

EFFECTS OF ENVIRONMENT AND GENOTYPE ON HARDNESS AND  
ALKALINE COOKING PROPERTIES OF MAIZE

A Thesis

by

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ALKALINE COOKING PROPERTIES OF MAIZE

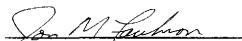
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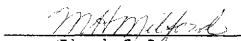
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## ABSTRACT

Effects of Environment and Genotype on Hardness and  
Alkaline Cooking Properties of Maize (December 1983)

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Grain of fifty nine white dent maize samples, comprising twelve hybrids grown in six environments, was evaluated for density, test weight, one thousand kernel weight, hardness, protein content, moisture uptake and dry matter losses during cooking and nixtamal shear force (NSF) or the amount of force required to extrude a given weight of nixtamal through a shear cell and die. Both genetics and environment significantly affected most properties. Also, large hybrid by environment interactions occurred. Environment had a larger effect than genotype on many properties. Maize properties varied as much between years for a given location as they did among locations. Several environmental factors probably interacted to affect grain properties as few relationships were found between any single climatological or agronomic condition and maize properties.

Visual examination revealed large differences in kernel size and shape among both hybrids and environments. A brownish pigmentation was present at the base of the kernels of brown-banded hybrids (CI66 x Tx81, CI66 x Tx71, Tx71 x Ga209, Tx81 x Tx585, Tx71 x Tx585). The amount of this pigmentation varied over locations. The pigmented

areas appeared to impart a greenish color to a small number of alkali-cooked kernels of the affected samples.

The ability of three maize hardness methods to distinguish among samples varied. The percent "floaters" and a grinding method more effectively differentiated among samples than a centrifugal impact (CI) method which has been proposed as a method to predict breakage susceptibility of maize during transit. Grain density had a large effect on the flotation and grinding hardness methods. However, density only slightly affected the centrifugal impactor. Percent protein slightly affected all but the flotation test. Sometimes, large differences in CI hardness were observed between samples which also displayed large dissimilarities in grinding and flotation hardness.

Apparent differences occurred among some samples for ease of pericarp removal during traditional alkali cooking. A simple alkali test was used to determine if differences in pericarp removal could be detected using small samples. Results of this test indicated it may be potentially useful as a rapid method to screen for dissimilarities in pericarp removal of maize during alkali cooking.

## DEDICATION

This thesis is dedicated to my parents whose many sacrifices in my behalf and whose encouragement made it a reality.

## ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my Committee Co-Chairmen, Dr. L. W. Rooney and Dr. J. M. Faubion, for their assistance and encouragement that helped make this thesis possible.

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## INTRODUCTION

Maize is grown extensively in the United States and Latin America (Belavady 1975). For hundreds of years, maize has been the principal food for many people in Mexico and Central America where tortillas are the predominant form of consumption (Bressani et al 1958, Katz et al 1974). Tortillas are also popular in certain areas of the United States (Martinez-Herrera and Lachance 1979).

The traditional method of tortilla preparation involves cooking maize in a lime water solution. Many factors may affect the alkaline cooking properties of maize to be used for tortillas. These factors can alter the cooking time required to produce an optimal end product. Thus, they are of concern to tortilla producers. Nevertheless, only a few studies have focused on maize cooking characteristics. Martinez-Herrera and Lachance (1979) used four maize types with widely different endosperm characteristics in an effort to relate raw kernel hardness to maize cooking properties. Cooking time was found to increase as grain hardness increased. However, the variation within any given sample was large. Therefore, it was not likely that this method could differentiate between maize samples having similar endosperm properties. Likewise, hard sorghum varieties have been shown to require longer cooking times than intermediate or soft sorghums (Khan et al 1980). Bedolla (1980) reported significant genetic effects on mechanically measured nixtamal (cooked and steeped maize) "texture" of white maize hybrids with similar endosperm type.

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Citations follow the style of Cereal Chemistry.

In addition, most of the hybrids fell within a narrow range of "texture" when cooked to optimum. This method has potential to objectively determine the proper cooking time of maize for tortillas.

Particular varieties of maize grown in different locations can have different cooking times,<sup>1</sup> but little if any research has been conducted on the effect of environment on maize cooking characteristics. This study was done to assess both environmental and genetic effects on the physical, chemical and alkaline cooking properties of maize. In the process, data was supplied to either support or challenge previous work which described a potential objective method to predict the optimum cooking time for maize (Bedolla 1980).

The extent to which the maize pericarp is removed during alkali cooking likely affects the final product quality.<sup>2</sup> Therefore, finding and characterizing maize with relatively greater ease of pericarp removal during the lime cooking process is desirable. Thus, an additional goal of this study was to evaluate differences in the amount of pericarp separation of the various maize samples during alkali cooking and to look for gross differences which might help to explain any dissimilarities in ease of pericarp removal among the samples. Knowledge pertaining to the factors affecting maize cooking quality will be of interest not only to processors, but also to

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<sup>1</sup>R. Velasco Jr., Amigos Food Company, Inc., San Antonio, Texas. 1981. Personal communication.

<sup>2</sup>Dr. E. B. Ellis, Frito-Lay Inc., Irving, Texas. 1982. Personal communication.

breeders who attempt to improve the quality of grain to be processed.

## REVIEW OF LITERATURE

### Origin of Maize

Maize (Zea mays) probably originated in Mexico (Mangelsdorf 1974). After its discovery in the New World, it rapidly spread to other areas of the world suitable for its growth. The ancestor of modern maize is thought to be wild maize. This belief stems from the discovery, in Mexico, of fossil maize pollen that has been estimated to be 80,000 years old (Mangelsdorf 1974). This is before agriculture, and perhaps even humans, existed in the area. Since modern maize is an obligate cultivar, this pollen would have to represent a wild form.

### Maize Kernel Morphology and Features

The maize kernel consists of pericarp, tipcap, testa, hilar layer, endosperm and the germ. The pericarp and testa are fused together, a condition that defines maize as a caryopsis (Wolf et al 1952a, Inglett 1970). The pericarp, testa and aleurone cover all but the basal portions of the kernel. This region is covered by extensions of the aforementioned tissues. The tip cap is continuous with the pericarp, the hilar layer with the testa and a distinctly different portion of parenchymal cells with the aleurone layer (Wolf et al 1952b, Wolf et al 1952c). The endosperm makes up 80 to 84% of the weight of the maize kernel. It is composed of an aleurone layer one cell thick which encloses an inner, storage endosperm. Three areas of the storage endosperm can be identified. These are the

subaleurone, horny or vitreous endosperm and floury endosperm. The subaleurone lies immediately beneath the aleurone layer. The horny endosperm is a hard translucent area consisting of starch granules tightly packed or embedded in a thick protein matrix. The floury endosperm is opaque and fragile. It is characterized by thick cell walls and loosely packed starch granules embedded in a thin, discontinuous protein matrix (Inglett 1970, Wolf et al 1952c). In addition to the matrix protein, spherical protein bodies are present in the endosperm. The protein bodies are largest and most numerous in the subaleurone layer and progressively decrease in size and number from the outer to the inner endosperm (Inglett 1970). The relative proportion of floury and horny endosperm is dependent on the environment and variety of maize. The amount of floury endosperm is greater in soft dent maize than harder dents (Bennet 1950). In general, United States yellow dent maize has twice as much horny as floury endosperm.

The germ makes up 10 to 14% of the kernel and comprises the scutellum and embryonic axis. It is located in the endosperm. The aleurone layer is the only portion of the endosperm to contact the germ (Wolf et al 1952c).

The kernels present on a single cob vary greatly in both size and shape. Large varietal differences are also seen in these characteristics. Kernel color varies, and the pattern may be solid or variegated. Pigments can be present in the pericarp, aleurone layer, endosperm and/or scutellum (Wolf et al 1952a).

### Types and Uses of Maize

The basic types of maize are dent, flint, pod, pop, soft or floury, sweet (sugary genes) and waxy. Dent and flint are the most common types which enter the commercial trade channels (Kent 1978). The principal products of maize dry-milling are grits, meal and flour. These products are incorporated into food products such as breakfast cereals, snack foods, malt beverages and bakery products. Starch is obtained through the wet-milling process. Syrups and dextrose are produced from starch. Also, maize is used for feed. As feed, it has a number of advantages such as a relatively high digestibility, excellent palatability and it is a source of energy. Maize is also the highest yielding cereal grain. Maize products are also utilized in non-food industries for a variety of uses (Senti and Schaefer 1972).

### Composition and Nutritional Value

The kernel contains approximately 12.0% water, 74.5% carbohydrates, 6.8-12.0% protein, 4.5% oil and 1.0% ash and crude fiber (Katz et al 1974). The protein quality of maize is poor, being deficient in lysine and tryptophan. Its isoleucine to leucine ratio is also unfavorably low. Two-thirds of the lysine is present in the glutelin protein fraction, which is relatively indigestible by humans (Katz et al 1974). The poorest quality protein fraction, zein, becomes proportionally greater as the total nitrogen in the grain (therefore protein) increases. This leads to a poorer amino acid balance (Belavady 1975, Mitchell et al 1952). Maize is also deficient in



niacin. Vitamin content is low generally, but is affected by both genetic and environmental factors (Aguirre et al 1953, Hunt et al 1950).

#### Kernel Hardness

Grain hardness is an important factor in a number of maize processing schemes including milling and cooking. Despite its importance, hardness is difficult to measure accurately. Because of this, many techniques to measure hardness exist. An early method used to evaluate wheat hardness involved pearling a given amount of grain with a barley pearler for a definite period of time (Taylor et al 1939). Less material was removed from harder grain. A standard load used to cause the penetration of a diamond-shaped stylus into a section of grain has also been used to measure wheat hardness (Grosh and Milner 1959). A microscope was used to evaluate the size of the indentation made by the stylus. Larger indentations indicated softer grain. Katz et al (1959) used a similar method to measure grain hardness. An instrument that was originally used to test soft metals was modified and used to make the grain hardness measurements. The method involved the penetration of a spring-loaded stylus into a kernel section. The distance the stylus was displaced into a case containing it was used as an indicator of hardness. Several independent measurements of each kernel section were possible. However, the exact number varied with the size of the stylus used. This method could detect very slight varietal and environmental differences in grain hardness (Katz et al 1961). Cutler and Brinson (1935) found that

wheat could be classified on the basis of a granulation index after a standardized grinding and sifting step. Finer granulation was associated with softer wheats. The Brabender hardness tester has been used to determine the hardness of barley (Anderson et al 1966). The instrument is comprised of a burr mill connected to a farinograph dynamometer. Hardness is determined by measuring the amount of energy needed to grind a given amount of grain. Greenaway (1969) used the Brabender hardness tester to develop a wheat hardness index. The maximum curve height from the Brabender hardness tester divided by the percent flour yield of a sample was defined as the wheat hardness index. Anderson et al (1966) found that wheats could be rated by kernel hardness or friability by determining the flour yield or flour fraction surface area after a standardized grinding process. A Brabender hardness tester and a pin mill were used to grind wheat samples. The yield of flour obtained was a useful indicator of hardness, but the surface area of the flour fraction was an even more sensitive indicator of hardness. The flour fraction surface area per unit of work expended during grinding with the Brabender hardness tester was the most useful indicator of wheat hardness. These three methods, unlike many others, could effectively distinguish between the harder wheat classes.

Bedolla (1980) used a method in which maize kernels were fed at a uniform rate into the blades of a fan rotating at a set speed. The "overs" of a 0.64 cm screen were divided by the original sample weight and used as a hardness indicator. A narrow range of values were obtained, indicating that the method did not clearly distinguish one

sample from another. Martinez-Herrera and LaChance (1979) used uniaxial compression force provided by an Instron Universal Testing Instrument to determine maize kernel hardness. This method could differentiate between maize varieties. However, large variations within a variety also were noted. The dynamic hardness (resistance to indentation) of maize kernels struck with a steel ball using an impacting pendulum was determined by Jindal and Mohsenin (1978) by using 3 methods of analysis. The horny endosperm was the major contributor of hardness under the test conditions used. Each method of analysis produced different values of dynamic hardness. However, each method detected a decrease in hardness when moisture content of the maize increased. Likewise, Shelef and Mohsenin (1969) observed a decrease in hardness of yellow dent maize with increasing moisture content. Uniaxial compression force from a Instron Universal Testing Instrument was the method used to determine maize hardness. Tran et al (1981) observed satisfactory differentiation in maize hardness as a function of grain moisture content using several different tests. The grinding index and grinding energy exhibited the best differentiating abilities. For these tests, maize was ground with a modified disc grinding mill equipped with electromechanical sensors so that torque during grinding could be recorded. Grinding index was determined by sifting the ground samples with a 1.70 mm aperture sieve. The weight of "overs", expressed as a percentage of initial sample weight, was defined as the grinding index. Grinding energy was determined from the area under the curve obtained from converting torque to power. The value obtained from the ratio of grinding index to grinding energy

improved the differentiating ability over each test alone.

### Tortilla Production

The manufacture of tortillas varies by location. In Mexico, the usual method is to combine one part of maize and two parts of a 1% lime solution. The combination is heated at 80°C for 20 to 45 min and allowed to steep overnight at ambient temperature. The cooked, steeped maize, called nixtamal, is washed and stone ground into masa. In larger towns, the nixtamal may be ground on a power-driven mill. The masa is shaped into tortillas and cooked on a hot griddle 30 sec, turned and cooked for 75 to 100 sec and finally turned again and cooked for 30 more sec (Cravioto et al 1945). In Mexican cities, maize is cooked, ground, moulded and baked using automated equipment.

In Guatemala, one part of maize is added to 1.2 parts of a 0.38 to 0.47% lime solution. The mixture is heated at 94°C for 45 to 61 min. The cooked maize is steeped overnight and the nixtamal is washed and ground. Tortillas are cooked 3 min on each side at 170-212°C. The basic procedure varies from family to family (Bressani et al 1958).

### Prediction of Optimum Cooking Time

Currently, the optimization process for tortilla production is subjective. Cooked maize kernels are crushed between the fingers to evaluate if the maize has been properly cooked (Des Rosiers 1979). This method is useful when trained and experienced technicians are involved. Nevertheless, due to the subjective nature of the

evaluation, over or under cooking of the maize may occur. This will result in a poorer quality product. An objective method to determine the proper cooking time of maize should make the maize cooking process more efficient.

