8%	9	25.0
11/16/2006	34D71	Control	21C9	38.6	11.8%	9	25.0
11/16/2006	34D71	Control	21A10	38.6	11.8%	10	25.0
11/16/2006	34D71	Control	21B10	38.6	11.8%	10	25.0
11/16/2006	34D71	Control	21C10	38.6	11.8%	10	25.0
11/16/2006	34D71	Control	21A11	38.6	11.8%	11	25.0
11/16/2006	34D71	Control	21B11	38.6	11.8%	11	25.0
11/16/2006	34D71	Control	21C11	38.6	11.8%	11	25.0
11/17/2006	34D71	Control	22A9	38.7	12.0%	9	25.0
11/17/2006	34D71	Control	22B9	38.7	12.0%	9	25.0
11/17/2006	34D71	Control	22C9	38.7	12.0%	9	25.0
11/17/2006	34D71	Control	22A10	38.7	12.0%	10	25.0
11/17/2006	34D71	Control	22B10	38.7	12.0%	10	25.0
11/17/2006	34D71	Control	22C10	38.7	12.0%	10	25.0
11/17/2006	34D71	Control	22A11	38.7	12.0%	11	25.0
11/17/2006	34D71	Control	22B11	38.7	12.0%	11	25.0
11/17/2006	34D71	Control	22C11	38.7	12.0%	11	25.0

TABLE IV

RAW CORN PROPERTIES CONT.

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
11/30/2006	34D71	Control	23A9	38.7	11.7%	9	25.0
11/30/2006	34D71	Control	23B9	38.7	11.7%	9	25.0
11/30/2006	34D71	Control	23C9	38.7	11.7%	9	25.0
11/30/2006	34D71	Control	23A10	38.7	11.7%	10	25.0
11/30/2006	34D71	Control	23B10	38.7	11.7%	10	25.0
11/30/2006	34D71	Control	23C10	38.7	11.7%	10	25.0
11/30/2006	34D71	Control	23A11	38.7	11.7%	11	25.0
11/30/2006	34D71	Control	23B11	38.7	11.7%	11	25.0
11/30/2006	34D71	Control	23C11	38.7	11.7%	11	25.0
12/1/2006	34D71	Control	24A9	38.6	12.0%	9	25.0
12/1/2006	34D71	Control	24B9	38.6	12.0%	9	25.0
12/1/2006	34D71	Control	24C9	38.6	12.0%	9	25.0
12/1/2006	34D71	Control	24A10	38.6	12.0%	10	25.0
12/1/2006	34D71	Control	24B10	38.6	12.0%	10	25.0
12/1/2006	34D71	Control	24C10	38.6	12.0%	10	25.0
12/1/2006	34D71	Control	24A11	38.6	12.0%	11	25.0
12/1/2006	34D71	Control	24B11	38.6	12.0%	11	25.0
12/1/2006	34D71	Control	24C11	38.6	12.0%	11	25.0
12/7/2006	34D71	Control	25A9	38.7	11.7%	9	25.0
12/7/2006	34D71	Control	25B9	38.7	11.7%	9	25.0
12/7/2006	34D71	Control	25C9	38.7	11.7%	9	25.0
12/7/2006	34D71	Control	25A10	38.7	11.7%	10	25.0
12/7/2006	34D71	Control	25B10	38.7	11.7%	10	25.0
12/7/2006	34D71	Control	25C10	38.7	11.7%	10	25.0
12/7/2006	34D71	Control	25A11	38.7	11.7%	11	25.0
12/7/2006	34D71	Control	25B11	38.7	11.7%	11	25.0
12/7/2006	34D71	Control	25C11	38.7	11.7%	11	25.0
12/8/2006	34D71	Control	26A9	38.5	11.9%	9	25.0
12/8/2006	34D71	Control	26B9	38.5	11.9%	9	25.0
12/8/2006	34D71	Control	26C9	38.5	11.9%	9	25.0
12/8/2006	34D71	Control	26A10	38.5	11.9%	10	25.0
12/8/2006	34D71	Control	26B10	38.5	11.9%	10	25.0
12/8/2006	34D71	Control	26C10	38.5	11.9%	10	25.0
12/8/2006	34D71	Control	26A11	38.5	11.9%	11	25.0
12/8/2006	34D71	Control	26B11	38.5	11.9%	11	25.0
12/8/2006	34D71	Control	26C11	38.5	11.9%	11	25.0

TABLE IV

RAW CORN PROPERTIES CONT.

Set Date	Strain	Corn Type	ID	Max Theo CO_2 loss	% Moisture	Cooker #	Cook Size Theo (L)
12/14/2006	34D71	Control	27A9	38.5	11.8%	9	25.0
12/14/2006	34D71	Control	27B9	38.5	11.8%	9	25.0
12/14/2006	34D71	Control	27C9	38.5	11.8%	9	25.0
12/14/2006	34D71	Control	27A10	38.5	11.8%	10	25.0
12/14/2006	34D71	Control	27B10	38.5	11.8%	10	25.0
12/14/2006	34D71	Control	27C10	38.5	11.8%	10	25.0
12/14/2006	34D71	Control	27A11	38.5	11.8%	11	25.0
12/14/2006	34D71	Control	27B11	38.5	11.8%	11	25.0
12/14/2006	34D71	Control	27C11	38.5	11.8%	11	25.0
12/15/2006	34D71	Control	28A9	38.7	11.5%	9	25.0
12/15/2006	34D71	Control	28B9	38.7	11.5%	9	25.0
12/15/2006	34D71	Control	28C9	38.7	11.5%	9	25.0
12/15/2006	34D71	Control	28A10	38.7	11.5%	10	25.0
12/15/2006	34D71	Control	28B10	38.7	11.5%	10	25.0
12/15/2006	34D71	Control	28C10	38.7	11.5%	10	25.0
12/15/2006	34D71	Control	28A11	38.7	11.5%	11	25.0
12/15/2006	34D71	Control	28B11	38.7	11.5%	11	25.0
12/15/2006	34D71	Control	28C11	38.7	11.5%	11	25.0

TABLE V

SET DATA

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
1A9	22.6	5.78	19.5	310	448	3727	3279	676
1B9	22.6	5.78	19.5	312	452	3718	3266	673
1C9	22.6	5.78	19.5	313	445	3463	3018	622
1A10	22.6	5.81	19.5	312	451	3543	3092	638
1B10	22.6	5.81	19.5	312	456	3616	3160	652
1C10	22.6	5.81	19.5	312	455	3746	3291	679
2A9	23.6	5.74	18.9	314	453	3558	3105	628
2B9	23.6	5.74	18.9	313	452	3607	3155	639
2C9	23.6	5.74	18.9	312	451	3636	3185	645
2A10	23.6	5.72	18.3	312	451	3575	3124	632
2B10	23.6	5.72	18.3	315	453	3818	3365	681
2C10	23.6	5.72	18.3	315	450	3649	3199	648
3A9	18.2	5.94	20.1	312	444	3545	3101	629
3B9	18.2	5.94	20.1	314	456	3552	3096	628
3C9	18.2	5.94	20.1	314	443	3493	3050	619
3A10	20.9	5.94	19.2	313	453	3411	2958	600
3B10	20.9	5.94	19.2	314	453	3647	3194	648
3C10	20.9	5.94	19.2	314	456	3646	3190	647
4A9	23.7	5.78	18.9	311	446	3583	3137	636
4B9	23.7	5.78	18.9	312	450	3617	3167	643
4C9	23.7	5.78	18.9	312	446	3649	3203	650
4A10	23.7	5.78	19.5	311	451	3487	3036	616
4B10	23.7	5.78	19.5	316	456	3598	3142	637
5A9	22.7	5.88	17.7	312	461	3758	3297	674
5B9	22.7	5.88	17.7	314	454	3667	3213	656
5C9	22.7	5.88	17.7	314	454	3674	3220	658
5A10	22.7	5.91	17.7	313	465	3585	3120	637
5B10	22.7	5.91	17.7	314	464	3601	3137	641
5C10	22.7	5.91	17.7	314	474	3722	3248	664
6A9	24.6	5.84	18.0	313	453	3595	3142	641
6B9	24.6	5.84	18.0	310	450	3664	3214	656
6C9	24.6	5.84	18.0	312	449	3443	2994	611
6A10	24.6	5.82	17.7	312	449	3597	3148	642
6B10	24.6	5.82	17.7	313	455	3612	3157	644
6C10	24.6	5.82	17.7	312	447	3692	3245	662
6A11	24.6	5.83	18.6	312	453	3600	3147	642
6B11	24.6	5.83	18.6	313	448	3429	2981	608
6C11	24.6	5.83	18.6	315	454	3547	3093	631

TABLE V

SET DATA CONT.

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
7A9	25.8	5.85	18.3	315	456	3542	3086	641
7B9	25.8	5.85	18.3	312	449	3496	3047	633
7C9	25.8	5.85	18.3	313	452	3604	3152	655
7A10	25.0	5.90	17.1	313	447	3581	3134	651
7B10	25.0	5.90	17.1	312	452	3574	3122	648
7C10	25.0	5.90	17.1	313	456	3743	3287	683
7A11	23.9	5.91	17.7	313	453	3639	3186	662
7B11	23.9	5.91	17.7	316	457	3551	3094	642
7C11	23.9	5.91	17.7	314	451	3705	3254	676
8A9	25.4	5.91	17.4	314	455	3640	3185	662
8B9	25.4	5.91	17.4	311	457	3367	2910	605
8C9	25.4	5.91	17.4	314	454	3615	3161	657
8A10	24.6	5.86	17.1	315	457	3477	3020	628
8B10	24.6	5.86	17.1	311	455	3608	3153	655
8C10	24.6	5.86	17.1	311	451	3553	3102	645
8A11	25.8	5.92	16.8	313	457	3557	3100	644
8B11	25.8	5.92	16.8	315	459	3379	2920	607
8C11	25.8	5.92	16.8	315	456	3419	2963	616
9A9	24.6	5.87	17.7	312	451	3364	2913	607
9B9	24.6	5.87	17.7	313	454	3620	3166	660
9C9	24.6	5.87	17.7	314	456	3626	3170	661
9A10	25.4	5.83	18.0	312	448	3439	2991	623
9B10	25.4	5.83	18.0	313	457	3515	3058	637
9C10	25.4	5.83	18.0	312	456	3479	3023	630
9A11	25.0	5.96	17.7	315	460	3697	3237	675
9B11	25.0	5.96	17.7	313	455	3747	3292	686
9C11	25.0	5.96	17.7	313	456	3853	3397	708
10A9	24.6	5.98	19.2	314	450	3674	3224	668
10B9	24.6	5.98	19.2	314	462	3495	3033	628
10C9	24.6	5.98	19.2	310	452	3696	3244	672
10A10	24.6	5.99	18.3	315	455	3466	3011	624
10B10	24.6	5.99	18.3	313	454	3696	3242	672
10C10	24.6	5.99	18.3	314	453	3606	3153	653
10A11	24.6	5.98	18.3	312	459	3737	3278	679
10B11	24.6	5.98	18.3	317	461	3718	3257	675
10C11	24.6	5.98	18.3	313	452	3593	3141	651
11A9	20.5	5.75	18.0	314	446	3613	3167	648
11B9	20.5	5.75	18.0	314	447	3665	3218	659
11C9	20.5	5.75	18.0	314	444	3506	3062	627
11A10	19.3	5.77	18.6	314	449	3519	3070	629
11B10	19.3	5.77	18.6	312	453	3674	3221	660
11C10	19.3	5.77	18.6	313	447	3529	3082	631

TABLE V

SET DATA CONT.

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
12A9	20.3	5.81	18.6	314	459	3586	3127	638
12B9	20.3	5.81	18.6	313	457	3546	3089	630
12C9	20.3	5.81	18.6	314	462	3580	3118	636
12A10	20.7	5.81	18.6	314	460	3714	3254	664
12B10	20.7	5.81	18.6	312	449	3284	2835	578
12C10	20.7	5.81	18.6	315	457	3659	3202	653
13A9	24.6	6.13	16.5	315	458	3600	3142	643
13B9	24.6	6.13	16.5	313	451	3497	3046	624
13C9	24.6	6.13	16.5	314	453	3763	3310	678
13A10	25.4	6.12	15.9	314	463	3616	3153	646
13B10	25.4	6.12	15.9	316	461	3277	2816	577
13C10	25.4	6.12	15.9	316	459	3325	2866	587
13A11	25.0	5.95	18.0	313	453	3715	3262	668
13B11	25.0	5.95	18.0	313	460	3764	3304	677
13C11	25.0	5.95	18.0	313	458	3542	3084	631
14A9	23.9	6.00	18.3	312	462	3451	2989	603
14B9	23.9	6.00	18.3	314	447	3693	3246	655
14C9	23.9	6.00	18.3	313	459	3600	3141	634
14A10	23.3	5.85	18.3	312	454	3451	2997	605
14B10	23.3	5.85	18.3	313	462	3608	3146	635
14C10	23.3	5.85	18.3	314	460	3535	3075	620
15A9	20.1	5.81	17.1	314	458	3510	3052	623
15B9	20.1	5.81	17.1	314	460	3643	3183	649
15C9	20.1	5.81	17.1	316	462	3800	3338	681
15A10	16.3	5.82	16.5	315	456	3403	2947	601
15B10	16.3	5.82	16.5	312	460	3624	3164	646
15C10	16.3	5.82	16.5	314	460	3662	3202	653
16A9	25.2	6.08	18.9	314	454	3546	3092	624
16B9	25.2	6.08	18.9	315	466	3356	2890	583
16C9	25.2	6.08	18.9	314	448	3497	3049	615
16A10	24.9	6.08	18.9	313	451	3555	3104	626
16B10	24.9	6.08	18.9	314	453	3594	3141	634
16C10	24.9	6.08	18.9	315	448	3632	3184	642
16A11	25.0	6.08	18.9	314	452	3577	3125	630
16B11	25.0	6.08	18.9	313	458	3821	3363	678
16C11	25.0	6.08	18.9	314	446	3593	3147	635
17A9	22.6	5.73	19.2	313	447	3551	3104	647
17B9	22.6	5.73	19.2	313	459	3506	3047	635
17C9	22.6	5.73	19.2	315	451	3537	3086	643
17A10	21.8	5.80	18.9	314	448	3611	3163	659
17B10	21.8	5.80	18.9	314	454	3730	3276	683
17C10	21.8	5.80	18.9	311	458	3722	3264	680

TABLE V

SET DATA CONT.

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
18A9	24.6	5.92	19.2	313	449	3702	3253	655
18B9	24.6	5.92	19.2	313	458	3570	3112	626
18C9	24.6	5.92	19.2	315	456	3446	2990	602
18A10	25.0	5.91	18.6	314	449	3369	2920	588
18B10	25.0	5.91	18.6	314	451	3522	3071	618
18C10	25.0	5.91	18.6	315	461	3592	3131	630
18A11	24.6	5.93	18.3	313	461	3323	2862	576
18B11	24.6	5.93	18.3	316	459	3354	2895	583
18C11	24.6	5.93	18.3	313	451	3673	3222	648
19A9	20.5	5.94	18.9	313	461	3370	2909	594
19B9	20.5	5.94	18.9	313	451	3663	3212	656
19C9	20.5	5.94	18.9	313	451	3656	3205	655
19A10	20.5	5.96	19.8	313	451	3456	3005	614
19B10	20.5	5.96	19.8	316	453	3599	3146	643
19C10	20.5	5.96	19.8	311	454	3714	3260	666
20A9	23.7	6.03	19.8	312	448	3551	3103	624
20B9	23.7	6.03	19.8	313	448	3369	2921	588
20C9	23.7	6.03	19.8	314	455	3568	3113	627
20A10	24.6	5.99	18.6	314	458	3606	3148	634
20B10	24.6	5.99	18.6	313	454	3444	2990	602
20C10	24.6	5.99	18.6	314	462	3660	3198	644
20A11	24.3	6.05	18.6	314	446	3588	3142	632
20B11	24.3	6.05	18.6	313	454	3425	2971	598
20C11	24.3	6.05	18.6	313	455	3548	3093	622
21A9	24.6	5.93	18.9	314	453	3591	3138	628
21B9	24.6	5.93	18.9	313	460	3611	3151	631
21C9	24.6	5.93	18.9	316	458	3346	2888	578
21A10	25.8	5.91	18.6	311	458	3729	3271	655
21B10	25.8	5.91	18.6	314	455	3591	3136	628
21C10	25.8	5.91	18.6	313	460	3605	3145	629
21A11	25.0	5.98	18.3	312	452	3536	3084	617
21B11	25.0	5.98	18.3	313	457	3566	3109	622
21C11	25.0	5.98	18.3	313	453	3817	3364	673
22A9	24.3	5.87	18.9	316	454	3571	3117	625
22B9	24.3	5.87	18.9	313	459	3751	3292	660
22C9	24.3	5.87	18.9	314	457	3772	3315	665
22A10	26.1	5.90	18.3	314	457	3419	2962	594
22B10	26.1	5.90	18.3	313	458	3675	3217	645
22C10	26.1	5.90	18.3	312	456	3423	2967	595
22A11	24.6	5.93	18.6	313	453	3548	3095	621
22B11	24.6	5.93	18.6	316	456	3468	3012	604
22C11	24.6	5.93	18.6	316	457	3688	3231	648

TABLE V

SET DATA CONT.