One study showed that commercial dent maize hybrids could be divided into floury, intermediate and corneous subclasses by the force required to extrude nixtamal, cooked 70 min, through a die located at the end of a shear cell (Bedolla 1980). The force was measured with an Instron Universal Testing Instrument. One hybrid from each of these subclasses was cooked for 60, 80, 100, 120 and 140 min. A negative linear relationship was present between nixtamal shear force (NSF) and cooking time. The NSF of the nixtamal from the corneous hybrid was greater than that from intermediate and floury hybrids at all cooking times. These differences decreased as cooking time increased. The negative correlation between NSF and cooking time was used to predict the amount of cooking needed to obtain nixtamal that fell within an NSF range of 224 to 275 pounds. Nixtamal with NSF within this range, when ground, produced an optimum tortilla. Tortillas were evaluated subjectively by their rollability, texture, flexibility and color. This method appears promising. However, its performance has not been established.

#### Physical and Chemical Losses During Tortilla Preparation

During the tortilla making process, maize constituents are lost via two pathways (Bressani et al 1958). A physical loss occurs as a result of complete or partial removal of kernel fractions. The

destruction of various nutrients represents a chemical loss. Large amounts of fat, crude fiber, nitrogen, iron, thiamine, niacin and riboflavin are lost during the preparation of tortillas. Substantial losses of amino acids also occur (Bressani et al 1958, Massieu et al 1949). Most of these losses occur during the lime heat-treatment process. The loss of nutrients is mainly affected by the type of maize used rather than by slight variations in procedures. Not all nutrients are lost. The amount of available phosphorous increases, and the lime cooking drastically increases calcium content (Bressani et al 1958, Cravioto et al 1945).

#### Nutritional Modifications of Alkali Cooking

Despite the large losses of certain nutrients from maize during its alkali cooking, its overall nutritional value is enhanced. This may result, in part from an improved amino acid balance (Braham et al 1966). However, De Groot and Slump (1969) have shown that some alkali-treated food proteins have a decreased nutritional value for rats. Proteins exposed to alkali can undergo alterations which include the formation of new amino acids such as lysinoalanine (Friedman et al 1981). Nutritional value may be decreased by the destruction of limiting amino acids and by the decreased enzymatic digestion of proteins containing new residues (Friedman et al 1981). Although some alkali-treated food proteins have a decreased nutritional value, no evidence has been found for reduced nutritional value of proteins from alkali-treated maize or tortillas.

Pellagra, a disease caused by niacin deficiency, has been long recognized to be associated with diets prominent in maize consumption (Hankes et al 1971). This pellagragenic property of maize has been attributed to the relative inaccessibility of niacin in maize (Kodicek 1956). Nearly all the niacin in cereals, including maize, is in the form of a bound precursor, niacytin, that has no biological activity for animals and bacteria (Kodicek 1956, Kodicek 1960, McDaniel and Hundley 1958). In alkaline solution, niacin is released by hydrolysis and thereby made available. Pellagragic mammals fed alkali-treated maize or maize fractions are cured, whereas no change occurs with similar grain that is not first cooked in alkali.

#### Safety of Alkali-Treated Proteins

The safety of alkali-treated proteins has been questioned due to the finding that they can cause a toxic response, nephrocytomegaly, in rats. The condition is characterized by the enlargement of the epithelial cells located in a particular region of the rat kidney (De Groot et al 1976, Woodard and Short 1973). Lysinoalanine (LAL) has been implicated as the active agent. Small amounts of LAL have been reported in alkali-processed maize products including tortilla (Sternberg et al 1975). It was reported that very low amounts of LAL were formed in maize when lime or calcium hydroxide was used as the alkali source rather than sodium or potassium hydroxide (Chu et al 1976). Temperature, pH and, to a lesser extent, time also affect LAL production (Friedman et al 1981, Struthers 1981).

The tendency of different species to develop the condition varies (De Groot et al 1976). The rat seems to be more prone to developing the defect than are other species. The rat kidney retains LAL and its catabolites to a much higher degree than do the kidneys of other species, with retention localized in the affected region (Pinot et al 1977). It is unknown if LAL can induce nephrocytomegaly in humans and, if so, what implications to health it would represent.

#### Pericarp Removal

The eating quality of products made from cereal grains is generally enhanced by removing the pericarp from the seed (Scheuring and Rooney 1979). The relative ease with which the pericarp is separated from some cereals varies. The thickness of the sorghum pericarp has an effect on its ease of removal by either manual or mechanical means (Earp and Rooney 1982). Thick pericarps, which have a thick, starchy mesocarp, are easier to remove than are their thin counterparts with only a vestigial mesocarp. During milling, large flakes break off from the thick pericarp varieties, for the fracturing occurs in the mesocarp region. This is reflected by the much shorter milling times required to decorticate sorghums with thick pericarps. Published material pertaining to the factors affecting the ease of pericarp removal of sorghum or maize during alkali cooking is not available.



## Grain Storage

The purpose of grain storage is to preserve, as nearly as possible, the grain quality present immediately following harvesting and drying (Brooker et al 1974). The practical storage life of any seed depends on the kind of seed, its prestorage history and the conditions of storage (Thomson 1979). Chemical changes occur in all stored grains regardless of storage conditions (Zeleny 1954). Most of these changes result in deterioration of grain quality which ultimately leads to loss of germ viability. Advanced stages of deterioration are visibly evident during germination and seedling growth (Copeland 1976). Loss of enzyme activity, decreased respiration, increases in leachates and increase in free fatty acid content of the seed precede this loss of vigor and germination. The two most important extrinsic factors influencing the deterioration of stored grain are relative humidity and temperature (Douglas 1975). Deterioration increases as temperature and relative humidity increase. However, grain stored at a moisture content below 5% also shows an increased rate of deterioration. Additional factors affecting the storability of grain are the oxygen and carbon dioxide content of the atmosphere enveloping the seed, sunlight, seed treatments, grain soundness, and attack by rodents, insects, mites and molds. Decreased germ viability diminishes the value of grain for most commercial purposes (Brooker et al 1974). It is more difficult to separate starch during the wet-milling of improperly stored maize than sound maize (Zeleny 1954). Both the palatability and nutritional value for rats of ground maize decreases as storage time increases. Another

factor to consider is the possible formation of toxic materials that result from the uncontrolled growth of microorganisms in improperly stored grain (Fan et al 1976).

## MATERIALS AND METHODS

### Grain Samples

Twelve white dent maize hybrids, each grown at various locations in Texas for different years, were obtained from the maize hybrid yield performance trials conducted annually by the Texas Agricultural Experiment Station.<sup>3</sup> A list of the hybrids, locations and years during which they were grown is presented in Table I. All analyses were conducted on maize samples after thorough cleaning to remove all broken kernels, trash and abnormal kernels. During cleaning, kernels with yellow endosperm (outcrosses) were removed. The seed was not selfed seed so some kernels were from a yellow male parent. All samples were field-dried. Moisture content of the grain ranged from 10.8 to 12.3 percent. The samples were stored in a freezer until the time they were analyzed.

### Physical Properties

Test weight (kg/hl) was measured with a Winchester Bushel Meter. One thousand kernel weight was determined by weighing 1000 randomly selected kernels from each sample. A model 930 Air Comparison Pycnometer (Beckman Instruments Inc., Fullerton, CA) was used for measuring grain density (g/cm<sup>3</sup>). Grain hardness was assessed using a flotation method (Quaker Oats Company 1953), a centrifugal impact method (Singh 1980) and a grinding method.<sup>4</sup> For the flotation method,

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<sup>3</sup>Texas Agricultural Experiment Station, Texas A&M University, College Station. 1982. Personal communication.

TABLE I  
Identification of 12 White Maize Hybrids and Locations and  
Years for Which They Were Grown

Hybrid	College Station 1980	College Station 1981	Farwell 1980	Corpus Christi 1979	Corpus Christi 1980	Corpus Christi 1981
TX81 x Tx585	X	X	X	X	X	NA
Tx71 x Tx585	X	X	X	X	X	X
CI66 x Tx71	X	X	X	X	X	X
Tx71 x Tx80	X	X	X	NA	X	NA
Tx29A x Tx80	X	X	X	NA	X	X
Tx71 x Ga209	X	X	X	NA	X	NA
TX61M x Tx80	X	X	X	NA	X	X
CI66 x Tx81	X	X	X	X	NA	X
Mo14w x Tx71	X	X	X	X	NA	X
Tx29A x Tx71	X	X	X	X	X	NA
CI66 x Tx80	X	X	NA	NA	X	X
Tx61M x Tx71	X	NA	X	X	X	X

NA = not available.

100 randomly chosen kernels were put into a 1.275 specific gravity solution consisting of deodorized kerosene and tetrachloroethylene. Hardness decreases as the percentage of kernels that float increases. The centrifugal impactor was comprised of an impeller situated within an impact cylinder made of heavy steel pipe. The impeller was comprised of a thick aluminum disc with four equally spaced slots radiating out from a circular opening in the center. The maize samples were sieved over a 4.76 mm round hole sieve and 100 g of "overs" were used for the test. Maize kernels were poured into a hopper and fed at a controlled rate into the impeller which rotated at 2200 rpm. They were propelled out of the slots against the wall of the impact cylinder. The percent of the original sample weight passing through a 4.76 mm round hole sieve was taken as the percent breakage. Two replicates were done for each of the hardness methods.

#### Protein Content

Crude protein content (Nx6.25) was determined using the Technicon Autoanalyzer II Industrial Method No. 334-74 A/A.

#### Moisture Content

Moisture content of the maize samples was determined as described in AACC method 44-19 (1976).

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<sup>4</sup>The grinding method is the property of a commercial milling company. Published material pertaining to it is not available.

### Cooking Of Maize

The maize hybrids were cooked using a crude fiber reflux-condensing system to prevent evaporative losses. For each sample, 100 g of maize was added to a 600 ml pyrex beaker containing 300 ml of tap water and 1.0 g of CaO. Cooking continued for 70 min after the boiling point was reached. Aluminum foil was used to seal the beakers, and the maize was soaked at room temperature for 15 hrs to produce nixtamal. Nixtamal was washed by rubbing it between the hands for 30 sec in 500 ml of tap water. This was done twice, each time with fresh water.

### Determination of Cooking Properties

Nixtamal shear force (NSF) was determined using an Instron Universal Testing Instrument model 1122 equipped with a shear cell comprised of a tube that terminated with a die preceded by an entrance cone (Bedolla and Rooney 1982). First, 30 g of nixtamal were placed inside the cell and loosely packed by manual pressure with a plunger. The cell was placed on the crosshead of the testing machine which moved upward at a rate of 50 mm/min. The plunger used to force the nixtamal through the shear cell was attached to a stationary 1000 lb load cell. The chart, to record the force from the load cell, was run at 100 mm/min. The average force was determined by visual examination of the shear force recording. Two cooking trials for each maize sample were done within three months of each other. As the samples were stored in the freezer, it was assumed that minimal change occurred during the storage period. Nixtamal shear force was done in

triplicate after each cooking trial, making a total of six replicates for each sample.

Maize cooking properties were subjectively evaluated by crushing four kernels, one at a time, between two glass plates with manual pressure applied for 5 sec. A value was assigned to each sample reflecting the average extent of crushing the four kernels. A rating scale from one to five was used with one describing very little crushing and five depicting kernels that were completely crushed. In addition, the samples were rated by the average degree the interiors of the four kernels appeared to be cooked. Again, a scale from one to five was used. A score of one was given to samples that appeared only slightly cooked, and a rating of five was given to samples that appeared thoroughly cooked. One replicate was done for these tests.

#### Moisture Content of Nixtamal and Dry Matter Losses

A stainless steel steam cooker, holding 5 L of water and 11 g of CaO, was used to cook 5 g samples contained in aluminum tea balls. Cooking lasted 90 min after the lime water began to boil. The unsteeped nixtamal was wiped with paper towels to remove excess water and weighed. Nixtamal was dried in two stages. Samples were first placed in a large baking oven at 38°C for 15 hrs, followed by 24 hrs at 130°C in a forced-draft air oven. Moisture uptake was calculated by the weight loss divided by the final dry weight times 100. Dry matter losses were expressed as the percentage of the original dry weight lost during cooking.

## Statistical Interpretation of Results

Some observations were missing, so analysis of variance using a general linear models (GLM) procedure was used to determine the effect of environment, hybrids and environment by hybrid interactions on all properties tested. All possible correlations were determined (Steel and Torrie 1980).

### Evaluation of Pericarp Removal

The maize samples were evaluated subjectively for the amount of pericarp removal after the cooking and steeping periods. Five kernels of each sample were visually examined to determine the amount of pericarp adhering to the kernel, followed by removal of any pericarp still adhering to determine the amount present and the difficulty with which it was removed. The samples were rated on a scale of one to five which reflected the amount and difficulty of pericarp removal. Samples which showed little pericarp removal were rated one. Kernels which appeared to have the highest relative ease of pericarp removal rated five. One replication was done for this evaluation. A few samples which appeared to have large differences in ease of pericarp removal had their pericarps stained using a May-Grunwald dye (Scheuring and Rooney 1979) to enable one to observe with greater ease the pericarp layer of maize and, therefore, facilitate recognition of when the pericarp was beginning to peel away from the seed. Then, the selected samples were put in a 1.0 N NaOH solution for 5 hrs. The samples were observed hourly to evaluate the degree of pericarp removal. Two replicates were done for this method.



## RESULTS AND DISCUSSION

### Visual Characteristics of Maize Samples

The maize hybrids used for this study represent a relatively narrow genetic range. However, they include the genetic diversity of United States white dent maize used for food. The conditions prevalent over the various environments in which the hybrids were grown were sometimes quite different (Tables II, III and IV). These widely different environmental conditions provided an excellent opportunity to study the relative effects of environment, genetics and environment by genetic interactions on a number of maize quality parameters. Visual characteristics varied widely among the various samples. Despite the similarity of the hybrids, genetics appeared to affect these traits, as did the environment. For instance, some hybrids (CI66 x Tx81, CI66 x Tx71, Tx71 x Ga209, Tx81 x Tx585, Tx71 x Tx585) tended to develop a brownish discoloration (brown banding) at the base of their kernels. The trait was pronounced in some environments (Corpus Christi 1979, Corpus Christi 1981, College Station 1981). In others, it was only slightly evident or was absent. In addition, the degree of brown banding varied among the hybrids involved. Hybrid by environment interactions also affected this characteristic. For example, two of the most affected hybrids (CI66 x Tx71, CI66 x Tx81) differed greatly in the amount of brown banding which developed during 1981 in College Station. CI66 x Tx81 was extensively pigmented while CI66 x Tx71 showed very little brown banding. The discoloration was present exclusively in the pericarp

TABLE II  
Agronomic Conditions and Precipitation Totals for Six Growing  
Environments of 12 White Maize Hybrids

Location		Soil Type	Fertilizer	Row Width (cm)	Irrigation <sup>a</sup> (cm)	Precipitation (cm)	
						Pre- Silk	Post- Silk
College Station	1980	Ship's Clay	73-73-37 <sup>b</sup> 100-0-0	101.6	15.2	31.3	2.7
College Station	1981	Ship's Clay	48-96-48 <sup>b</sup> 100-0-0	101.6	None	29.7	20.9
Farwell	1980	NA	NA	101.6	NA <sup>c</sup>	NA	NA
Corpus Christi	1979	Victoria Clay	40-20-0	96.5	None	23.3	13.6
Corpus Christi	1980	Victoria Clay	40-20-0	96.5	None	8.1	0.0
Corpus Christi	1981	Victoria Clay	40-20-0	96.5	None	30.5	20.3

<sup>a</sup>During post-silk period.

<sup>b</sup>Pre-plant application.

<sup>c</sup>Test was irrigated but number of irrigations and amount of moisture applied is unknown.

NA = not available.

Source of information is Texas Agricultural Experiment Station and National Weather Service.

TABLE III  
Average Atmospheric Temperatures for Six Locations During Pre-Silk  
and Post-Silk Periods of 12 White Maize Hybrids

Location		Temperature <sup>a</sup> (°C)			Temperature <sup>b</sup> (°C)		
		Average Maximum	Average Minimum	Average	Average Maximum	Average Minimum	Average
College Station	1980	25.6	14.7	20.2	37.6	23.2	30.4
	1981	26.6	16.2	21.4	32.4	23.3	27.9
	1979	27.8	17.7	22.7	33.3	23.3	28.3
Corpus Christi	1980	27.6	16.3	22.0	34.5	23.7	29.1
	1981	26.7	17.3	22.0	31.9	24.4	28.2
Farwell	1980	31.4	12.7	22.1	34.1	17.1	25.6

<sup>a</sup>Pre-silk period.

<sup>b</sup>Post-silk period.

Source of information is National Weather Service.

TABLE IV  
Average Soil Temperatures<sup>a</sup> for Five Locations During  
Pre-Silk and Post-Silk Periods of 12 White Maize Hybrids

Location		Temperature <sup>b</sup> (°C)			Temperature <sup>c</sup> (°C)		
		Average Maximum	Average Minimum	Average	Average Maximum	Average Minimum	Average
College Station	1980	21.1	18.3	19.7	33.9	28.7	31.3
	1981	24.9	18.4	21.7	32.4	27.1	29.8
	1979	26.3	21.8	24.1	35.7	29.1	32.4
Corpus Christi	1980	27.8	22.4	25.1	40.4	32.1	36.3
	1981	25.7	21.2	23.5	33.2	27.6	30.4

<sup>a</sup>Depth of reading is 10.2 cm.

<sup>b</sup>Pre-silk period.

<sup>c</sup>Post-silk period.

Information was not available for Farwell.

Source of information is National Weather Service.

region. A microbiological assay of a few of the affected samples revealed only fungi that are typically associated with stored maize.<sup>5</sup> Therefore, it is unlikely that the discoloration is a disease initiated response. In the more conspicuous cases of brown banding, the pigmentation circumscribed the entire basal portion of the kernels excluding the germ area. Only small, localized pigmented areas were seen in the less notable cases. Only insignificant traces of discoloration were present over the germ region of any of the affected samples. It is possible that the pigment is synthesized to a lesser or greater extent, depending on hybrids and environmental conditions. This would explain the variation in brown banding among hybrids and within hybrids grown over different locations.

Kernel shape also varied among the samples. The kernels of most of the hybrids were mainly rounded, but kernels with a relatively larger longitudinal axis compared to kernel width (elongated kernels) predominated in the majority of hybrids grown at Farwell, in West Texas. Elongated kernels also developed at certain other locations for some hybrids. Mol4w x Tx71 was the only hybrid which produced relatively elongated kernels at more than half of the environments it was grown in.

Climatological conditions drastically affected the kernel size of the samples. The hybrids grown in Corpus Christi during 1980 experienced hot, dry conditions during the grain maturation period. Accordingly, the kernels of these hybrids were, in general, small and

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<sup>5</sup>Assays performed by the plant disease diagnostic laboratory, Texas A&M University, College Station 77843.

shriveled. The grain of hybrids grown during the same period in College Station was also relatively small, but usually not to the same extent as the Corpus Christi samples. The average atmospheric temperature in College Station at the time was very high and exceeded those for any other environment in which the maize hybrids were grown. Although very little rainfall fell during this period, water stress was either partially or totally alleviated due to the application of two irrigations. Genetics had a noticeable effect on kernel size. The kernels of Tx81 x Tx585 were at least as large as any for the five locations at which it was grown. The grain of Tx71 x Tx585, Tx29A x Tx80, CI66 x Tx71 and CI66 x Tx81 was also relatively large across environments. The kernels of Tx61M x Tx71 and Tx61M x Tx80 were, in general, among the smallest across locations. Surprisingly, however, the Corpus Christi 1980 grain of Tx61M x Tx71 was larger than that of most of the other hybrids grown during the same period in Corpus Christi. This indicated that genotype and environment interacted to produce the final appearance of the grain.

#### Physical and Chemical Properties of Maize Samples

The environment, genetics and environment by genetic interactions had a highly significant effect on all the physical and chemical properties tested for the maize samples. The means of these properties by hybrids and by environments are presented in Tables V and VI respectively. The analyses of variance are shown in Table VII. The statistical parameters of the properties are shown in Table A of the appendix. Density, test weight and one thousand kernel weight

TABLE V  
Weighted Mean<sup>a</sup> Physical and Chemical Properties for Grain of Each  
of 12 White Maize Hybrids Grown at Six Locations

Hybrid	Property						
	Density (g/cm <sup>3</sup> )	Test Weight (kg/hl)	One Thousand Kernel Weight (g)	Protein (Nx6.25) (%)	Floaters (%)	Hardness	
						Grinding <sup>b</sup>	Centrifugal <sup>c</sup> Impacting (%)
TX29A x Tx71	1.308a	75.7a	259e	9.9d	31g	74a	7.1b
CI66 x Tx81	1.302b	74.1c	327a	9.5e	22h	73b	5.5e
Tx61M x Tx71	1.300b	73.9d	261de	9.0f	36f	71c	6.9bc
CI66 x Tx71	1.290c	74.3b	304bc	11.1b	38f	69d	5.7e
Tx29A x Tx80	1.283d	73.2c	311b	9.5e	57e	63g	7.2b
Tx81 x Tx585	1.280d	71.6g	322a	10.9c	63d	67e	6.0de
Tx71 x Tx585	1.276e	71.0i	321a	12.3a	67cd	67e	5.9de
Mo14w X Tx71	1.273ef	71.6g	300c	8.3g	74a	63g	6.1de
Tx71 x Tx80	1.273fg	71.5g	246f	10.0d	73ab	65f	6.4cd

TABLE V (Continued).

Hybrid	Property						
	Density (g/cm <sup>3</sup> )	Test Weight (kg/hl)	One Thousand Kernel Weight (g)	Protein (Nx6.25) (%)	Floaters (%)	Hardness	
						Grinding <sup>b</sup>	Centrifugal <sup>c</sup> Impacting (%)
CI66 x Tx80	1.273fg	72.7f	267d	9.8d	72ab	65f	4.7f
Tx61M x Tx80	1.271fg	71.1h	248f	9.5e	76a	62h	5.9de
Tx71 x Ga209	1.269g	72.8f	258e	9.2f	69bc	63g	8.4a

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Results obtained by a commercial grain milling company. Published material pertaining to the method is not available but results are probably expressed as a percent of material that remained as overs after a sieving step.

<sup>c</sup>Expressed as a percentage of material passing through a 4.76 mm sieve.



TABLE VI  
Weighted Mean<sup>a</sup> Physical and Chemical Properties for Grain of 12  
White Maize Hybrids Grown at Each of Six Locations

		Property						
		Density (g/cm <sup>3</sup> )	Test Weight (kg/hl)	One Thousand Kernel Weight (g)	Protein (Nx6.25) (%)	Hardness		
Location						Floaters (%)	Grinding <sup>b</sup>	Centrifugal <sup>c</sup> Impacting (%)
College Station	1980	1.296a	73.0b	243d	10.4b	48d	70.7a	5.6cd
College Station	1981	1.288b	72.8c	323c	10.6a	53c	69.7b	6.0c
Corpus Christi	1979	1.282c	71.6e	348a	10.2c	57b	67.9d	6.5b
Corpus Christi	1980	1.250d	65.9f	182e	10.0d	91a	55.4f	7.9a
Corpus Christi	1981	1.287b	72.5d	341b	9.9e	50cd	68.8c	5.5d
Farwell	1980	1.295a	74.0a	320c	8.7f	37e	67.5e	6.5b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Results obtained by a commercial grain miller. Published material is not available but results are probably expressed as a percent of material that remained as overs after a sieving step.

<sup>c</sup>Expressed as a percentage of material passing through a 4.76 mm sieve.

TABLE VII  
ANOVA For Physical and Chemical Properties for Grain of  
12 White Maize Hybrids from Six Locations

Source	df	F Value			
		Density	One Thousand Kernel Weight	Floater	Test Weight
Hybrid	11	110**	82**	142**	
Location	5	308**	640**	210**	
Hybrid*Location	42	16**	11**	16**	
Error	59				
Total	117				
Hybrid	11				545**
Location	5				1310**
Hybrid*Location	36				68**
Error	68				
Total	120				

TABLE VII (Continued).

Source	df	F Value		
		Protein (Nx6.25)	Grinding	Centrifugal Impacting
Hybrid	11	203**		
Location	5	174**		
Hybrid*Location	42	50**		
Error	93			
Total	151			
Hybrid	11		323**	
Location	5		1078**	
Hybrid*Location	41		47**	
Error	58			
Total	115			
Hybrid	11			14**
Location	5			14**
Hybrid*Location	39			3**
Error	51			
Total	106			

\*\* Highly significant at 0.01 level.

of the hybrids were at least as variable between years at a given location as they were among locations. This indicates that factors which varied randomly among and within locations, such as temperature, rainfall etc., had a greater bearing on these properties than did factors, such as soil type, which varied little or not at all between years at a specific location. The densities of Tx29A x Tx71, Tx61M x Tx71, CI66 x Tx81 and CI66 x Tx71 were generally higher than those of the other hybrids across environments. Tx29A x Tx71 was at least as dense as any hybrid at four of five locations. Mol4w x Tx71 was generally the least dense hybrid across locations. However, Tx71 x Ga209, Tx61M x Tx80 and Tx71 x Tx80 also produced grain that was among the least dense over locations. The density ranking of CI66 x Tx80 varied from the lowest at College Station 1980 to among the highest at Corpus Christi 1981 indicating a large genetic by environment interaction. The density of the maize hybrids generally was greater at College Station and Farwell during 1980 than at the other locations. The average daytime temperatures during the grain-fill period for these environments were among the highest experienced in any environment. However, the majority of the Corpus Christi 1980 samples, which also experienced hot temperatures during grain-fill, had substantially lower grain density than did the same samples grown in any other environment. But, unlike the other samples, the Corpus Christi 1980 samples were completely deprived of moisture during the grain maturation period. Also, these samples grew in soils with much higher temperatures than did the other samples. High soil temperatures may have had some effect on the absorption of moisture

and nutrients into the root systems of the maize plants. If so, this could have affected grain properties. However, the total lack of moisture during grain-fill probably had a much larger effect on grain development. It is probable that white dent maize must have a certain amount of moisture available to it during the period of grain maturation to preclude a drastic and adverse effect on grain density. Maize density may tend to increase somewhat when higher daytime temperatures occur only if adequate moisture is available. The kernel size of many hybrids (CI66 x Tx71, Tx81 x Tx585, Tx71 x Tx585, Tx71 x Tx80, Tx71 x Ga209, Tx29A x Tx71, CI66 x Tx80) increased as grain density decreased across locations. However, there were two exceptions to this trend. The College Station 1980 and Corpus Christi 1980 samples of all hybrids were always smaller than the grain from any other environment. This suggests that when sufficient moisture is available and temperatures are not too hot, the kernel size of these hybrids increases when density decreases. The remaining hybrids either exhibited additional exceptions to the trend of larger kernel sizes associated with smaller densities or the relationship between kernel size and density was not clear. No relationship between density and kernel size was observed among the hybrids at any given environment. This indicated that some hybrids had a greater capacity than others for producing larger kernels given a particular value of density.