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
23A9	25.6	5.94	18.9	311	462	3481	3019	603
23B9	25.6	5.94	18.9	316	457	3532	3075	615
23C9	25.6	5.94	18.9	313	451	3522	3071	614
23A10	25.4	5.99	17.7	312	459	3487	3028	605
23B10	25.4	5.99	17.7	313	456	3569	3113	622
23C10	25.4	5.99	17.7	315	456	3392	2936	587
23A11	24.6	6.03	18.6	312	455	3664	3209	641
23B11	24.6	6.03	18.6	315	458	3628	3170	634
23C11	24.6	6.03	18.6	313	456	3883	3427	685
24A9	24.5	5.93	19.2	313	457	3641	3184	639
24B9	24.5	5.93	19.2	313	458	3530	3072	616
24C9	24.5	5.93	19.2	314	456	3688	3232	648
24A10	26.2	5.97	18.3	315	458	3417	2959	593
24B10	26.2	5.97	18.3	313	457	3431	2974	596
24C10	26.2	5.97	18.3	315	466	3519	3053	612
24A11	25.6	6.00	18.0	311	453	3749	3296	661
24B11	25.6	6.00	18.0	314	457	3702	3245	651
24C11	25.6	6.00	18.0	314	457	3639	3182	638
25A9	25.0	6.05	18.6	313	454	3416	2962	592
25B9	25.0	6.05	18.6	312	460	3772	3312	662
25C9	25.0	6.05	18.6	314	462	3582	3120	624
25A10	25.8	6.07	18.6	316	460	3665	3205	641
25B10	25.8	6.07	18.6	317	462	3588	3126	625
25C10	25.8	6.07	18.6	313	451	3467	3016	603
25A11	25.4	6.09	18.6	316	465	3317	2852	570
25B11	25.4	6.09	18.6	313	457	3533	3076	615
25C11	25.4	6.09	18.6	314	458	3643	3185	637
26A9	25.8	5.90	18.9	313	456	3448	2992	599
26B9	25.8	5.90	18.9	315	454	3503	3049	611
26C9	25.8	5.90	18.9	314	460	3254	2794	560
26A10	26.2	5.93	18.6	312	455	3361	2906	582
26B10	26.2	5.93	18.6	315	465	3367	2902	581
26C10	26.2	5.93	18.6	312	451	3399	2948	591
26A11	26.2	5.95	20.1	313	453	3417	2964	594
26B11	26.2	5.95	20.1	314	459	3595	3136	628
26C11	26.2	5.95	20.1	315	452	3463	3011	603

TABLE V

SET DATA CONT.

ID	Cook Size Actual (L)	Set pH	Set Balling (%)	Nalgene wt (g)	Total wt w/ yeast (g)	Total set wt (g)	Mash wt (g)	g dry corn mashed
27A9	25.6	5.99	18.9	314	464	3634	3170	634
27B9	25.6	5.99	18.9	317	463	3616	3153	631
27C9	25.6	5.99	18.9	312	455	3780	3325	665
27A10	25.8	6.08	18.9	313	454	3499	3045	609
27B10	25.8	6.08	18.9	314	455	3485	3030	606
27C10	25.8	6.08	18.9	314	453	3616	3163	633
27A11	25.6	6.09	18.9	316	454	3429	2975	595
27B11	25.6	6.09	18.9	315	449	3458	3009	602
27C11	25.6	6.09	18.9	316	464	3383	2919	584
28A9	26.5	6.03	18.0	313	458	3456	2998	598
28B9	26.5	6.03	18.0	313	461	3553	3092	617
28C9	26.5	6.03	18.0	312	454	3694	3240	646
28A10	26.1	6.07	18.6	316	450	3521	3071	612
28B10	26.1	6.07	18.6	314	462	3541	3079	614
28C10	26.1	6.07	18.6	312	453	3352	2899	578
28A11	25.6	6.11	18.9	313	445	3516	3071	612
28B11	25.6	6.11	18.9	313	466	3640	3174	633
28C11	25.6	6.11	18.9	314	463	3704	3241	646

TABLE VI

DROP DATA

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
1A9	8/22/2006	3485	242	35.79	4.50	9.225	9.547	9.39	1.2
1B9	8/22/2006	3476	242	35.94	4.54	9.528	9.513	9.52	0.9
1C9	8/22/2006	3239	224	36.00	4.54	9.404	9.468	9.44	0.9
1A10	8/22/2006	3309	234	36.70	4.41	9.712	9.735	9.72	0.9
1B10	8/22/206	3378	238	36.53	4.42	9.375	9.737	9.56	0.9
1C10	8/22/2006	3499	247	36.40	4.35	9.492	9.600	9.55	0.9
2A9	8/23/2006	3331	227	36.12	4.44	9.568	9.555	9.56	0.9
2B9	8/23/2006	3376	231	36.17	4.45	9.570	9.561	9.57	0.9
2C9	8/23/2006	3402	234	36.30	4.50	9.557	9.506	9.53	0.9
2A10	8/23/2006	3342	233	36.85	4.50	9.715	9.505	9.61	0.9
2B10	8/23/2006	3568	250	36.71	4.54	9.731	9.746	9.74	0.9
2C10	8/23/2006	3411	238	36.76	4.52	9.698	9.719	9.71	0.9
3A9	8/29/2006	3324	221	35.13	4.03	9.357	9.326	9.34	0.9
3B9	8/29/2006	3332	220	35.03	4.05	9.280	9.299	9.29	0.9
3C9	8/29/2006	3275	218	35.23	4.00	9.249	9.356	9.30	0.9
3A10	8/29/2006	3195	216	35.99	4.07	9.452	9.513	9.48	0.9
3B10	8/29/2006	3416	231	35.65	3.99	9.481	9.467	9.47	0.9
3C10	8/29/2006	3414	232	35.85	4.10	9.354	9.468	9.41	0.9
4A9	8/30/2006	3355	228	35.83	4.43	9.440	9.442	9.44	0.9
4B9	8/30/2006	3387	230	35.80	4.46	9.492	9.373	9.43	0.9
4C9	8/30/2006	3417	232	35.70	4.43	9.500	9.500	9.50	0.9
4A10	8/30/2006	3260	227	36.86	4.62	9.749	9.754	9.75	0.9
4B10	8/30/2006	3363	235	36.87	4.52	9.662	9.732	9.70	0.9
5A9	9/13/2006	3506	252	37.42	4.52	10.330	10.654	10.49	0.3
5B9	9/13/2006	3421	246	37.48	4.54	10.334	10.302	10.32	0.3
5C9	9/13/2006	3429	245	37.25	4.55	10.319	10.358	10.34	0.3
5A10	9/13/2006	3344	241	37.81	4.54	10.474	10.418	10.45	0.3
5B10	9/13/2006	3359	242	37.76	4.56	10.446	10.405	10.43	0.3
5C10	9/13/2006	3472	250	37.68	4.63	10.467	10.477	10.47	0.3
6A9	9/15/2006	3387	208	32.44	3.85	8.698	8.719	8.71	1.2
6B9	9/15/2006	3452	212	32.33	3.86	8.727	8.738	8.73	1.5
6C9	9/15/2006	3246	197	32.25	3.87	8.663	8.707	8.69	1.2
6A10	9/15/2006	3392	205	31.91	3.88	8.473	8.592	8.53	1.2
6B10	9/15/2006	3406	206	31.98	3.91	8.514	8.605	8.56	1.2
6C10	9/15/2006	3480	212	32.02	3.87	8.666	8.680	8.67	1.2
6A11	9/15/2006	3386	214	33.33	3.96	8.967	8.888	8.93	0.9
6B11	9/15/2006	3226	203	33.37	3.93	9.006	8.809	8.91	1.2
6C11	9/15/2006	3316	231	36.60	3.93	8.984	8.965	8.97	0.9

TABLE VI

DROP DATA CONT.

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
7A9	9/19/2006	3320	222	34.64	4.39	9.422	9.440	9.43	0.6
7B9	9/19/2006	3276	220	34.77	4.39	9.428	9.451	9.44	0.9
7C9	9/19/2006	3376	228	34.84	4.39	9.457	9.453	9.46	0.9
7A10	9/19/2006	3368	213	32.73	3.99	8.877	8.897	8.89	0.9
7B10	9/19/2006	3361	213	32.86	3.99	8.765	8.870	8.82	1.2
7C10	9/19/2006	3519	224	32.82	4.00	8.893	8.841	8.87	1.2
7A11	9/19/2006	3414	225	34.01	4.30	9.216	9.168	9.19	1.2
7B11	9/19/2006	3331	220	34.24	4.32	9.177	9.189	9.18	1.2
7C11	9/19/2006	3476	229	33.89	4.31	9.248	9.230	9.24	0.9
8A9	9/20/2006	3425	215	32.47	4.26	8.822	8.809	8.82	0.6
8B9	9/20/2006	3170	197	32.56	4.28	8.748	8.791	8.77	0.9
8C9	9/20/2006	3400	215	32.72	4.28	8.809	8.788	8.80	0.9
8A10	9/20/2006	3268	209	33.29	4.11	8.866	8.874	8.87	0.9
8B10	9/20/2006	3392	216	32.95	4.09	8.891	8.875	8.88	1.2
8C10	9/20/2006	3339	214	33.18	4.08	8.874	8.900	8.89	0.9
8A11	9/20/2006	3345	212	32.90	4.43	8.910	8.938	8.92	0.6
8B11	9/20/2006	3178	201	33.11	4.43	8.921	8.920	8.92	0.9
8C11	9/20/2006	3215	204	33.12	4.44	8.955	8.933	8.94	0.6
9A9	9/26/2006	3167	197	32.45	4.10	6.940	8.730	7.84	0.5
9B9	9/26/2006	3406	214	32.44	4.15	8.880	8.860	8.87	0.8
9C9	9/26/2006	3413	213	32.24	4.14	8.920	8.950	8.94	1.2
9A10	9/26/2006	3237	202	32.41	4.04	8.960	8.950	8.96	1.2
9B10	9/26/2006	3308	207	32.48	4.04	8.760	8.970	8.87	1.2
9C10	9/26/2006	3274	205	32.54	4.05	8.950	8.920	8.94	0.8
9A11	9/26/2006	3481	216	32.02	4.10	8.770	8.790	8.78	0.0
9B11	9/26/2006	3525	222	32.36	4.10	8.860	9.990	9.43	0.4
9C11	9/26/2006	3626	227	32.07	4.05	8.900	10.280	9.59	0.4
10A9	9/27/2006	3451	223	33.39	4.22	9.200	9.102	9.15	0.8
10B9	9/27/2006	3284	211	33.58	4.30	9.057	9.090	9.07	0.6
10C9	9/27/2006	3470	226	33.63	4.33	9.002	9.118	9.06	0.4
10A10	9/27/2006	3258	208	33.35	4.31	9.061	9.088	9.07	0.2
10B10	9/27/2006	3471	225	33.50	4.32	9.117	9.090	9.10	0.0
10C10	9/27/2006	3388	218	33.38	4.33	9.033	9.057	9.05	1.0
10A11	9/27/2006	3509	228	33.58	4.31	9.084	9.133	9.11	0.4
10B11	9/27/2006	3491	227	33.64	4.33	8.978	9.088	9.03	0.6
10C11	9/27/2006	3375	218	33.50	4.35	9.140	9.183	9.16	0.4
11A9	10/10/2006	3392	221	34.08	4.40	9.178	9.140	9.16	1.8
11B9	10/10/2006	3439	226	34.30	4.37	8.991	9.145	9.07	1.8
11C9	10/10/2006	3285	221	35.25	4.31	9.182	9.164	9.17	1.5
11A10	10/10/2006	3282	237	37.70	4.47	10.080	10.097	10.09	1.5
11B10	10/10/2006	3427	247	37.45	4.49	10.052	10.077	10.06	1.5
11C10	10/10/2006	3292	237	37.56	4.47	10.118	10.068	10.09	1.5

TABLE VI

DROP DATA CONT.

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
12A9	10/11/2006	3355	231	36.20	4.42	9.554	9.600	9.58	1.8
12B9	10/11/2006	3317	229	36.33	4.41	9.651	9.636	9.64	1.5
12C9	10/11/2006	3350	230	36.15	4.49	9.635	9.595	9.62	1.5
12A10	10/11/2006	3468	246	37.05	4.49	9.760	9.776	9.77	1.5
12B10	10/11/2006	3071	213	36.82	4.59	9.757	9.805	9.78	1.2
12C10	10/11/2006	3419	240	36.73	4.55	9.827	9.807	9.82	1.2
13A9	10/17/2006	3400	200	31.09	4.02	8.187	8.214	8.20	1.5
13B9	10/17/2006	3299	198	31.75	4.03	8.350	8.378	8.36	0.9
13C9	10/17/2006	3549	214	31.58	4.05	8.385	8.289	8.34	1.5
13A10	10/17/2006	3407	209	32.37	4.09	8.543	8.536	8.54	0.9
13B10	10/17/2006	3088	189	32.78	3.95	8.323	8.337	8.33	0.9
13C10	10/17/2006	3139	186	31.70	3.91	8.633	8.639	8.64	0.3
13A11	10/17/2006	3492	223	33.39	4.27	8.854	8.931	8.89	0.9
13B11	10/17/2006	3539	225	33.26	4.25	8.854	8.884	8.87	0.9
13C11	10/17/2006	3331	211	33.41	4.24	8.931	8.895	8.91	0.9
14A9	10/18/2006	3234	217	35.99	4.33	9.177	8.868	9.02	0.6
14B9	10/18/2006	3461	232	35.43	4.39	9.238	9.328	9.28	0.6
14C9	10/18/2006	3376	224	35.35	4.36	9.304	9.295	9.30	0.6
14A10	10/18/2006	3232	219	36.23	4.44	9.471	9.471	9.47	0.3
14B10	10/18/2006	3378	230	36.24	4.43	9.540	9.531	9.54	0.6
14C10	10/18/2006	3311	224	36.11	4.39	9.501	9.531	9.52	0.6
15A9	10/24/2006	3297	213	34.20	4.45	9.070	9.090	9.08	0.3
15B9	10/24/2006	3420	223	34.34	4.46	9.105	9.091	9.10	0.3
15C9	10/24/2006	3566	234	34.36	4.44	9.193	9.146	9.17	0.3
15A10	10/24/2006	3196	207	34.42	4.21	9.120	9.107	9.11	1.5
15B10	10/24/2006	3404	220	34.08	4.24	9.047	9.078	9.06	1.8
15C10	10/24/2006	3435	227	34.74	4.23	9.179	9.152	9.17	1.5
16A9	10/25/2006	3334	212	33.99	4.23	8.818	8.904	8.86	1.2
16B9	10/25/2006	3155	201	34.48	4.30	8.870	8.871	8.87	1.2
16C9	10/25/2006	3288	209	33.98	4.18	8.912	8.878	8.90	1.2
16A10	10/25/2006	3337	218	34.82	4.23	9.151	9.157	9.15	1.5
16B10	10/25/2006	3373	221	34.88	4.24	9.193	9.183	9.19	1.2
16C10	10/25/2006	3407	225	35.03	4.28	9.092	9.225	9.16	1.2
16A11	10/25/2006	3365	212	33.63	3.97	8.774	8.603	8.69	1.2
16B11	10/25/2006	3594	227	33.46	3.95	8.746	8.767	8.76	1.2
16C11	10/25/2006	3381	212	33.40	3.96	8.747	8.739	8.74	1.2
17A9	10/31/2006	3330	221	34.17	4.46	9.365	9.361	9.36	0.9
17B9	10/31/2006	3287	219	34.49	4.43	9.329	9.332	9.33	0.9
17C9	10/31/2006	3317	220	34.21	4.45	9.682	9.471	9.58	0.9
17A10	10/31/2006	3385	226	34.29	4.41	9.435	9.433	9.43	0.6
17B10	10/31/2006	3496	234	34.28	4.44	9.435	9.437	9.44	0.9
17C10	10/31/2006	3488	234	34.40	4.41	9.415	9.412	9.41	0.9

TABLE VI

DROP DATA CONT.

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
18A9	11/1/2006	3476	226	34.52	4.12	9.082	9.094	9.09	0.6
18B9	11/1/2006	3354	216	34.49	4.15	9.024	9.062	9.04	1.5
18C9	11/1/2006	3238	208	34.57	4.12	9.053	9.002	9.03	1.2
18A10	11/1/2006	3166	203	34.54	4.07	9.020	9.024	9.02	1.5
18B10	11/1/2006	3309	213	34.46	4.07	9.064	9.051	9.06	1.2
18C10	11/1/2006	3374	218	34.60	4.04	9.062	9.025	9.04	1.2
18A11	11/1/2006	3127	196	34.03	4.07	8.864	8.882	8.87	1.2
18B11	11/1/2006	3155	199	34.16	4.07	8.871	8.907	8.89	1.5
18C11	11/1/2006	3452	221	34.08	4.07	8.873	8.867	8.87	1.8
19A9	11/8/2006	3157	213	35.84	4.40	9.411	9.517	9.46	0.6
19B9	11/8/2006	3428	235	35.81	4.45	9.600	9.583	9.59	0.6
19C9	11/8/2006	3421	235	35.89	4.46	9.615	9.559	9.59	0.6
19A10	11/8/2006	3232	224	36.49	4.49	9.742	9.747	9.74	0.6
19B10	11/8/2006	3365	234	36.41	4.49	9.847	9.798	9.82	0.6
19C10	11/8/2006	3471	243	36.49	4.50	9.685	9.632	9.66	0.6
20A9	11/15/2006	3338	213	34.11	3.87	8.914	8.961	8.94	2.4
20B9	11/15/2006	3169	200	34.02	3.96	8.916	8.925	8.92	2.1
20C9	11/15/2006	3355	213	34.00	3.98	8.956	8.933	8.94	2.1
20A10	11/15/2006	3386	220	34.73	4.19	8.996	9.026	9.01	1.8
20B10	11/15/2006	3236	208	34.57	4.21	9.047	9.025	9.04	1.8
20C10	11/15/2006	3438	222	34.49	4.18	9.050	9.055	9.05	1.8
20A11	11/15/2006	3373	215	34.00	4.04	8.941	8.933	8.94	1.8
20B11	11/15/2006	3221	204	34.12	4.05	8.832	8.894	8.86	1.5
20C11	11/15/2006	3337	211	33.90	4.04	8.792	8.803	8.80	1.5
21A9	11/21/2006	3371	220	35.03	3.85	9.200	9.196	9.20	1.8
21B9	11/21/2006	3389	222	35.21	3.91	9.202	9.241	9.22	1.8
21C9	11/21/2006	3141	205	35.47	3.92	9.213	9.196	9.20	1.8
21A10	11/21/2006	3498	231	35.29	4.13	9.270	9.300	9.29	1.2
21B10	11/21/2006	3368	223	35.53	4.15	9.336	9.296	9.32	1.2
21C10	11/21/2006	3382	223	35.43	4.19	9.134	9.285	9.21	1.2
21A11	11/21/2006	3325	211	34.19	3.96	8.990	8.978	8.98	1.5
21B11	11/21/2006	3353	213	34.24	3.96	8.961	8.958	8.96	1.8
21C11	11/21/2006	3586	231	34.31	3.95	8.623	8.507	8.57	1.5
22A9	11/22/2006	3348	223	35.67	4.15	9.397	9.397	9.40	0.9
22B9	11/22/2006	3516	235	35.59	4.14	9.433	9.386	9.41	0.9
22C9	11/22/2006	3535	237	35.65	4.14	9.457	9.425	9.44	0.9
22A10	11/22/2006	3209	210	35.35	4.22	9.203	9.162	9.18	1.2
22B10	11/22/2006	3448	227	35.18	4.19	9.149	9.185	9.17	0.9
22C10	11/22/2006	3214	209	35.12	4.24	9.197	9.152	9.17	1.2
22A11	11/22/2006	3329	219	35.28	4.15	9.287	9.298	9.29	1.5
22B11	11/22/2006	3255	213	35.26	4.12	9.275	9.224	9.25	1.5
22C11	11/22/2006	3461	227	35.03	4.13	9.320	9.322	9.32	1.2

TABLE VI

DROP DATA CONT.