Test weight was highly correlated with density (Table VIII). Test weight is related to grain density and other factors that affect the weight of grain per unit of volume. Hybrids with larger kernel

TABLE VIII  
Correlations Between Physical and Chemical Properties for Grain of 12 White  
Maize Hybrids from Six Locations

Dependent Variable	Test Weight	One Thousand Kernel Weight	Protein (N6.25)	Mixtamal Shear Force	Dry Matter Loss Index	Moisture Uptake Index	Degree Crushed	Extent Cooked	Hardness		
									Floaters	Grinding	Centrifugal Impacting
Density	0.90**	0.42**	-0.02	0.31*	-0.14	-0.71**	-0.16	-0.33*	-0.91**	0.92**	-0.44**
Test Weight		0.42**	-0.13	0.32*	-0.24	-0.72**	-0.18*	-0.27	-0.84**	0.79**	-0.35*
One Thousand Kernel Weight			0.03	0.06	0.07	-0.62**	-0.35*	-0.36*	-0.44**	0.49**	-0.30*
Protein				0.39**	-0.22	-0.13	-0.10	-0.19	0.08	0.21	-0.33*
Mixtamal Shear Force					-0.40**	-0.61**	-0.35*	-0.41*	-0.25	0.41**	-0.49**
Dry Matter Loss Index						0.30*	0.04	0.33**	0.23	-0.27*	0.08
Moisture Uptake Index							0.45**	0.49**	0.70**	-0.76**	0.53**
Degree Crushed								0.58**	0.15	-0.19	0.18
Extent Cooked									0.37*	-0.37*	0.22
Floaters										-0.82**	0.27*
Grinding											-0.57**

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 52 to 59 for most, but for correlations between degree crushed and extent cooked and all other properties N ranged from 32 to 47.

sizes also had greater one thousand kernel weights. One thousand kernel weight tended to be higher in environments where abundant moisture was available concomitant with slightly cooler daytime temperatures during grain maturation. One thousand kernel weight showed a significant albeit slight correlation with density. This was because the more dense samples many times had smaller than average kernel sizes.

The protein content of Tx71 x Tx585 was generally higher than that of the other hybrids across environments. Mol4w x Tx71 and Tx61M x Tx71 had protein contents which were among the lowest across environments. Overall, protein content varied more among hybrids than it did among environments. However, a very wide range in protein content was observed for Tx61M x Tx80. This hybrid displayed both the single lowest and single highest protein percentage observed for any sample. The samples grown at Farwell generally had notably lower protein concentrations than did the same samples grown at the other locations. The Farwell samples yielded much higher than the others. This helped to explain the low protein contents observed for many Farwell samples. The maize hybrids showed no tendency to have greater protein concentrations at any one location. Figure 1 illustrates hybrid by environment interactions affecting protein content of the samples. The pattern of Tx61M x Tx80 is similar to that shown for CI66 x Tx71 for locations which were common to both hybrids. The patterns of the other hybrids, at most were only somewhat similar to any of those illustrated. However, several hybrids (Tx71 x Tx80, Tx29A x Tx80, Tx71 x Ga209, Tx61M x Tx80, Mol4w x Tx71, Tx29A x Tx71)

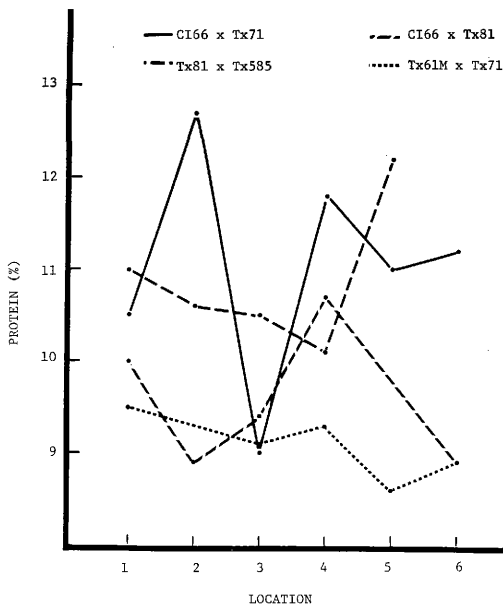


Fig. 1. Genetic by environment interactions affecting grain protein content of four white maize hybrids. Locations are as follows: 1=College Station 1980, 2=College Station 1981, 3=Farwell 1980, 4=Corpus Christi 1979, 5=Corpus Christi 1980, 6=Corpus Christi 1981.



displayed a significant decrease in percent protein at Farwell relative to the other samples similar to that shown for CI66 x Tx71. Also, all hybrids except CI66 x Tx80 showed an increase in percent protein in Corpus Christi 1981 samples over that of Corpus Christi 1980 samples. Tx81 x Tx585 was the only hybrid to show a decrease in percent protein from Farwell to Corpus Christi 1979. None showed a significant increase in Farwell protein over College Station samples. CI66 x Tx81 was the only hybrid to show a significant decrease in percent protein from Corpus Christi 1979 to Corpus Christi 1981.

#### Maize Hardness Methods

The three different methods used for evaluating maize hardness differed widely in the amount of variation they produced among the various samples (Table A, appendix). The percent floaters showed the greatest range in variability over all samples (6-100), while the grinding method produced an intermediate range of variability (46.5-77.0). However, the centrifugal impact (CI) method generated a relatively narrow range of values (4.1-10.2). A similar amount of CI breakage was reported for several field-dried maize genotypes grown in the Midwest and tested using conditions similar to those used for this study (Paulsen et al 1981). The moisture content of those samples (12.6 to 13.1 percent) was slightly higher than that of the maize samples used for this study (10.8 to 12.3 percent). The percent floaters and the grinding method correlated well with one another. Both were strongly related to grain density. This is illustrated for each of four hybrids across environments by comparing Figs. 2 and 3a.

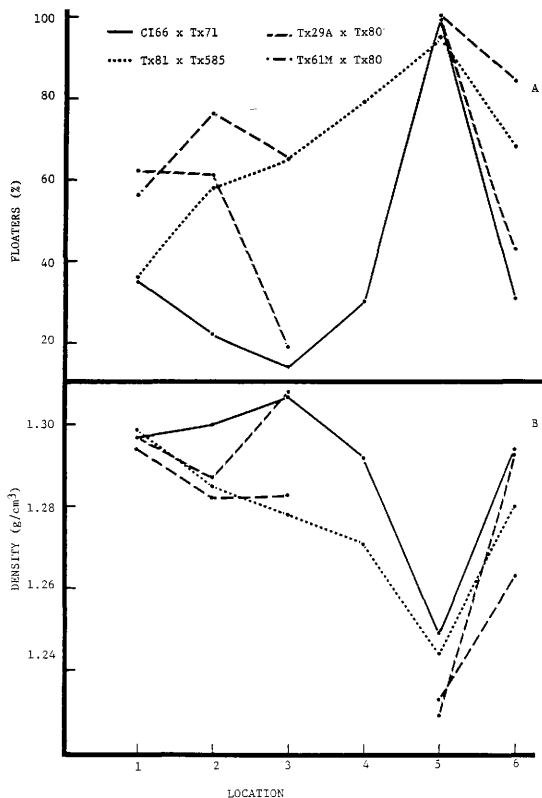


Fig. 2. Relationship of percent floaters to grain density for four white maize hybrids across locations. Locations identified in Fig. 1. p. 38.

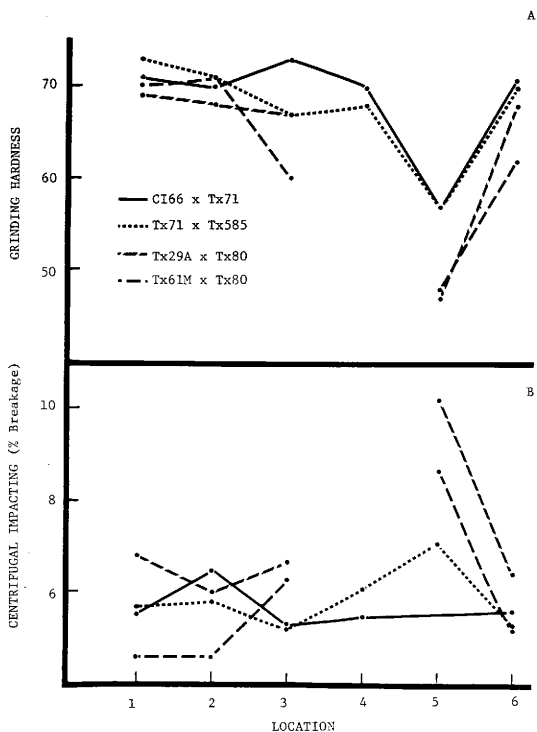


Fig. 3. Comparison of grinding and centrifugal impact grain hardness of four white maize hybrids across locations. Locations are identified in Fig. 1. p. 38.

The association between percent floaters and density was anticipated since as the density of the maize samples increased, there was a corresponding increase in the number of kernels able to overcome the buoyancy force provided by the test solution. As a result, the percent floaters decreased as the grain density of the samples increased. In contrast to the other hardness methods, the CI method was only slightly related to density. Nevertheless, a small but significant correlation was present between it and the grinding and flotation methods. Paulsen et al (1981) did not observe a significant correlation between CI breakage and percent floaters of several field-dried maize hybrids. However, they did note a negative correlation between floaters and CI breakage of samples which had been dried with high-temperature (60°C) air. The amount of breakage for samples dried with low-temperature (24°C) air was not related to the floaters test. The CI test was slightly but significantly related to the protein content of the maize samples, whereas the density and percent floaters were not associated with the protein content of maize. These results differ from those of Mancharkumar et al (1978) who found that the protein content of twenty German maize varieties was highly correlated to the floaters test. The type of maize these researchers used for their study was not specified. The grinding method did not show a significant correlation with protein content. However, a stepwise regression analysis showed that protein was affecting maize hardness (Table C, appendix). Together, density and protein accounted for most of the variability in grain hardness as determined by the grinding method. Additional factors probably contributed to grinding hardness

as well. The effect of the combination of grain density and protein content on grinding hardness can be seen from Fig. 4. The contribution that protein makes to kernel hardness might stem from the relative strength of the intra- and inter-molecular chemical bonds of the protein making up the protein matrix of the endosperm.

The CI method detected significant differences among hybrids at four of the six locations (Table D6, appendix). An earlier study (Paulsen et al 1981) revealed significant differences in CI breakage of several maize hybrids. The CI method was unable to detect significant differences across locations for six of the twelve hybrids (Table E6, appendix). In contrast, the grinding method always detected significant differences in hardness due to both environmental and genetic factors (Tables E5 and D5 respectively, appendix). The CI method at times failed to distinguish among samples because of large differences which occasionally occurred between replicates. However, the CI method could not distinguish among samples as clearly as the grinding method even when the differences among replicates were small. This indicated that the CI method was not as sensitive as the grinding method to detect differences in hardness among maize samples.

Correlations between the CI and grinding hardness methods occurred across locations for four of twelve hybrids (Tables G1-G12, appendix). However, there were no correlations between the grinding method and CI method among hybrids within any given location (Tables F1-F6, appendix). Figure 3 (p. 41) compares grain hardness determined by both the CI and grinding methods for each of four hybrids across environments. A slight inverse relationship between the two hardness

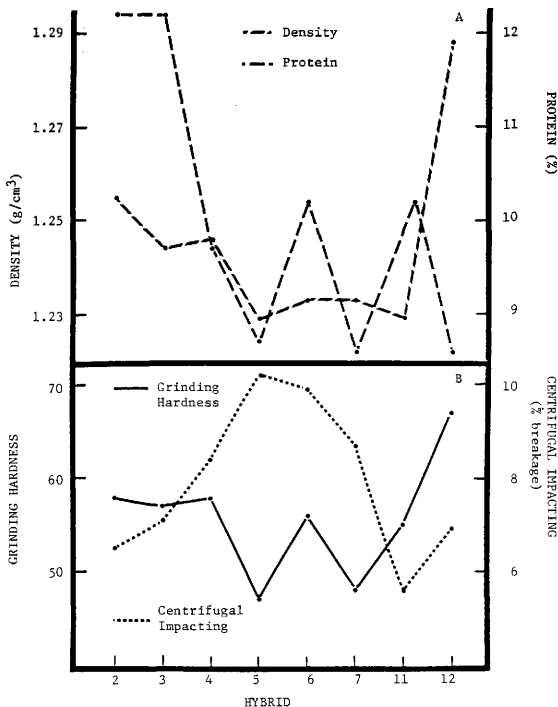


Fig. 4. Comparison of grinding hardness, centrifugal impact hardness, density and protein content for grain of eight white maize hybrids grown during 1980 at Corpus Christi. Hybrids are as follows: 2=Tx81 x Tx585, 3=Tx71 x Tx585, 4=Tx71 x Tx80, 5=Tx29A x Tx80, 6=Tx71 x Ga209, 7=Tx61M x Tx80, 11=CI66 x Tx80, 12=Tx61M x Tx71.

methods can be seen for Tx71 x Tx585. However, the CI method could not detect statistically significant environmental differences for this hybrid despite the variability of values. This demonstrates the ineffectiveness of this method to differentiate between samples because of the large coefficients of variation which were sometimes produced. The two hardness methods displayed a much stronger relationship with one another for the hybrids Tx29A x Tx80 and Tx61M x Tx80. There was no association between the two hardness methods for CI66 x Tx71. However, the Corpus Christi 1980 sample of this hybrid was not tested with the centrifugal impactor. The association seen between the grinding and CI methods for some samples probably resulted from the much lower grinding hardness of the Corpus Christi 1980 samples compared to the other samples. The CI method was apparently not as sensitive to certain factors affecting grain hardness as was the grinding method. However, some samples which had much lower grinding hardness also clearly displayed lower CI hardness. This indicated that the CI method could detect large differences in grinding hardness. This would help explain the lack of a relationship between grinding and CI hardness within locations among hybrids. The differences in grinding hardness among hybrids at a given location were usually not as great as those across environments for many hybrids. Figure 4 (p. 44) illustrates the typical non-association between grinding and CI hardness among hybrids within locations. Grain of Tx61M x Tx71 had a substantially greater grinding hardness than the other hybrids. However, CI66 x Tx80 was rated hardest by the CI method. This, plus the general non-agreement between these two

hardness methods, suggests that there were genetic factors which the CI method was sensitive to but which did not affect the grinding method. The CI method may also have been affected by environmental factors which did not affect the grinding method. This would help to explain the discordance between the two methods for some hybrids across environments. Stress cracks within the endosperm might have affected the amount of breakage with the CI technique. Evidence for this came from observing a few kernels from many of the samples which were broken completely through the kernel, apparently along planes of cleavage that may have resulted from weak areas, possibly fissures, in the endosperm. Paulsen et al (1981) reported that breakage susceptibility with the CI test was three to six times greater for high-temperature dried maize averaging 99 percent stress cracks than for low-temperature dried maize with an average of one percent stress cracks. The presence of stress cracks might partially explain the discrepancies between the grinding and CI hardness tests.