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
23A9	12/5/2006	3266	215	35.63	4.29	9.327	9.346	9.34	0.9
23B9	12/5/2006	3311	221	35.96	4.33	9.400	9.393	9.40	0.6
23C9	12/5/2006	3300	222	36.17	4.35	9.614	9.653	9.63	0.3
23A10	12/5/2006	3263	224	37.01	4.30	9.670	9.626	9.65	0.6
23B10	12/5/2006	3338	231	37.12	4.42	9.747	9.674	9.71	0.9
23C10	12/5/2006	3172	220	37.49	4.41	9.636	9.686	9.66	0.9
23A11	12/5/2006	3434	230	35.86	4.31	9.442	9.353	9.40	1.2
23B11	12/5/2006	3401	227	35.82	4.35	9.431	9.376	9.40	0.9
23C11	12/5/2006	3637	246	35.91	4.34	9.426	9.446	9.44	0.9
24A9	12/6/2006	3413	228	35.70	4.22	9.334	9.450	9.39	0.6
24B9	12/6/2006	3309	221	35.87	4.33	9.389	9.430	9.41	0.6
24C9	12/6/2006	3456	232	35.79	4.35	9.437	9.440	9.44	0.6
24A10	12/6/2006	3204	213	35.89	4.40	9.309	9.284	9.30	0.6
24B10	12/6/2006	3219	212	35.54	4.41	9.305	9.306	9.31	0.6
24C10	12/6/2006	3300	219	35.76	4.42	9.314	9.227	9.27	0.6
24A11	12/6/2006	3514	235	35.55	4.14	9.261	9.296	9.28	0.9
24B11	12/6/2006	3473	229	35.19	4.19	9.266	9.243	9.25	0.9
24C11	12/6/2006	3414	225	35.25	4.11	9.249	9.285	9.27	1.2
25A9	12/12/2006	3206	210	35.47	4.43	9.176	9.170	9.17	0.9
25B9	12/12/2006	3537	235	35.50	4.41	9.190	9.228	9.21	0.9
25C9	12/12/2006	3360	222	35.60	4.45	9.192	9.203	9.20	0.9
25A10	12/12/2006	3437	228	35.59	4.61	9.279	9.243	9.26	0.9
25B10	12/12/2006	3367	221	35.37	4.59	9.185	9.262	9.22	0.9
25C10	12/12/2006	3252	215	35.66	4.65	9.255	9.250	9.25	0.9
25A11	12/12/2006	3110	207	36.31	4.35	9.235	9.238	9.24	0.9
25B11	12/12/2006	3300	233	37.90	4.31	9.337	9.340	9.34	0.9
25C11	12/12/2006	3413	230	36.13	4.33	9.196	9.117	9.16	0.9
26A9	12/13/2006	3236	212	35.37	4.47	9.232	9.238	9.24	0.9
26B9	12/13/2006	3285	218	35.69	4.56	9.250	9.241	9.25	0.9
26C9	12/13/2006	3055	199	35.55	4.55	9.233	9.217	9.23	0.9
26A10	12/13/2006	3151	210	36.07	4.69	9.394	9.382	9.39	0.9
26B10	12/13/2006	3157	210	36.12	4.69	9.409	9.380	9.39	0.9
26C10	12/13/2006	3186	213	36.06	4.68	9.460	9.425	9.44	0.9
26A11	12/13/2006	3207	210	35.36	4.65	9.224	9.253	9.24	0.9
26B11	12/13/2006	3373	222	35.34	4.66	9.248	9.267	9.26	0.9
26C11	12/13/2006	3249	214	35.48	4.65	9.342	9.256	9.30	0.9

TABLE VI

DROP DATA CONT.

ID	Drop date	Drop wt (g)	wt loss (g)	Calculated CO2 g / 100 g dry corn	Drop pH	Distill 1 ABV (%)	Distill 2 ABV (%)	Avg ABV (%)	Drop Balling (%)
27A9	12/19/2006	3405	229	36.10	4.29	9.353	9.732	9.54	0.9
27B9	12/19/2006	3387	229	36.29	4.36	9.318	9.365	9.34	0.9
27C9	12/19/2006	3539	241	36.22	4.38	9.438	9.430	9.43	0.9
27A10	12/19/2006	3274	225	36.92	4.73	9.641	9.628	9.63	0.9
27B10	12/19/2006	3260	225	37.11	4.69	9.615	9.609	9.61	0.9
27C10	12/19/2006	3382	234	36.97	4.68	9.680	9.653	9.67	0.9
27A11	12/19/2006	3216	213	35.78	4.59	9.253	9.257	9.26	0.9
27B11	12/19/2006	3241	217	36.04	4.61	9.247	9.262	9.25	0.6
27C11	12/19/2006	3174	209	35.78	4.62	9.192	9.204	9.20	0.6
28A9	12/20/2006	3244	212	35.46	4.36	9.212	9.211	9.21	0.6
28B9	12/20/2006	3333	220	35.68	4.41	9.210	9.210	9.21	0.9
28C9	12/20/2006	3465	229	35.44	4.46	9.263	9.292	9.28	0.9
28A10	12/20/2006	3297	224	36.57	4.53	9.454	9.422	9.44	0.9
28B10	12/20/2006	3316	225	36.64	4.56	9.484	9.478	9.48	0.9
28C10	12/20/2006	3141	211	36.49	4.57	9.462	9.417	9.44	0.9
28A11	12/20/2006	3298	218	35.59	4.38	9.305	9.278	9.29	0.9
28B11	12/20/2006	3415	225	35.54	4.43	9.278	9.212	9.25	1.2
28C11	12/20/2006	3473	231	35.74	4.44	9.307	9.262	9.28	1.2

TABLE VII

HPLC DATA

ID	**Highers as Maltose**	**Maltotriose**	**Citric Acid**	**Maltose**	**Glucose**	**Fructose**	**Succinic Acid**	**Lactic Acid**	**Glycerol**	**Acetic Acid**	**Ethanol**	**Residual sugars as glucose (PPM)**
1A9	7880	1040	670	1000	220	420	660	220	5110	40	9.3	10682
1B9	7770	1030	700	960	240	410	549	200	5110	40	9.2	10533
1C9	7850	940	640	1010	250	420	650	200	4960	40	9.2	10583
1A10	7330	360	200	1200	40	840	890	2040	4660	140	9.3	9405
1B10	7500	370	170	1280	30	880	900	2120	4790	140	9.5	9669
1C10	7500	390	170	1280	40	870	920	2140	4800	120	9.5	9700
2A9	9000	1020	320	1250	70	460	550	970	5250	40	9.6	11952
2B9	8830	970	310	1180	50	450	550	790	5090	40	9.4	11626
2C9	8840	1010	300	1240	60	460	550	820	5160	40	9.4	11753
2A10	8170	610	540	1200	300	630	560	230	4990	40	9.5	10817
2B10	8100	570	500	1230	320	630	550	260	4960	40	9.5	10752
2C10	8100	560	510	1220	320	640	550	240	4920	30	9.5	10731
3A9	9480	1920	130	1440	240	110	590	2730	4890	320	8.3	13792
3B9	10450	2170	150	1700	240	140	670	2940	5460	340	9.3	15354
3C9	10220	2160	140	1580	260	210	660	2950	5440	330	9.2	14995
3A10	9160	920	210	1290	30	380	650	3570	5170	180	9.6	12016
3B10	9730	1042	200	1500	20	360	640	3750	5180	200	9.5	12957
3C10	9580	1000	200	1300	30	110	640	3710	5170	190	9.4	12554
4A9	9180	1230	790	930	440	400	620	490	5430	30	9.5	12400
4B9	9370	1300	800	920	460	400	600	360	5430	20	9.4	12684
4C9	8960	1260	800	890	450	390	620	350	5410	20	9.5	12168
4A10	8860	600	540	1240	160	590	550	530	5200	30	9.6	11434
4B10	8780	610	550	1200	160	580	530	530	5200	20	9.7	11319
5A9	10000	2068	950	0	40	470	450	400	5250	20	10.3	12782
5B9	9540	1930	850	0	40	420	400	450	5000	20	10.1	12150
5C9	9600	1960	930	0	90	450	410	500	5070	50	10.2	12295
5A10	9640	1330	1090	0	30	560	420	350	5080	50	10.2	11602
5B10	9540	1220	1050	0	30	560	390	400	5080	50	10.3	11379
5C10	9330	1220	1090	0	30	550	460	350	5140	40	10.3	11158
6A9	10560	3730	940	60	70	310	460	2700	5180	400	8.7	15245
6B9	10980	3560	910	80	150	300	440	2650	5320	380	8.0	15606
6C9	10890	3540	920	100	140	310	430	2670	5140	360	8.5	15501
6A10	10100	3220	910	600	110	460	460	2950	4990	450	8.5	14823
6B10	10440	2980	900	660	70	500	460	2780	5040	450	8.3	14947
6C10	10020	2950	880	500	100	500	460	2770	5010	480	8.5	14334
6A11	10300	3060	700	640	80	440	520	2350	5220	360	8.9	14874
6B11	10100	3010	400	340	80	420	500	2380	5220	370	8.9	14294
6C11	10100	3010	500	330	100	380	500	2270	5240	350	8.4	14304

TABLE VII

HPLC DATA CONT.

ID	Highers as Maltose	Maltotriose	Citric Acid	Maltose	Glucose	Fructose	Succinic Acid	Lactic Acid	Glycerol	Acetic Acid	Ethanol
7A9	9100	1330	1030	400	710	1550	980	1520	5470	80	9.4
7B9	8690	1330	980	160	210	860	910	1500	5270	70	8.8
7C9	8990	1340	1030	340	600	1430	970	1480	5440	80	8.8
7A10	9038	1110	950	370	320	1180	980	3110	5210	140	8.5
7B10	8890	1090	900	300	70	390	960	3090	5100	140	8.7
7C10	9090	1080	900	300	60	340	950	3170	5140	170	7.7
7A11	9250	2050	1367	100	100	720	970	1040	5410	80	9.2
7B11	9090	1900	1580	0	100	630	970	790	5480	70	9.2
7C11	8380	1892	1628	0	40	610	970	750	5440	60	9.2
8A9	8850	1240	1770	0	60	650	900	630	5230	60	8.7
8B9	8890	1290	1850	0	40	630	900	660	5270	60	8.3
8C9	8830	1150	1870	0	50	630	900	700	5330	70	8.7
8A10	8840	840	880	300	10	150	830	3480	5020	200	8.7
8B10	8880	830	750	640	20	300	850	3550	5060	200	8.8
8C10	8800	830	840	310	10	300	800	3590	4970	200	8.6
8A11	9010	2000	1930	0	440	600	830	320	5660	60	8.9
8B11	8650	1900	1850	0	400	570	800	360	5460	60	8.4
8C11	9120	1940	1930	0	516	630	820	310	5480	60	8.6
9A9	9230	2310	720	210	260	680	910	1640	5700	100	8.4
9B9	9840	2180	750	280	260	690	910	1620	5560	110	8.3
9C9	9660	2330	750	320	270	690	940	1710	5760	120	8.6
9A10	9470	1270	810	340	190	1050	790	2370	5750	210	8.7
9B10	8990	1100	800	280	20	810	1000	2310	5490	210	8.7
9C10	8440	1110	800	300	210	1030	980	2300	5460	220	8.7
9A11	8940	1400	760	270	120	860	1050	1830	5730	180	8.6
9B11	9020	1190	770	330	285	1090	960	1880	5660	150	8.6
9C11	9330	1290	810	300	260	1070	1000	1950	5840	150	8.6
10A9	9240	2503	*	0	140	710	1040	510	5620	60	8.6
10B9	9350	2310	*	0	70	720	1000	420	5440	60	9.3
10C9	8620	1740	*	*	170	810	1010	420	5400	60	8.9
10A10	8590	1700	*	0	170	780	1100	290	5600	60	8.9
10B10	8880	1860	*	0	130	760	1020	340	5500	50	8.8
10C10	9360	1690	*	0	40	760	1050	340	5480	50	8.9
10A11	9400	2200	*	0	160	840	990	340	5460	50	8.9
10B11	9700	1950	*	0	240	970	1000	350	5490	50	9.0
10C11	9500	2100	*	0	30	760	1000	360	5470	50	9.0
11A9	9040	1420	*	*	160	640	330	360	5460	*	9.0
11B9	9170	1540	*	*	200	550	370	330	5330	*	8.8
11C9	8770	1520	*	*	350	520	370	320	5300	*	8.9
11A10	8944	1220	*	*	190	750	320	840	5280	*	9.9
11B10	8898	1200	*	*	90	700	480	770	5270	*	10.0
11C10	8920	1220	*	*	170	690	350	940	5290	*	9.6

TABLE VII

HPLC DATA CONT.

ID	Highers as Maltose	Maltotriose	Citric Acid	Maltose	Glucose	Fructose	Succinic Acid	Lactic Acid	Glycerol	Acetic Acid	Ethanol
12A9	9050	1600	*	*	110	490	420	340	5380	*	8.9
12B9	8800	1560	*	*	190	490	390	330	5200	*	9.4
12C9	8900	1600	*	*	190	500	400	350	5240	*	9.0
12A10	8730	1280	*	*	100	800	340	400	5080	*	9.6
12B10	9040	1340	*	*	110	790	350	420	5160	*	9.6
12C10	8950	1350	*	*	170	600	340	440	5140	*	9.5
13A9	8010	570	20	120	260	660	430	4950	4400	550	8.2
13B9	7880	560	20	110	100	550	420	5000	4300	580	8.3
13C9	7870	600	30	130	90	400	420	5170	4330	550	8.4
13A10	7830	200	20	130	70	530	470	4590	4520	430	8.0
13B10	7790	470	10	100	40	460	520	4180	4620	360	7.6
13C10	7650	440	10	90	60	560	450	4300	4414	380	8.5
13A11	8080	1460	10	270	20	270	560	1600	6200	200	8.8
13B11	8200	1480	20	460	70	390	590	1570	6200	180	8.7
13C11	8200	1480	50	300	70	390	600	1550	6300	180	8.0
14A9	7800	920	80	490	340	380	590	400	5350	80	9.0
14B9	7520	530	80	80	100	650	420	5000*	4350	570*	8.3
14C9	7700	900	80	400	110	600	400	450	5260	90	8.9
14A10	6400	840	80	290	1010	680	500	530	5170	90	9.0
14B10	6470	760	80	290	1030	980	500	400	5150	80	9.2
14C10	6380	760	80	290	1020	980	500	480	5160	90	9.2
15A9	7070	670	180	310	1010	570	460	380	4760	90	9.1
15B9	7200	600	170	300	980	580	460	390	4700	90	8.9
15C9	6820	600	160	290	990	800	450	370	4660	90	8.9
15A10	7010	390	10	150	1040	540	580	1730	4820	140	9.0
15B10	7280	400	5	150	1080	670	610	2150	4920	220	7.9
15C10	7100	380	20	110	1090	460	660	1880	4860	150	8.9
16A9	7620	1430	5	640	1300	570	440	1580	5660	100	9.0
16B9	7580	1190	30	410	1060	450	440	1460	5400	90	8.6
16C9	7580	1340	30	440	1010	440	430	1550	5520	80	8.1
16A10	7690	1000	190	520	1090	900	460	330	5440	50	8.7
16B10	7910	940	190	540	1090	1320	460	300	5530	50	9.0
16C10	7820	920	180	510	1100	1120	460	290	5500	50	8.9
16A11	8130	1690	60	530	980	300	520	2370	5660	200	8.1
16B11	8160	1920	60	540	1000	310	530	2510	5690	230	8.0
16C11	8170	2010	40	610	1000	340	520	2620	5720	240	7.1
17A9	8920	1410	40	1060	670	480	570	540	5690	50	9.3
17B9	8870	1240	180	900	660	530	560	430	5480	50	9.3
17C9	8610	1280	220	890	570	370	530	360	5400	50	9.3
17A10	8670	1270	220	890	550	380	540	380	5550	40	9.4
17B10	8780	1230	240	730	610	480	560	420	5600	40	9.2
17C10	8570	1160	210	890	520	390	570	370	5510	50	9.3

TABLE VII

HPLC DATA CONT.