The grinding hardness of CI66 x Tx81, Tx29A x Tx71 and Tx61M x Tx71 generally was greater than that of the other hybrids. Mol4w x Tx71 usually had the softest grain across locations. Other hybrids observed to have relatively low grinding hardness at many locations were Tx61M x Tx80, Tx29A x Tx80, Tx71 x Ga209 and Tx71 x Tx80. The CI method showed that CI66 x Tx80 was always among the hardest grain across locations. Tx71 x Ga209 was always among the softest grain. The College Station 1980 grain samples were generally among the hardest across hybrids by both grinding and CI hardness. Both hardness methods showed Corpus Christi 1980 samples were the softest.



Hybrid by environment interactions affecting flotation, grinding and CI hardness are shown in Figs. 2a and 3 (pp. 40 and 41). For the flotation test, Tx81 x Tx585 and Tx71 x Ga209 displayed similar trends as that shown for Tx61M x Tx80 for locations which were common to all. The tendencies in variability of the grinding hardness of Tx71 x Tx80 and Tx71 x Ga209 were similar to that demonstrated for their sister hybrid Tx71 x Tx585 at the four locations all were grown. Tx81 x Tx585 displayed a similar trend as that illustrated for Tx61M x Tx80 for common locations. The sister hybrids CI66 x Tx81 and CI66 x Tx80 (neither shown) exhibited a significant increase in the hardness of their College Station 1981 samples over that of the 1980 College Station samples. The hardness of all hybrids, except Tx71 x Tx585, was less at Corpus Christi 1979 than at Farwell 1980. Finally, all hybrids were softest at Corpus Christi 1980. Similarities in the patterns of CI hardness were seen between Tx71 x Ga209 and Tx29A x Tx80 for shared locations. Tx81 x Tx585 and Tx29A x Tx71 (neither shown) displayed similar variation over locations. Many hybrids displayed patterns of variation across locations for the three hardness tests that were somewhat similar to one another. However, the patterns of variation were not the same for any two hybrids in most cases. Therefore, it is difficult to predict how grain hardness of a particular maize hybrid will respond to different growing conditions.

### Visual Characteristics of Nixtamal

A definite yellow color developed in all maize samples during alkali cooking. The alkali probably reacted with components located in the pericarp of the samples. Once the pericarp was completely washed off, very little yellow color remained in the endosperm. During the tortilla-making process, alkali reacts with color precursors (polyphenols) located within the pericarp of many different sorghum varieties, imparting pronounced color changes which are conveyed to the tortillas made from the grain (Earp and Rooney 1982). It is reasonable that a similar process occurs to a much lesser degree in white maize. The slight yellow tinge still present after the pericarp was removed may have resulted from leaching of the pigment from the pericarp to the endosperm. Differences in the amount of color which developed among samples could not be distinguished visually. A greenish-brown color was also noted in the endosperm of a small number of cooked kernels from many of the hybrids which were brown-banded. Again, leaching of pigment from the pericarp to the endosperm was likely as the pigmented areas of the nixtamal corresponded to regions of brown banding in the raw grain.

### Cooking Properties of Maize Samples

The means for hybrids and environments and analyses of variance for the alkaline cooking properties of the maize samples, as determined by nixtamal shear force (NSF), nixtamal moisture uptake and dry matter losses, are presented in Tables IX, X and XI respectively. The statistical parameters are given in Table B of the appendix. NSF

TABLE IX  
Weighted Mean<sup>a</sup> Nixtamal Properties for Grain of Each of  
12 White Maize Hybrids Grown at Six Locations

Hybrid	Property		
	Nixtamal Shear Force (lbs force)	Dry Matter <sup>b</sup> Loss Index (%)	Moisture Uptake <sup>c</sup> Index (%)
CI66 x Tx80	292a	6.6cd	89f
Tx29A x Tx80	286a	7.1b	93de
CI66 x Tx81	270b	6.0ef	85g
CI66 x Tx71	265b	6.3de	90ef
Tx29A x Tx71	264b	7.1b	91ef
Tx71 x Tx585	251c	6.6cd	96bc
Tx71 x Tx80	245cd	6.8bc	100a
Tx81 x Tx585	239de	6.4cde	95cd
Tx71 x Ga209	231ef	5.8f	97bc
Tx61M x Tx80	228f	7.2b	99ab
Mol4w x Tx71	218g	7.7a	98ab
Tx61M x Tx71	206h	6.8bc	99ab

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Percent of original grain dry matter lost during cooking.

<sup>c</sup>Expressed as a percentage of dry matter remaining after cooking.

TABLE X  
Weighted Mean<sup>a</sup> Nixtamal Properties for Grain of 12  
White Maize Hybrids Grown at Each of Six Locations

Location		Nixtamal Shear Force (lbs force)	Dry Matter Loss Index (%)	Moisture Uptake Index (%)
College Station	1980	276b	6.3	92b
College Station	1981	285a	6.7	88d
Farwell	1980	220e	6.9	94b
Corpus Christi	1979	219e	6.9	94b
Corpus Christi	1980	232d	6.7	107a
Corpus Christi	1981	249c	6.8	90c

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Percent of original grain dry matter lost during cooking.

<sup>c</sup> Expressed as a percentage of dry matter remaining after cooking.

TABLE XI  
ANOVA for Nixtamal Properties for Grain of 12 White  
Maize Hybrids from Six Locations

Source	df	F Value		
		Nixtamal Shear Force	Dry Matter Loss Index	Moisture Uptake Index
Hybrid	11	70**		
Location	5	96**		
Hybrid*Location	42	16**		
Error	295			
Total	353			
Hybrid	11		13**	20**
Location	5		2.2	51**
Hybrid*Location	41		8**	4**
Error	58			
Total	115			

\*\* Highly significant at 0.01 level.

and moisture uptake were significantly affected by hybrids at all locations (Tables D1 and D10 respectively, appendix). Also, these properties were significantly affected by the environment for most hybrids (Tables E1 and E10 respectively, appendix). Only CI66 x Tx81 displayed no significant differences in NSF over locations. This hybrid was unusually stable across locations for many of the properties tested. The NSF of Tx29A x Tx80 was as high as that of any hybrid at four of five locations. CI66 x Tx81 had NSF values which were among the highest at three of five locations. The NSF of Tx71 x Ga209 and Tx61M x Tx71 was among the lowest at most locations. The NSF of the hybrids tended to be higher for College Station 1980 and 1981 samples. There was no definite tendency for the hybrids to exhibit lower NSF values for any one location. The amount of moisture absorbed during cooking tended to be greater for Mol4w x Tx71 and Tx71 x Tx80. Relatively low moisture uptakes were observed for the sister hybrids CI66 x Tx71, CI66 x Tx81 and CI66 x Tx80. The Corpus Christi 1980 samples usually absorbed more moisture than did the others. There was not a strong trend for samples from a given location to absorb less moisture than others. Figure 5 illustrates that environment by hybrid interactions affected these properties. The NSF of Tx29A x Tx71 generally followed the same trend as that shown for Tx61M x Tx80 across common locations. Like Tx61M x Tx80, CI66 x Tx80 showed a significantly greater NSF for the College Station 1981 sample relative to the College Station 1980 sample. However, this hybrid was unique from all others in showing a significant decrease in NSF from Corpus Christi 1980 to Corpus Christi 1981. The NSF of the College

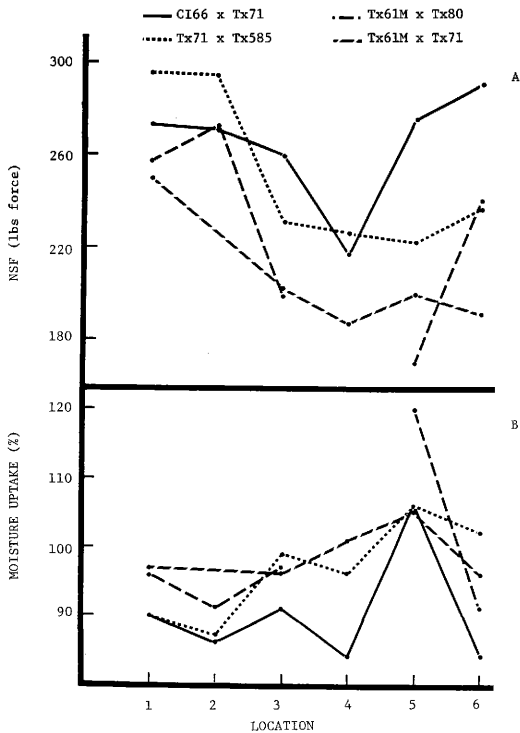


Fig. 5. Nixtamal shear force and moisture uptake of four white maize hybrids across locations. Locations are identified in Fig. 1. p. 38.

Station samples of Tx29A x Tx80, Tx71 x Tx80 and Tx81 x Tx585 was, like that shown for Tx61M x Tx71, Tx61M x Tx80 and Tx71 x Tx585, significantly higher than that of the remaining samples. The pattern of moisture uptake for Tx71 x Tx80, Tx71 x Ga209, Tx29A x Tx80 and CI66 x Tx80 was similar to that shown for Tx61M x Tx80. Like other maize properties, the variation in NSF and moisture uptake of certain hybrids was similar at some locations but different at others making it difficult to predict how any hybrid will perform at a particular location.

Environment did not have a significant effect on the dry matter losses of Tx81 x Tx585, Mol4w x Tx71, CI66 x Tx80 or Tx61M x Tx71 (Table E9, appendix). This is of practical importance to tortilla processors. It implies that these varieties obtained from any environment may be processed without greatly affecting the processor's economic losses resulting from loss of dry matter. The other hybrids, with the exception of Tx29A x Tx71 and CI66 x Tx81, showed only slight but significant environmental differences in dry matter loss. There were significant genetic differences in dry matter losses at each location (Table D9, appendix). Mol4w x Tx71 consistently had among the highest dry matter losses over locations. Tx71 x Ga209 tended to have lower losses of dry matter. The extent of dry matter losses of the other hybrids relative to one another varied over locations.

#### Relationship of Nixtamal Properties to Optimum Cooking Time

NSF might be used to predict the optimum cooking time of maize for tortillas (Bedollia 1980). Significant correlations were observed



between NSF and moisture uptake, grain density, protein content, percent dry matter losses, the degree nixtamal was crushed between glass plates, the extent that the interior of nixtamalized kernels appeared to be cooked and the three hardness methods (Table VIII, p. 36). A stepwise regression analysis revealed that, of these properties, only moisture uptake and protein content were interacting to produce a significant effect on NSF (Table XII). However, the combination of these factors could only explain one-half the variability of NSF. The relationship of density, dry matter losses and the degree to which the interior of nixtamalized maize was cooked to NSF can be explained by the connection between these properties and nixtamal moisture uptake. As maize density decreased, moisture was usually absorbed more readily since the endosperm structure was more open for moisture to freely penetrate within it. The dry matter losses of some samples increased as moisture uptake increased. More endosperm components could be solubilized by the greater amount of moisture available. The ratings for the extent to which maize appeared to be cooked was based on how well the interior of the cooked kernels appeared to be hydrated. Hence, the relation between it and moisture uptake. A somewhat similar method is used to determine when the proper cooking time of rice has been reached.\* Cooked rice kernels are completely crushed between glass plates and the amount of uncooked endosperm can be easily observed. The association between NSF and the three hardness methods is reasonable since all these

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\*Dr. Bill Webb, USDA, Texas A&M University Agricultural Research and Extension Center, Beaumont, Texas. 1983. Personal communication.

TABLE XII  
Stepwise Regression Analysis for 12 White Maize Hybrids  
from Six Locations with NSF as Dependent Variable

Variable Entered	R Square	P Value of Variable Entered
MUI <sup>a</sup>	0.37**	33.3**
MUI + P <sup>b</sup>	0.48**	10.8**
MUI + P + CI <sup>c</sup>	0.49**	1.3
MUI + P + G <sup>d</sup>	0.50**	2.0
MUI + P + DMI <sup>e</sup>	0.50**	3.0

\*\* Highly significant at 0.01 level.

N ranged from 54 to 57.

<sup>a</sup>Moisture uptake index.

<sup>b</sup>Percent protein.

<sup>c</sup>Centrifugal impact hardness.

<sup>d</sup>Grinding hardness.

<sup>e</sup>Dry matter loss index.

properties were related to grain density. Furthermore, the protein content of the grain was related to NSF and to the grinding and CI hardness methods. This helped to explain the relation between these two hardness methods and NSF.

A simple and inexpensive method to simulate NSF would be desirable if NSF can be used to predict the optimum cooking time of maize. Therefore, nixtamal was crushed between glass plates in an effort to determine the deformation resistance of cooked kernels without the aid of an Instron. Results of the glass plate crushing method are presented in Table XIII. The small correlation between results obtained from the glass plate method and NSF was a reflection of the subjective nature involved when manually crushing cooked maize kernels between glass plates. Thus, this method probably would not be a useful substitute for NSF.

Tx71 x Tx585 was the only hybrid to show a correlation across environments between moisture uptake and NSF (Tables G1-G12, appendix). Figure 5 (p. 53) compares the moisture uptake and NSF of four hybrids across locations. Some hybrids (Tx81 x Tx585, Tx29A x Tx80, Tx61M x Tx80, Tx29A x Tx71) displayed a negative trend between these two variables which was non-significant due to the small number of observations used to make comparisons. It is unlikely that the nixtamal moisture content had no effect on the NSF of the remaining hybrids. The effect of moisture probably was concealed by unknown factors which had an important effect on NSF and which varied across environments. A significant correlation between the amount of nitrogen applied and NSF was observed for the hybrids Tx81 x Tx585,

TABLE XIII  
Subjective Evaluation of Nixtamal Properties and Pericarp  
Removal of 12 White Maize Hybrids from Six Locations

Maize Sample		Degree <sup>a</sup> Crushed	Extent <sup>b</sup> Cooked	Pericarp Removal <sup>c</sup>
CI66 x Tx71				
College Station	1980	4	NA	3
College Station	1981	2	NA	4
Farwell	1980	5	NA	3
Corpus Christi	1979	4	NA	3
Corpus Christi	1980	5	NA	4
Corpus Christi	1981	2	NA	4
Tx81 x Tx585				
College Station	1980	3	NA	3
College Station	1981	4	NA	3
Farwell	1980	4	NA	3
Corpus Christi	1979	5	NA	2
Corpus Christi	1980	4	NA	NA
Tx71 x Tx585				
College Station	1980	NA	NA	NA
College Station	1981	2	1	3
Farwell	1980	4	3	4
Corpus Christi	1979	2	1	3
Corpus Christi	1980	4	4	3
Corpus Christi	1981	5	4	3

TABLE XIII (Continued).