ID	Highers as Maltose	Maltotriose	Citric Acid	Maltose	Glucose	Fructose	Succinic Acid	Lactic Acid	Glycerol	Acetic Acid	Ethanol
18A9	9100	1690	50	900	140	580	600	2250	5790	150	9.2
18B9	8720	1620	30	890	110	340	550	2130	5620	140	9.0
18C9	9000	1580	30	790	70	320	550	2140	5590	150	8.8
18A10	8800	970	20	730	100	750	580	2180	5640	160	8.9
18B10	8690	950	30	850	60	450	560	2200	5660	170	8.9
18C10	8780	920	30	710	70	720	560	2270	5620	170	8.8
18A11	9090	1650	40	680	120	380	580	2300	5600	230	8.6
18B11	9030	1700	40	840	130	360	680	2400	5700	230	8.5
18C11	8950	1900	40	920	200	390	720	2520	5780	250	8.8
19A9	8510	1025	830	930	ND	180	1020	400	5350	20	9.7
19B9	8460	990	620	1040	ND	260	1020	350	5230	50	9.6
19C9	8320	1000	670	1020	100	200	970	320	5260	60	9.6
19A10	8720	830	530	1130	100	280	460	310	5200	60	9.7
19B10	8320	860	530	1180	160	340	470	350	5270	70	9.7
19C10	8290	860	550	1190	310	620	1102	350	5260	60	9.7

TABLE VIII

GC DATA

ID	Acetaldehyde	Methanol	Ethyl Acetate	n-Propyl Alcohol	Isobutyl Alcohol	Isoamyl Alcohol #1	Isoamyl Alcohol #2	Total Fusel Oils @ 100 proof
1A9	2.272	0.001	1.621	2.795	19.444	13.437	25.224	324
1B9	2.816	0.000	1.630	2.930	20.084	13.877	25.249	326
1C9	2.622	0.000	1.569	2.785	19.618	13.432	24.520	320
1A10	2.285	0.001	2.224	2.958	20.941	12.179	30.796	344
1B10	0.518	0.001	2.258	2.969	21.238	12.368	31.077	354
1C10	0.737	0.000	2.624	3.485	25.758	15.028	38.303	433
2A9	0.955	0.001	1.883	3.360	17.489	13.449	26.707	319
2B9	1.574	0.001	1.960	3.450	17.547	13.535	27.082	322
2C9	1.364	0.001	1.837	3.391	16.829	13.003	26.187	312
2A10	2.445	0.001	2.143	3.380	22.034	14.453	26.674	346
2B10	1.577	0.001	1.969	3.273	21.793	14.316	26.150	336
2C10	2.113	0.001	2.034	3.364	21.878	14.379	26.263	339
3A9	1.060	0.000	1.409	1.353	9.261	7.490	30.193	259
3B9	1.389	0.000	1.543	1.464	9.680	7.778	31.163	270
3C9	1.371	0.000	1.472	1.417	9.549	7.748	31.028	267
3A10	3.061	0.000	1.514	2.089	9.838	7.274	27.930	249
3B10	2.696	0.000	1.563	2.115	9.841	7.315	28.374	251
3C10	2.499	0.001	1.560	2.111	9.989	7.378	28.569	255
4A9	1.595	0.000	1.591	2.936	18.819	14.530	27.083	336
4B9	1.812	0.001	1.796	3.129	19.795	15.333	28.426	353
4C9	2.217	0.000	1.649	3.051	19.079	14.785	27.524	339
4A10	1.853	0.000	1.970	3.303	22.088	14.583	26.225	339
4B10	3.885	0.000	2.000	3.402	22.398	14.798	26.727	347
5A9	1.538	0.001	2.863	3.449	21.679	14.612	31.135	338
5B9	1.033	0.000	2.353	3.071	19.509	13.094	28.103	309
5C9	0.694	0.000	2.457	3.128	19.632	13.192	28.238	310
5A10	1.392	0.001	2.641	3.303	19.310	13.148	28.980	310
5B10	2.100	0.000	2.790	3.357	19.564	13.292	29.918	317
5C10	1.496	0.001	2.955	3.406	19.764	13.448	30.435	320
6A9	0.878	0.000	1.482	1.492	11.720	7.305	28.132	279
6B9	1.356	0.001	1.611	1.635	12.315	7.872	29.505	294
6C9	0.958	0.000	1.481	1.514	11.866	7.581	28.495	285
6A10	0.352	0.000	1.511	1.391	10.297	6.339	24.107	247
6B10	2.682	0.001	2.139	2.043	14.542	9.016	33.832	347
6C10	0.665	0.000	1.692	1.584	11.571	7.142	26.461	270
6A11	1.632	0.004	1.949	2.023	14.630	9.497	34.007	337
6B11	1.300	0.000	1.637	1.691	12.253	7.918	28.362	282
6C11	0.535	0.000	1.585	1.652	12.092	7.830	28.141	277

TABLE VIII

GC DATA CONT.

ID	Acetaldehyde	Methanol	Ethyl Acetate	n-Propyl Alcohol	Isobutyl Alcohol	Isoamyl Alcohol #1	Isoamyl Alcohol #2	Total Fusel Oils @ 100 proof
7A9	0.000	0.000	1.870	3.011	16.904	14.321	30.229	342
7B9	0.361	0.000	1.818	2.939	16.658	14.175	29.881	337
7C9	0.000	0.000	1.795	2.915	16.631	14.089	30.264	338
7A10	0.000	0.000	1.430	2.051	12.967	10.062	31.162	316
7B10	0.000	0.000	1.889	2.727	17.276	13.404	41.499	425
7C10	0.000	0.000	1.226	2.007	13.368	10.286	32.122	326
7A11	0.000	0.000	2.041	3.436	21.758	19.056	33.543	423
7B11	0.000	0.000	1.668	2.809	17.590	15.319	27.057	342
7C11	0.000	0.000	1.607	2.773	17.809	15.536	27.232	343
8A9	0.000	0.000	1.746	2.688	15.957	14.940	28.775	354
8B9	1.027	0.000	1.712	2.620	15.419	14.393	27.730	343
8C9	0.971	0	1.718	2.7145	15.7545	14.6615	28.662	351
8A10	3.540	0.000	1.708	2.556	14.834	11.078	32.218	342
8B10	0.131	0.000	1.674	2.404	14.523	10.653	32.733	339
8C10	3.008	0	1.509	2.32	13.8655	10.2095	30.923	322
8A11	0.955	0.000	1.813	3.097	18.655	15.194	28.301	366
8B11	1.318	0.000	1.896	3.182	18.823	15.270	28.528	369
8C11	1.0705	0	1.8005	3.021	18.017	14.6035	27.32	352
9A9	0.414	0.000	1.557	2.141	11.452	11.029	27.660	334
9B9	0.595	0.000	1.720	2.461	12.691	12.318	30.927	329
9C9	0.257	0.000	1.588	2.288	12.596	12.057	30.579	322
9A10	1.521	0.000	1.577	1.665	12.142	8.993	31.208	302
9B10	1.286	0.000	1.576	1.698	12.222	9.077	31.450	307
9C10	1.206	0.000	1.590	1.674	12.069	8.843	30.799	299
9A11	0.680	0.000	1.631	2.116	12.952	10.452	32.123	328
9B11	0.435	0.000	1.680	2.118	12.824	10.417	31.815	303
9C11	0.332	0.000	1.702	2.107	12.565	10.097	30.905	290
10A9	0.318	0.000	1.577	2.546	15.616	14.357	25.277	316
10B9	0.990	0.000	1.575	2.578	15.710	14.429	25.330	320
10C9	0.456	0.000	1.685	2.578	15.469	14.281	25.382	318
10A10	0.504	0.000	1.750	2.740	16.592	14.265	25.469	325
10B10	0.571	0.000	1.791	2.760	16.692	14.354	25.651	327
10C10	0.516	0.000	1.784	2.732	16.443	14.137	25.276	324
10A11	1.122	0.000	1.578	2.641	17.276	14.612	25.844	331
10B11	0.642	0.000	1.565	2.536	16.706	14.112	25.012	323
10C11	0.000	0.000	1.640	2.593	17.177	14.520	25.648	327
11A9	1.850	0.000	1.628	2.641	14.828	13.208	27.473	317
11B9	1.839	0.000	1.536	2.427	13.661	12.175	25.497	296
11C9	2.172	0.000	1.596	2.558	14.191	12.611	26.178	303
11A10	2.017	0.001	2.165	3.388	16.970	13.314	26.870	300
11B10	2.094	0.001	2.192	3.445	17.340	13.580	27.362	307
11C10	1.831	0.001	2.221	3.435	17.388	13.626	27.361	306

TABLE VIII

GC DATA CONT.