Maize Sample		Degree <sup>a</sup> Crushed	Extent <sup>b</sup> Cooked	Pericarp Removal <sup>c</sup>
Tx71 x Tx80				
College Station	1980	3	4	3
College Station	1981	3	4	3
Farwell	1980	2	4	3
Corpus Christi	1980	4	4	3
Tx29A x Tx80				
College Station	1980	4	2	3
College Station	1981	3	3	1
Farwell	1980	2	2	2
Corpus Christi	1980	4	3	2
Corpus Christi	1981	2	1	2
Tx71 x Ga209				
College Station	1980	5	5	5
College Station	1981	2	1	3
Farwell	1980	4	4	3
Corpus Christi	1980	4	4	3
Tx61M x Tx80				
College Station	1980	NA	NA	NA
College Station	1981	NA	NA	NA
Farwell	1980	NA	NA	NA
Corpus Christi	1980	NA	NA	NA
Corpus Christi	1981	NA	NA	NA

TABLE XIII (Continued).

Maize Sample		Degree <sup>a</sup> Crushed	Extent <sup>b</sup> Cooked	Pericarp Removal <sup>c</sup>
CI66 x Tx81				
College Station	1980	3	1	NA
College Station	1981	3	3	4
Farwell	1980	4	1	3
Corpus Christi	1979	4	3	3
Corpus Christi	1981	4	3	4
Mol4w x Tx71				
College Station	1980	5	4	5
College Station	1981	3	4	5
Farwell	1980	4	4	5
Corpus Christi	1979	4	5	5
Corpus Christi	1981	4	3	3
Tx29A x Tx71				
College Station	1980	NA	NA	NA
College Station	1981	3	2	3
Farwell	1980	5	4	4
Corpus Christi	1979	NA	NA	NA
Corpus Christi	1980	5	4	4
CI66 x Tx80				
College Station	1980	3	3	3
College Station	1981	1	1	1
Corpus Christi	1980	4	3	2
Corpus Christi	1981	2	3	1

TABLE XIII (Continued).

Maize Sample		Degree <sup>a</sup> Crushed	Extent <sup>b</sup> Cooked	Pericarp Removal <sup>c</sup>
Tx61M x Tx71				
College Station	1980	NA	NA	NA
Farwell	1980	NA	NA	NA
Corpus Christi	1979	NA	NA	NA
Corpus Christi	1980	NA	NA	NA
Corpus Christi	1981	4	1	3

<sup>a</sup>1 = least crushed kernels, 5 = most crushed kernels.

<sup>b</sup>1 = least cooked kernels, 5 = most cooked kernels.

<sup>c</sup>1 = least amount of pericarp removed, 5 = greatest amount of pericarp removed.

NA = not available.

Tx71 x Tx585 and Tx61M x Tx71. A relationship between both the amount of phosphorous and potassium applied and NSF was observed for Tx71 x Tx585, Tx29A x Tx71 and Tx61M x Tx71. The amounts of nitrogen, phosphorous and potassium applied were greater at College Station for both years than they were at the other locations for which the amounts of fertilizer used were known. Whether chemicals from applied fertilizer had any bearing on the high NSF seen for College Station samples of some hybrids or it was just chance association cannot be established from these results. Figure 6 illustrates the typical relationship between moisture uptake and NSF across hybrids within locations. Moisture uptake was significantly related to NSF over hybrids at most locations. This indicated that additional factors that had an effect on NSF of the maize hybrids, in general, varied more due to environmental factors than due to genetic differences among hybrids.

A portion of the association between grain protein content and NSF may result from the mutually low protein percentages and NSF values for Farwell samples of several hybrids (Tx71 x Tx80, Tx29A x Tx80, Tx71 x Ga209, Tx61M x Tx80, Mol4w x Tx71, Tx29A x Tx71). A comparison of Figs. 1 and 5a for CI66 x Tx81 (pp. 38 and 53) shows that a substantial decrease in protein content at Farwell occurred but NSF was nearly as high as that of most other samples. The NSF value of the Tx61M x Tx71 Farwell sample was no lower than most but much lower than the College Station 1980 sample. However, its percent protein was only slightly lower than that of the College Station sample. A similar situation occurred for Tx71 x Tx585 and Tx81 x



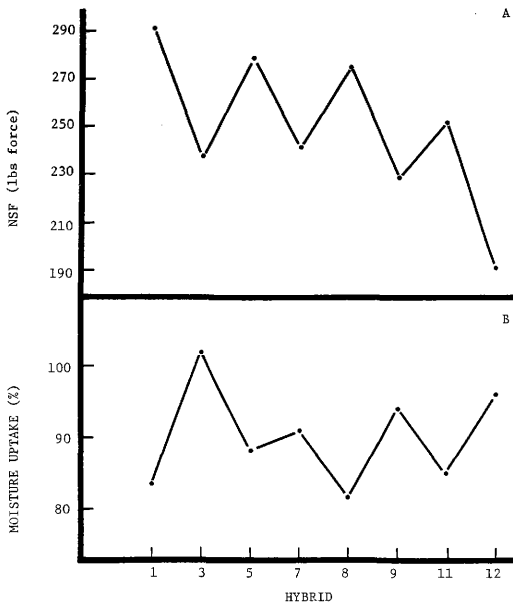


Fig. 6. Relationship between nixtamal shear force and moisture uptake for grain of eight white maize hybrids grown during 1981 at Corpus Christi. Hybrids are as follows: 1=CI66 x Tx71, 3=Tx71 x Tx585, 5=Tx29A x Tx80, 7=Tx61M x Tx80, 8=CI66 x Tx81, 9=Mol4w x Tx71, 11=CI66 x Tx80, 12=Tx61M x Tx71.

Tx585. This indicated that the relatively low NSF of many Farwell samples was due mainly to factors other than the percent protein of the maize. Nevertheless, the concentration of grain protein probably had a slight effect on the NSF of the maize samples. This may be because the protein matrix is slightly more resistant to deformation forces than is the starchy portion of the endosperm.

These results suggest that another factor(s), besides moisture uptake during cooking and protein content of the grain, had an effect on the NSF of the samples. Bedolla (1980) showed that enzyme susceptible starch (ESS) or the amount of starch gelatinization also significantly affected the NSF of the maize hybrids used for his study. However, a relationship was present between moisture uptake and ESS. The maize samples used for this study were not assayed for ESS, so any connection between it and the NSF of the samples could not be established. It is possible that the cell walls within the endosperm of some samples may be dissimilar with regard to the amount of resistance they can provide against externally applied deformation forces. NSF may also have been affected by interactions between protein, starch and other kernel components. This might explain why some of the nixtamal which Bedolla (1980) determined to be optimum for grinding and tortilla preparation exhibited NSF values greater than the "optimum" 224-275 range. This latter fact suggests that NSF is not reliable for determining the proper cooking time of maize for tortillas. Although NSF values varied quite a bit at the optimum cooking time, the moisture content was similar for all the optimally cooked samples. Since ESS was related to moisture content, the amount

of starch gelatinization may have been similar for the optimal nixtamal as well. It could be that the amount of gelatinized starch is the paramount factor affecting nixtamal quality. If so, factors which affect NSF other than the amount of ESS, would make the prediction of optimum cooking time based on a particular range of NSF ineffective. For instance, overcooking would occur if a particular maize sample required a cooking time to reach a certain range of NSF which resulted in a greater than optimal amount of starch gelatinization.

#### Pericarp Removal During Alkali Cooking

Some of the samples appeared to have large differences in the amount of pericarp removed during the lime cooking process (Table XIII, p. 58). The amount of pericarp remaining was very small for most samples of the hybrid Mol4w x Tx71. In contrast, most samples of the hybrids Tx29A x Tx80 and CI66 x Tx80 showed very little pericarp removal. The majority of samples of the other hybrids were intermediate between these two extremes. Larger differences seemed to be present among hybrids than among environments. This suggests that factors affecting the ease of pericarp removal from maize kernels may be relatively heritable.

A method to quickly screen small samples for ease of pericarp removal during alkali cooking should be beneficial to a maize breeding program. Thus, a modified alkali test was used to compare the amount of pericarp removed from certain samples which displayed large differences in this characteristic during traditional alkali cooking

(Table XIV). The selected samples were stained and put in a 1.0 N NaOH solution. Differences were evident after 2 hrs. Differences continued for the 5 hr observation time which was used. The amount of stained pericarp remaining was least for the Mol4w x Tx71 sample, while the CI66 x Tx71 Corpus Christi 1980 and Tx29A x Tx80 samples showed the largest amount of stained pericarp remaining. The CI66 x Tx71 Farwell sample was intermediate with respect to the other samples. Since the majority of samples used to make comparisons included different hybrids from different locations, it was not possible to determine whether the differences were mainly genetic or environmental in nature.

The Corpus Christi 1980 maize sample of CI66 x Tx71 exhibited a large amount of pericarp removal based on observations of the nixtamal. However, of the four samples placed in the dilute NaOH solution, it displayed the largest amount of pericarp remaining. This is probably an indication of the difficulty involved in evaluating the amount of pericarp removed from the seed when the pericarp is not clearly visible. However, the other three samples showed the same trends in the dilute NaOH solution as they did after they were cooked and steeped in alkali. Therefore, this test may be a useful method to determine the relative ease of pericarp removal of maize during traditional processing.

Although no stain was observed at certain regions of the grain samples, the pericarp still adhered slightly to the seed at many of these unstained areas. This was apparently because the alkali solution had penetrated under the pericarp corresponding to the

TABLE XIV  
Amount of Stained Pericarp Remaining for Kernels of Selected  
White Maize Samples After 5 Hrs in a 1.0 N NaOH Solution

Hybrid	Location		Kernel Section		
			Dorsal Side <sup>a</sup>	Ventral Side <sup>b</sup>	Crown Region <sup>c</sup>
Mol4w x Tx71	Farwell	1980	Top One-Quarter	NS	All
CI66 x Tx71	Farwell	1980	Top One-Quarter	Top One-Quarter	All
CI66 x Tx71	Corpus Christi	1980	All	All Excluding Germ Area	All
Tx29A x Tx80	College Station	1981	All	Top One-Quarter	All

<sup>a</sup>Amount of stained area remaining on dorsal side.

<sup>b</sup>Amount of stained area remaining on ventral side.

<sup>c</sup>Amount of stained area remaining on crown region.

NS = no stain remaining.

unstained portions and thereby degraded the stain. The alkali had not yet penetrated under the stained regions of the pericarp. The pericarp still adhered tightly to the seed in these regions. After the pericarp of some kernels was removed, a light yellow-green color still remained. As a microscopic examination was not done, it was not possible to determine if this was due to the aleurone layer, which also stains green with the dye, or to endocarp tissue. If it is the latter, the pericarp of at least some samples may separate at the interface of the cross and tube cells with the mesocarp.

The Mo14w x Tx71 sample, in addition to a greater amount of pericarp removed, swelled to a larger degree than did the other samples, and less solution was present in the test tube in which this hybrid was placed than was in the others at the end of the 5 hr period. This observation, along with the finding that none of the samples showed signs that the pericarp was beginning to separate until the alkali solution had migrated under the pericarp, implies that the speed with which alkali is absorbed by the maize kernel may be very important in affecting the ease of pericarp removal.

## CONCLUSIONS

Genetics greatly affected most of the maize properties at all locations. The environment also had a large effect on most hybrids for most properties. Exceptions were noted for centrifugal impact (CI) hardness, dry matter losses and moisture uptake during cooking. The environmental effects were more important than those due to genetics for many maize properties. Much of this could be attributed to the large differences seen for the Corpus Christi 1980 samples for several properties. In addition to hybrid and location effects, genetic by environment interactions were significant for all properties. A number of climatological and agronomic factors were probably involved in a complex interaction to produce the final effect on maize properties.

The floaters and grinding methods could effectively differentiate the maize samples by hardness. However, the CI method was not as sensitive to detecting hardness differences. This was partly due to large coefficients of variation which sometimes occurred. Using more replications may make it possible to better differentiate among maize samples. However, the centrifugal impactor should be more useful if modified so that more consistent results are obtained. The flotation and grinding tests correlated well with one another but only slightly with the CI method. This was because both flotation and grinding hardness were greatly affected by grain density but CI hardness was less sensitive to this property. Both the grinding and CI methods were affected by percent protein of the grain. However, the flotation test was not related to this property. Stress cracks may have

affected the centrifugal impactor. If so, this might partly explain the discrepancies seen between it and the other hardness tests.

The variability of NSF could not be totally attributed to the chemical and physical properties evaluated for the maize samples. This indicated that an unknown factor(s) had a large effect on NSF. These factors generally were affected more by environmental conditions than they were by genetic differences. The idea of an objective method to predict the optimum cooking time of maize based on NSF values was supported by large differences in NSF due to environmental factors. This is because it would be very unlikely for maize samples grown under widely different environmental conditions, such as those used for this study, to have largely similar optimum cooking times. However, the observation from a previous study that nixtamal, appraised as being optimal, made from some maize samples did not display NSF values within the "optimum" range may indicate that the method cannot reliably determine the proper cooking time for maize. Additional studies are needed to establish its validity. Overcooked nixtamal is sticky while that which is undercooked produces a crumbly masa which is difficult to handle. Both of these phenomena are related to the amount of starch gelatinization.

Apparent differences in the amount of pericarp removed from the maize samples during alkali cooking were noted. A large amount of the pericarp was removed from most samples of Mol4w x Tx71, but for most samples of C166 x Tx80 and Tx29A x Tx80, the major portion of the pericarp still adhered, though in most cases it could easily be removed. Although there appeared to be some differences due to



environment, genetics may be the major contributor to relative differences in ease of pericarp removal. Maize samples deemed to have large differences in ease of pericarp removal based on observations after they had been cooked in alkali and steeped, generally showed the same trends when placed in a dilute NaOH solution for several hours. The rate with which the solution was absorbed by the kernels seemed to be very important in effecting quick pericarp removal. The samples which took up the NaOH solution most rapidly also showed signs that their pericarps were separating from the seed at a faster rate.

Future studies should include SEM and fluorescence microscopy of raw and cooked maize samples shown to have widely different cooking properties to evaluate structural and chemical differences of the endosperm, including the cell walls, which might help to account for their dissimilar cooking characteristics. Also, studies should be done to try to relate the amount of starch gelatinization to optimum cooking time of maize for tortillas. If it proves to be a reliable method to determine when the proper amount of cooking has occurred, a quick and simple technique for quantifying starch gelatinization might be developed for use in the tortilla factory. This way each lot of maize which arrives could be quickly tested to determine the amount of cooking it requires to produce the proper degree of starch gelatinization. Additional and more detailed studies are necessary, including examination of the pericarp using SEM and fluorescence microscopic techniques, to determine if structural and chemical properties of the pericarp are associated with its ease of removal during cooking. Finally, if dissimilarities in pericarp removal prove

to be highly heritable, quick screening methods should be developed for use by maize breeders who will attempt to incorporate pericarps with improved ease of removal into maize hybrids and lines which are otherwise superior.

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TABLE A  
Statistical Descriptions of Physical and Chemical Properties for Grain  
of 12 White Maize Hybrids from Six Locations

Statistic	Property						
	Density (g/cm <sup>3</sup> )	Test Weight (kg/hl)	One Thousand Kernel Weight (g)	Protein (Nx6.25) (%)	Floaters (%)	Hardness	
						Grinding <sup>a</sup>	Centrifugal <sup>b</sup> Impacting (%)
Mean	1.284	72.3	288	10.0	56	67.0	6.2
Std Dev	0.003	0.14	8.0	0.2	4.2	0.6	0.6
C V	0.03	0.02	2.8	2.3	7.6	0.8	9.9
Maximum	1.324	77.2	384	14.7	100	77.0	10.2
Minimum	1.229	63.5	148	6.5	6	46.5	4.1

<sup>a</sup> Results obtained by a commercial grain miller. Published material pertaining to the method is not available but results are probably expressed as a percent of material that remained as overs after a sieving step.

<sup>b</sup> Expressed as a percentage of material passing through a 4.76 mm sieve.



TABLE B  
Statistical Descriptions of Nixtamal Properties for Grain  
of 12 White Maize Hybrids from Six Locations

Statistic	Property		
	Nixtamal Shear Force (lbs force)	Dry Matter <sup>a</sup> Loss Index (%)	Moisture Uptake <sup>b</sup> Index (%)
Mean	249	6.7	94
Std Dev	14.2	0.4	3.0
C V	5.7	6.6	3.2
Maximum	340	8.9	120
Minimum	170	5.2	80

<sup>a</sup>Percent of original grain dry matter lost during cooking.

<sup>b</sup>Expressed as a percentage of dry matter remaining after cooking.

TABLE C  
Stepwise Regression Analysis with Grinding  
Hardness as Dependent Variable

Variable Entered	R Square	F Value of Variable Entered
Density	0.85**	316**
Density and Protein	0.90**	28**

\*\* Highly significant at 0.01 level.

N = 57.

TABLE DJ  
Mean<sup>a</sup> Nixtamal Shear Force<sup>b</sup> for Grain of 12 White  
Maize Hybrids Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	273c	271bc	260a	217b	276b	291a
Tx91 x Tx585	279c	270bc	184d	228b	232cd	
Tx71 x Tx585	296b	293b	231b	226b	222ed	237bc
Tx71 x Tx80	277c	283bc	203c		218e	
Tx29A x Tx80	329a	328a	271a		223ed	279a
Tx71 x Gs209	247d	241d	197cd		241c	
Tx61H x Tx80	257d	273bc	199cd		170g	241bc
CI66 x Tx61	271c	264c	261a	278a		275a
Mol4w x Tx71	252d	238d	187cd	186c		229c
Tx29A x Tx71	300b	340a	229b	213b	237c	
CI66 x Tx80	278c	339a			299a	252b
Tx61H x Tx71	250d		202c	187c	200f	191d

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as lbs force.

<sup>c</sup>Locations are as follows: 1=College Station 1980, 2=College Station 1981, 3=Farwell 1980,  
4=Corpus Christi 1980, 5=Corpus Christi 1980, 6=Corpus Christi 1981.

TABLE D2  
Mean<sup>a</sup> Test Weight<sup>b</sup> for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5 <sup>d</sup>	6
Cl66 x Tx71	74.3bc	75.6a	75.0c	72.4c		74.2a
Tx81 x Tx585	72.4f	71.8e	72.2g	69.8e		
Tx71 x Tx585	72.8e	72.0e	71.7h	69.7e	65.3	70.1g
Tx71 x Tx80	71.0g	72.4d	73.3e		65.7	
Tx29A x Tx80	73.1d	73.9b	75.7b		63.5	73.2c
Tx71 x Ga209	72.5f	73.0c	73.0cf			
Tx61M x Tx80	72.5f	70.0f	73.7d		63.9	71.4f
Cl66 x Tx81	74.2c	73.8b	74.9c	73.9a		74.0ab
Mo14w x Tx71	70.9g	72.0	72.8f	70.2d		71.8e
Tx29A x Tx71	75.5a		77.2a	73.3b		
Cl66 x Tx80	72.6f	73.0c				72.4d
Tx61M x Tx71	74.5b		75.4b	74.1a	71.0	73.8b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as kg/hl.

<sup>c</sup>Locations identified in Table D1.

<sup>d</sup>Means could not be separated as only one replicate was done.

TABLE D3  
Mean<sup>a</sup> Grain Density<sup>b</sup> for 12 White Maize Hybrids  
Crown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	1.297cd	1.300b	1.307b	1.292b	1.249bc	1.294a
Tx81 x Tx585	1.296cd	1.282de	1.290c	1.279c	1.255b	
Tx71 x Tx585	1.299c	1.285d	1.278d	1.271d	1.244c	1.280b
Tx71 x Tx80	1.291d	1.276ef	1.278d		1.246c	
Tx29A x Tx80	1.297cd	1.287cd	1.308b		1.229d	1.293a
Tx71 x Ga209	1.291d	1.273f	1.281d		1.233d	
Tx61M x Tx80	1.295cd	1.282de	1.283cd		1.233d	1.263c
CI66 x Tx81	1.300c	1.299b	1.312b	1.303a		1.297a
Mol4w x Tx71	1.275c	1.272f	1.280d	1.259e		1.280b
Tx29A x Tx71	1.322a	1.324a	1.321a	1.278c	1.294a	
CI66 x Tx80	1.278e	1.292b			1.229d	1.292ab
Tx61M x Tx71	1.314b		1.308b	1.294b	1.288a	1.299a

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as g/cm<sup>3</sup>.

<sup>c</sup>Locations identified in Table D1.

TABLE D4  
Mean<sup>a</sup> Percent Floaters for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>b</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	35d	22e	14cd	30e	99a	31d
Tx81 x Tx585	41d	63bcd	53b	73b	86b	
Tx71 x Tx585	36d	58cd	65a	79b	95a	68b
Tx71 x Tx80	70ab	72ab	52b		99a	
Tx29A x Tx80	62bc	61cd	19c		99a	45c
Tx71 x Ga209	54c	68abc	55ab		100a	
Tx61M x Tx80	56c	76a	65a		100a	84a
CI66 x Tx81	34d	26e	12cd	18f		22d
Mo14w x Tx71	76a	76a	54b	95a		69b
Tx29A x Tx71	17e	7f	6d	59c	67c	
CI66 x Tx80	78a	55d			100a	56bc
Tx61M x Tx71	21e		18c	48d	65c	31d

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Locations identified in Table D1.

TABLE D5  
Mean<sup>a</sup> Grinding Hardness<sup>b</sup> for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	71.0cd	70.0c	73.0b	70.0b	56.5bc	70.5b
Tx81 x Tx585	72.0bc	71.0c	68.5d	66.5d	57.5b	
Tx71 x Tx585	72.5b	70.5c	66.5e	68.0c	56.5bc	70.0b
Tx71 x Tx80	71.0cd	68.5d	64.5f		57.5b	
Tx29A x Tx80	68.5f	67.5e	66.5e		46.5e	68.0cd
Tx71 x Ga209	70.0de	65.0f	63.0g		55.5cd	
Tx61M x Tx80	69.5ef	70.5c	60.0h		47.5e	62.0e
CI66 x Tx81	71.0cd	73.0b	74.5a	74.0a		72.0a
Mo14w x Tx71	63.5h	64.0g	63.0g	59.0e		67.0d
Tx29A x Tx71	76.5a	77.0a	72.5b	68.0c		
CI66 x Tx80	67.0g	70.0c			54.5d	68.5c
Tx61M x Tx71	75.5a		71.0c	70.0b	66.5a	72.0a

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Published material pertaining to the method is unavailable, but results are probably expressed as a percentage of grain that remained as overs after a sieving step.

<sup>c</sup> Locations identified in Table D1.

TABLE D6  
Mean<sup>a</sup> Centrifugal Impact Hardness<sup>b</sup> for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	5.5cde	6.5bc	5.3d	5.5		5.6
Tx81 x Tx585	5.2de	6.2bc	6.2bcd	6.2	6.5cd	
Tx71 x Tx585	5.7cd	5.8c	5.2d	6.1	7.1c	5.3
Tx71 x Tx80	4.6e	5.8c	7.0abcd		8.4b	
Tx29A x Tx80	6.8ab	6.0c	6.7abcd		10.2a	6.4
Tx71 x Ca209	7.5a	8.1a	8.2a		9.9a	
Tx61M x Tx80	4.6e	4.6d	6.3abcd		8.7b	5.2
CI66 x Tx81	5.5cde	6.0c	5.3cd	5.6		5.0
Ho14w x Tx71	4.8de	7.0b	6.8abcd	6.5		5.3
Tx29A x Tx71	6.3bc		7.9ab	7.2		
CI66 x Tx80	5.0de	4.1d			5.6d	4.4
Tx61M x Tx71	5.5cde		7.2abc	7.3	6.9c	7.1

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as a percentage of material passing through a 4.76 mm sieve.

<sup>c</sup>Locations identified in Table D1.



TABLE D7  
Mean<sup>a</sup> Percent Protein for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>b</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	10.5c	12.7b	9.0c	11.8b	11.0b	11.2b
Tx81 x Tx585	11.0b	10.6c	10.5b	9.6d	12.2a	
Tx71 x Tx585	11.5a	12.7b	11.8a	12.5a	12.2a	13.0a
Tx71 x Tx80	11.2ab	9.8c	9.0c		9.7d	
Tx29A x Tx80	10.9bc	10.4cd	8.1d		8.7e	9.6c
Tx71 x Ga209	9.9d	9.2f	7.9d		10.2c	
Tx61M x Tx80	10.5c	14.6a	6.5f		8.6e	9.1cd
CI66 x Tx81	10.0d	8.9f	9.4c	10.7c		8.9d
Mol4w x Tx71	9.2e	8.4g	7.2e	8.3e		8.8d
Tx29A x Tx71	11.1ab	10.5cd	8.1d	9.6d	10.1cd	
CI66 x Tx80	9.7d	10.0de			10.2c	9.5c
Tx61M x Tx71	9.5de		9.1c	9.3d	8.6e	8.9d

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Locations identified in Table D1.

TABLE D8  
Mean<sup>a</sup> One Thousand Kernel Weight<sup>b</sup> for 12 White Maize  
Hybrids Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
C166 x Tx71	259b	348ab	312cd	370ab	156d	380ab
Tx81 x Tx585	280a	359ab	374a	379a	219a	
Tx71 x Tx585	278a	368a	355b	358b	203b	365b
Tx71 x Tx80	206d	315cd	296cde		169c	
Tx29A x Tx80	286a	337bc	352b		198b	384a
Tx71 x Ga209	248b	303d	315c		167c	
Tx61M x Tx80	214cd	257e	292de		170c	308d
C166 x Tx81	259b	345ab	316c	372ab		342c
Mo14w x Tx71	210cd	308d	315c	329c		339c
Tx29A x Tx71	220c	298d	291e	337c	148d	
C166 x Tx80	252b	312cd			178c	328c
Tx61M x Tx71	206d		309cde	292d	217a	282e

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Expressed as grams.

<sup>c</sup> Locations identified in Table D1.

TABLE D9  
Mean<sup>a</sup> Dry Matter Loss Index<sup>b</sup> for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	6.2bcd	7.3ab	5.4g	7.1b	5.7fg	6.4cd
Tx81 x Tx585	6.0cd	6.5bcd	6.4efg	7.1b	6.1efg	
Tx71 x Tx585	5.7cd	6.3cd	6.9cde	5.3c	7.1bcd	8.1a
Tx71 x Tx80	6.4bcd	7.3ab	7.5bcd		6.2def	
Tx29A x Tx80	6.7abc		6.5def		8.0ab	7.3abc
Tx71 x Ga209	5.9cd	5.2e	7.1bcde		5.2g	
Tx61M x Tx80	6.3bcd	7.3ab	8.5a		7.4bc	6.6bcd
CI66 x Tx81	7.7a	6.1de	5.8fg	5.2c		5.4d
Mol4w x Tx71	7.1ab	7.6a	8.1ab	8.1ab		7.8ab
Tx29A x Tx71	5.6d	6.1d	6.3efg	8.9a	8.7a	
CI66 x Tx80	6.4bcd	7.1abc			6.1efg	7.0abc
Tx61M x Tx71	6.3bcd		7.9abc	7.1b	6.7cde	6.1cd

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as a percentage of original grain dry matter lost during cooking.

<sup>c</sup>Locations identified in Table D1.