ID	Acetaldehyde	Methanol	Ethyl Acetate	n-Propyl Alcohol	Isobutyl Alcohol	Isoamyl Alcohol #1	Isoamyl Alcohol #2	Total Fusel Oils @ 100 proof
12A9	1.998	0.000	1.843	3.302	19.447	76.340	28.702	667
12B9	1.966	0.000	1.614	2.895	16.903	12.355	24.925	296
12C9	1.414	0.000	1.613	3.093	18.389	13.471	27.225	323
12A10	1.710	0.000	1.987	3.518	19.781	13.802	27.721	332
12B10	0.929	0.000	1.936	3.517	20.037	13.941	27.869	334
12C10	1.665	0.000	1.919	3.370	19.018	13.234	26.353	316
13A9	0.000	0.000	1.173	0.921	8.771	5.374	18.514	205
13B9	0.000	0.000	1.364	0.975	9.347	5.607	18.811	208
13C9	0.000	0.000	1.357	0.963	8.893	5.368	18.022	199
13A10	0.000	0.000	1.387	1.062	10.620	6.279	21.141	229
13B10	0.000	0.000	1.320	1.227	10.906	6.711	23.515	254
13C10	0.000	0.000	1.641	1.158	11.044	6.494	21.495	233
13A11	0.706	0.003	1.871	2.350	14.388	12.464	33.175	351
13B11	0.000	0.000	1.663	2.165	13.663	11.673	31.588	333
13C11	0.667	0.000	1.913	2.397	14.579	12.626	32.869	350
14A9	0.000	0.000	1.182	2.773	16.444	12.527	23.763	308
14B9	0.000	0.000	1.228	2.836	16.959	12.975	24.507	308
14C9	0.000	0.000	1.291	2.764	16.941	12.950	24.531	307
14A10	0.000	0.000	1.321	2.852	17.860	12.832	24.518	307
14B10	0.000	0.000	1.416	2.968	18.056	13.013	24.921	309
14C10	0.000	0.000	1.377	2.887	18.128	13.026	24.873	310
15A9	0.000	0.000	1.549	2.615	19.741	12.589	23.456	322
15B9	0.000	0.000	1.536	2.607	19.586	12.461	23.334	319
15C9	1.626	0.000	1.594	2.645	19.855	12.653	23.512	320
15A10	1.667	0.000	1.620	2.030	12.043	8.342	27.019	271
15B10	0.000	0.000	1.582	1.847	11.571	7.792	27.146	267
15C10	0.000	0.000	1.499	2.160	12.426	8.544	26.079	268
16A9	0.000	0.000	1.664	2.491	13.981	12.574	29.849	332
16B9	0.000	0.000	1.776	2.663	14.104	12.766	28.592	328
16C9	0.000	0.000	1.706	2.546	14.057	12.641	30.530	336
16A10	0.222	0.000	1.818	2.922	16.789	14.200	27.722	337
16B10	0.895	0.000	1.808	3.056	17.050	14.435	27.965	340
16C10	0.523	0.001	2.130	3.263	17.785	15.026	29.253	357
16A11	1.160	0.000	1.273	1.636	10.348	8.831	30.988	298
16B11	0.986	0.000	1.274	1.542	10.385	8.722	30.972	295
16C11	0.278	0.000	1.069	1.428	9.978	8.387	29.862	284
17A9	0.913	0.001	1.940	2.972	16.717	13.984	26.633	322
17B9	1.392	0.001	2.035	2.899	16.072	13.464	25.753	312
17C9	1.032	0.001	2.013	2.951	16.587	13.932	26.504	313
17A10	0.542	0.001	2.066	3.027	16.196	13.833	26.518	316
17B10	0.894	0.001	2.143	3.145	16.388	13.955	26.850	320
17C10	1.052	0.001	2.216	3.185	16.601	14.076	27.239	325

TABLE VIII

GC DATA CONT.

ID	Acetaldehyde	Methanol	Ethyl Acetate	n-Propyl Alcohol	Isobutyl Alcohol	Isoamyl Alcohol #1	Isoamyl Alcohol #2	Total Fusel Oils @ 100 proof
18A9	1.210	0.001	1.718	2.180	13.452	11.147	32.746	327
18B9	0.840	0.001	1.835	2.217	13.483	11.352	32.744	331
18C9	1.098	0.001	1.742	2.228	13.517	10.857	32.613	328
18A10	1.630	0.000	1.905	2.543	13.537	10.662	31.436	322
18B10	1.436	0.001	1.974	2.385	13.951	11.098	32.680	332
18C10	1.601	0.001	1.990	2.363	13.807	10.922	31.981	327
18A11	1.483	0.001	1.666	1.956	13.056	10.606	32.193	326
18B11	0.843	0.000	1.616	1.825	12.360	10.024	31.087	311
18C11	1.065	0.000	1.540	1.700	11.955	9.555	30.196	301
19A9	2.247	0.004	1.948	3.244	20.752	15.747	29.688	367
19B9	1.278	0.001	1.790	2.971	19.771	15.056	28.126	344
19C9	2.182	0.001	1.848	3.077	19.887	15.100	28.206	346
19A10	2.127	0.001	1.996	3.186	19.633	14.472	26.954	330
19B10	1.803	0.001	1.959	3.203	19.793	14.568	27.153	329
19C10	1.786	0.001	2.007	3.220	20.109	14.805	27.675	341
20A9	1.496	0.001	1.820	2.017	11.775	9.986	32.679	316
20B9	1.375	0.000	1.622	1.825	10.616	8.970	29.419	285
20C9	0.473	0.000	1.689	1.780	10.823	8.955	29.522	286
20A10	0.720	0.000	1.889	2.513	13.124	10.726	30.574	316
20B10	0.661	0.000	1.890	2.520	14.058	11.188	31.422	328
20C10	1.169	0.001	2.120	2.777	14.265	11.786	32.236	337
20A11	1.302	0.000	1.734	1.921	11.842	9.494	30.543	301
20B11	0.909	0.000	1.620	2.017	12.434	9.961	31.547	316
20C11	0.727	0.001	0.888	1.626	9.968	8.010	25.703	257
21A9	0.000	0.000	1.577	1.919	12.556	9.527	32.960	310
21B9	0.580	0.000	1.696	1.970	12.666	9.759	32.828	310
21C9	0.000	0.000	1.713	2.057	13.030	10.082	33.493	319
21A10	0.000	0.000	1.847	2.576	17.415	13.863	27.464	330
21B10	0.000	0.000	1.740	2.503	16.863	13.439	26.549	319
21C10	0.551	0.000	1.794	2.532	17.315	13.803	26.942	329
21A11	0.660	0.001	1.698	2.088	13.449	10.904	33.105	331
21B11	0.782	0.000	1.614	1.977	13.048	10.619	32.644	325
21C11	0.475	0.001	1.615	1.949	12.875	10.379	32.096	334
22A9	0.000	0.001	1.913	2.819	17.486	13.822	27.861	330
22B9	0.304	0.000	2.012	2.769	17.343	13.751	27.406	326
22C9	0.000	0.001	1.832	2.659	16.876	13.252	26.354	313
22A10	0.855	0.000	2.057	2.732	17.152	12.698	25.800	318
22B10	0.912	0.000	2.529	3.404	22.052	16.245	33.107	408
22C10	0.834	0.000	2.094	2.718	17.482	12.913	26.205	323
22A11	0.427	0.000	1.804	2.504	15.926	12.605	25.546	304
22B11	0.000	0.000	1.959	2.600	16.517	13.108	26.599	318
22C11	0.000	0.000	1.787	2.484	15.931	12.578	25.357	302

APPENDIX D

CONVERSION DATA

TABLE IX

CONVERSION OF STARCH IN CLEAN FERMENTATIONS

Corn Type	Strain	Potential CO_2 Loss (g/ 100 g corn)	Actual CO_2 Loss (g/ 100 g corn)	Conversion of Starch to Sugar
HTF	All	38.58	36.12	93.7%
	35D28	38.40	36.19	94.2%
	35Y33	38.10	36.48	95.8%
	32K22	38.50	37.57	97.6%
	34P88	38.40	36.70	95.6%
	33A84	38.70	36.55	94.4%
	34H31	38.50	36.23	94.1%
	31G66	38.70	34.30	88.6%
	33N54	38.90	34.31	88.2%
	34A15	38.90	36.16	92.9%
Control	All	38.55	35.78	92.8%
	33N09	38.40	36.21	94.3%
	33M54	38.20	33.04	86.5%
	34D71	38.60	35.96	93.2%

TABLE X

CONVERSION OF SUGAR IN CLEAN FERMENTATIONS

Corn Type	Strain	Set Balling (%)	Drop Balling (%)	Conversion of Sugar to EtOH
HTF	All	18.6	0.9	95.4%
	35D28	19.5	1.0	95.1%
	35Y33	18.6	0.9	95.2%
	32K22	17.7	0.3	98.3%
	34P88	18.5	1.6	91.5%
	33A84	18.6	1.5	92.2%
	34H31	18.3	0.5	97.5%
	31G66	17.1	0.3	98.2%
	33N54	19.1	0.9	95.5%
	34A15	19.4	0.6	96.9%
Control	All	18.6	0.9	95.4%
	33N09	19.1	0.9	95.3%
	33M54	16.8	0.7	95.8%
	34D71	18.7	0.9	95.3%

APPENDIX E

STATISTICAL ANALYSIS

TABLE XI

STATISTICAL ANALYSIS OF ALL FERMENTATIONS

		Average ABV (%)	Std Dev	Variance	99% Confidence Level
Overall	All	9.244	0.3900	0.1521	0.0680
	Control	9.116	0.3140	0.0986	0.0644
	HTF	9.579	0.3727	0.1389	0.1239
Clean	Control	9.339	0.2019	0.0408	0.0812
	HTF	9.687	0.3692	0.1363	0.1434
Contaminated	Control	9.038	0.3095	0.0939	0.0737
	HTF	9.284	0.1708	0.0292	0.1100

VITA

Kara Zoeller was raised in Elizabethtown, KY and graduated from the University of Louisville with a B.S. in Chemical Engineering in May 2008. She performed all three of her semesters of co-op at Brown-Forman in Louisville, KY. She will receive her Master's degree in Chemical Engineering in May 2009 from the University of Louisville.