TABLE D10  
Mean<sup>a</sup> Moisture Uptake Index<sup>b</sup> for Grain of 12 White Maize Hybrids  
Grown at Each of Six Locations<sup>c</sup>

Hybrid	Location					
	1	2	3	4	5	6
CI66 x Tx71	90defg	86bcd	91bcd	84b	106bcd	84cd
Tx81 x Tx585	89fg	88abc	97abc	98a	101d	
Tx71 x Tx585	90efg	87bcd	99ab	96a	106bcd	102a
Tx71 x Tx80	99ab	94a	97abc		112b	
Tx29A x Tx80	85g		89cd		110bc	88bcd
Tx71 x Ga209	95bcde	94a	93abcd		105cd	
Tx61M x Tx80	96bcd	91ab	97abc		120a	91bc
CI66 x Tx81	92cdef	82de	84d	84b		82d
Mol4w x Tx71	103a	92a	102a	100a		94ab
Tx29A x Tx71	87fg	80c	89cd	96a	105cd	
CI66 x Tx80	87fg	84cde			101d	85cd
Tx61M x Tx71	97bc		96abc	101a	105cd	96ab

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as a percentage of dry matter remaining after cooking.

<sup>c</sup>Locations identified in Table D1.

TABLE E1  
Mean<sup>a</sup> Nixtawal Shear Force<sup>b</sup> for Grain of Each of 12 White  
Maize Hybrids<sup>c</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	273ab	279a	296a	277a	329a	247a	257b	271	252a	300b	278b	250a
College Station	1981	271ab	270a	293a	283a	328a	241a	273a	264	238b	340a	339a	
Farwell	1980	260b	184c	231b	203c	271b	197b	199d	261	187c	229cd		202b
Corpus Christi	1979	217c	228b	226b					278	186c	213d		187c
Corpus Christi	1980	276ab	232b	222b	218b	223c	241a	170e			237c	299b	200bc
Corpus Christi	1981	291a		237b		279b		241c	275	299b		252c	191bc

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as lbs force.

<sup>c</sup>Hybrids are as follows: 1=C166 x Tx71, 2=Tx81 x Tx585, 3=Tx71 x Tx585, 4=Tx71 x Tx80, 5=Tx29A x Tx80, 6=Tx71 x Ga209, 7=Tx61M x Tx80, 8=C166 x Tx81, 9=Mo14w x Tx71, 10=Tx29A x Tx71, 11=C166 x Tx80, 12=Tx61M x Tx71.

TABLE E2  
Mean<sup>a</sup> Test Weight<sup>b</sup> for Grain of Each of 12 White Maize  
Hybrids<sup>c</sup> Grown at Six Locations

		Hybrid											
Location		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	74.3c	72.4a	72.8a	71.0c	73.1c	72.5b	72.5b	74.2b	70.9c	75.5b	72.6b	74.5b
College Station	1981	75.6a	71.8b	72.0b	72.4b	73.9b	73.0a	70.0d	73.8b	72.0b		73.0a	
Farwell	1980	75.0b	72.2ab	71.7c	73.3a	75.7a	73.0a	73.7a	74.9a	72.8a	77.2a		75.4a
Corpus Christi	1979	72.4d	69.8c	69.7e					73.9b	70.2d	73.3c		74.1b
Corpus Christi	1980			65.3f	65.7d	63.5d		63.9e					71.0c
Corpus Christi	1981	74.2c		70.1d		73.2c		71.4c	74.0b	71.8b		72.4b	73.8b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as kg/hl.

<sup>c</sup>Hybrids identified in Table E1.

TABLE E3  
Mean<sup>a</sup> Grain Density<sup>b</sup> for Each of 12 White Maize Hybrids<sup>c</sup>  
Grown at Six Locations

Location	Hybrid											
	1	2	3	4	5	6	7	8	9	10	11	12
College Station 1980	1.297bc	1.296a	1.299a	1.291a	1.297b	1.291a	1.295a	1.300b	1.275ab	1.322a	1.278b	1.314a
College Station 1981	1.300b	1.282bc	1.285b	1.276b	1.287c	1.273c	1.282a	1.299b	1.272b	1.324a	1.292a	
Farwell 1980	1.307a	1.290ab	1.278bc	1.278b	1.308a	1.281b	1.283a	1.312a	1.280a	1.321a		1.308ab
Corpus Christi 1979	1.292c	1.279c	1.271c					1.303ab	1.259c	1.278c		1.294cd
Corpus Christi 1980	1.249d	1.255d	1.244d	1.246c	1.229d	1.233d	1.233c			1.294b	1.229c	1.288d
Corpus Christi 1981	1.294c		1.280bc		1.293bc		1.263b	1.297b	1.280a		1.292a	1.299bc

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as g/cm<sup>3</sup>.

<sup>c</sup>Hybrids identified in Table E1.

TABLE E4  
Mean<sup>a</sup> Percent Floaters for Grain of Each of 12 White Maize  
Hybrids<sup>b</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	35b	41d	36d	70b	62b	54c	56c	34a	76b	17b	78b	21b
College Station	1981	22cd	63bc	58c	72b	61b	68b	76b	26ab	76b	7c	55c	
Farwell	1980	14d	53cd	65c	52c	19d	55c	65c	12c	54c	6c		18b
Corpus Christi	1979	30bc	73b	79b					18bc	95a	59a		48a
Corpus Christi	1980	99a	86a	95a	99a	99a	100a	100a			67a	100a	65a
Corpus Christi	1981	31bc		68bc		45c		84b	22b	69b		56c	31b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Hybrids identified in Table E1.



TABLE E5  
Mean<sup>a</sup> Grinding Hardness<sup>b</sup> for Grain of Each of 12 White Maize  
Hybrids<sup>c</sup> Grown at Six Locations

		Hybrid											
Location		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	71.0b	72.0a	72.5a	71.0a	68.5a	70.0a	69.5a	71.0c	63.5bc	76.5a	67.0c	75.5a
College Station	1981	70.0b	71.0a	70.5b	68.5b	67.5ab	65.0b	70.5a	73.0ab	64.0b	77.0a	70.0a	
Farwell	1980	73.0a	68.5b	66.5d	64.5c	66.5b	63.0c	60.0c	74.5a	63.0c	72.5b		71.0b
Corpus Christi	1979	70.0b	66.5c	68.0c					74.0a	59.0d	68.0c		70.0b
Corpus Christi	1980	56.5c	57.5d	56.5e	57.5d	46.5c	55.5d	47.5d				54.5d	66.5c
Corpus Christi	1981	70.5b		70.0b		68.0ab		62.0b	72.0bc	67.0a		68.5b	72.0b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Results obtained by a commercial grain miller. No published material is available but results are probably expressed as a percent of material that remained as overs after a sieving step.

<sup>c</sup>Hybrids identified in Table E1.

TABLE E6  
Mean<sup>a</sup> Centrifugal Impact Hardness<sup>b</sup> for Grain of Each of 12 White  
Maize Hybrids<sup>c</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	5.5	5.2b	5.7	4.6c	6.8b	7.5b	4.6c	5.5	4.8	6.3b	5.0	5.5
College Station	1981	6.5	6.2a	5.8	5.8bc	6.0b	8.1b	4.6c	6.0	7.0		4.1	
Farwell	1980	5.3	6.2a	5.2	7.0ab	6.7b	8.2b	6.3b	5.3	6.8	7.9a		7.2
Corpus Christi	1979	5.5	6.2a	6.1					5.6	6.5	7.2a		7.3
Corpus Christi	1980		6.5a	7.1	8.4a	10.2a	9.9a	8.7a				5.6	6.9
Corpus Christi	1981	5.6		5.3		6.4b		5.2c	5.0	5.3		4.4	7.1

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as a percentage of material passing through a 4.76 mm sieve.

<sup>c</sup>Hybrids identified in Table E1.

TABLE E7  
Mean<sup>a</sup> Percent Protein for Grain of Each of 12 White  
Maize Hybrids<sup>b</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	10.5d	11.0b	11.5c	11.2a	10.9a	9.9b	10.5b	10.0b	9.2a	11.1a	9.9	9.5a
College Station	1981	12.7a	10.6b	12.7ab	9.8b	10.4a	9.2c	14.6a	8.9c	8.4c	10.5b	10.0	
Farwell	1980	9.0e	10.5b	11.8c	9.0c	8.1d	7.9d	6.5d	9.4bc	7.2d	8.1e		9.1abc
Corpus Christi	1979	11.8b	9.6c	12.5b					10.7a	8.3c	9.6d		9.3ab
Corpus Christi	1980	11.0cd	12.2a	12.2b	9.7b	8.7c	10.2a	8.6c			10.1c	10.2	8.6c
Corpus Christi	1981	11.2bc		13.0a		9.6b		9.1c	8.9c	8.8b		9.5	8.9bc

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Hybrids identified in Table E1.

TABLE EB  
Mean<sup>a</sup> One Thousand Kernel Weight<sup>b</sup> for Each of 12  
White Maize Hybrids<sup>c</sup> Grown at Six Locations

		Hybrid											
Location		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	259d	280b	278b	206b	286c	248b	214d	259c	210c	220c	252b	206c
College Station	1981	348b	359a	368a	315a	337b	303a	257c	345ab	308b	298b	312a	
Farwell	1980	312c	374a	355a	296a	352b	315a	292b	316b	315b	291b		309a
Corpus Christi	1979	370a	379a	358a					372a	329a	337a		292ab
Corpus Christi	1980	156e	219c	203c	169c	198d	167c	170e			148d	178c	217c
Corpus Christi	1981	380a		365a		384a		308a	342b	339a		328a	282b

<sup>a</sup>Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup>Expressed as grams.

<sup>c</sup>Hybrids identified in Table E1.

TABLE E9  
Mean<sup>a</sup> Dry Matter Loss Index<sup>b</sup> for Grain of Each of 12  
White Maize Hybrids<sup>c</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	6.2ab	6.0	5.7cd	6.4b	6.7b	5.9ab	6.3b	7.7a	7.1	5.6b	6.4	6.3
College Station	1981	7.3a	6.5	6.3bcd	7.3a		5.2b	7.3ab	6.1b	7.6	6.1b	7.1	
Farwell	1980	5.4b	6.4	6.9abc	7.5a	6.5b	7.1a	8.5a	5.8b	8.1	6.3b		7.9
Corpus Christi	1979	7.1a	7.1	5.3d					5.2b	8.1	8.9a		7.1
Corpus Christi	1980	5.7b	6.1	7.1ab	6.2b	8.0a	5.2b	7.4ab			8.7a	6.1	6.7
Corpus Christi	1981	6.4ab		8.1a		7.3ab		6.6b	5.4b	7.8		7.0	6.1

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Expressed as a percentage of original grain dry matter lost during cooking.

<sup>c</sup> Hybrids identified in Table E1.

TABLE E10  
Mean<sup>a</sup> Moisture Uptake Index<sup>b</sup> for Grain of Each of  
12 White Maize Hybrids<sup>c</sup> Grown at Six Locations

Location		Hybrid											
		1	2	3	4	5	6	7	8	9	10	11	12
College Station	1980	90bc	89b	90cd	99b	85b	95b	96b	92a	103a	87bc	87b	97
College Station	1981	86bc	88b	87d	94b		94b	91b	82b	92b	80c	84b	
Farwell	1980	91b	97a	99b	97b	89b	93b	97b	84b	102a	89bc		96
Corpus Christi	1979	84c	98a	96bc					84b	100ab	96ab		101
Corpus Christi	1980	106a	101a	106a	112a	110a	105a	120a			105a	101a	105
Corpus Christi	1981	84c		102ab		88b		91b	82b	94ab		85b	96

<sup>a</sup> Means in a column with same letter are not significantly different at 0.05 level.

<sup>b</sup> Expressed as a percentage of dry matter remaining after cooking.

<sup>c</sup> Hybrids identified in Table E1.

TABLE F1  
Correlations Between Physical and Chemical Characteristics for Grain  
of 12 White Maize Hybrids Grown During 1980 at College Station

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floater	Grinding	Centrifugal Impacting
Density		-0.90**	0.93**	0.33
Protein	0.67*	-0.24	0.45	0.06
Floater			-0.88**	-0.29
Grinding				0.25
Moisture Uptake Index	-0.75**			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N = 12.

TABLE F2  
Correlations Between Physical and Chemical Characteristics for Grain of  
11 White Maize Hybrids Grown During 1981 at College Station

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.93**	0.87**	-0.39
Protein	0.14	0.00	0.29	-0.44
Floaters			-0.75**	0.00
Grinding				-0.59
Moisture Uptake Index	-0.66*			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 10 to 11.



TABLE F3  
Correlations Between Physical and Chemical Characteristics for Grain of  
11 White Maize Hybrids Grown During 1980 at Farwell

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.96**	0.82**	0.01
Protein	0.15	0.04	0.43	-0.50
Floaters			-0.84**	-0.02
Grinding				-0.28
Moisture Uptake Index	-0.76**			

\*\* Highly significant at 0.01 level.

N = 11.

TABLE F4  
Correlations Between Physical and Chemical Characteristics for Grain  
of Seven White Maize Hybrids Grown During 1979 at Corpus Christi

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.96**	0.92**	-0.23
Protein	0.47	-0.35	0.54	-0.61
Floaters			-0.88**	0.35
Grinding				-0.25
Moisture Uptake Index	-0.72			

\*\* Highly significant at 0.01 level.

N = 7.

TABLE F5  
Correlations Between Physical and Chemical Characteristics for Grain of  
10 White Maize Hybrids Grown During 1980 at Corpus Christi

Dependent Variable: Nixtamal Shear Force	Hardness		
	Floaters	Grinding	Centrifugal Impacting
Density	-0.96**	0.86**	-0.39
Protein 0.42	0.11	0.22	-0.45
Floaters		-0.77*	0.39
Grinding			-0.54
Moisture Uptake Index -0.70*			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 8 to 10.

TABLE F6  
Correlations Between Physical and Chemical Characteristics for Grain of  
Eight White Maize Hybrids Grown During 1981 at Corpus Christi

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.92**	0.87**	0.34
Protein	0.21	0.14	0.21	-0.11
Floaters			-0.84**	-0.36
Grinding				0.28
Moisture Uptake Index	-0.73*			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N = 8.

TABLE G1  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for CI66 x Tx71 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.99**	0.99**	0.29
Protein	-0.10	0.08	-0.16	0.82
Floaters			-0.98**	-0.01
Grinding				-0.62
Moisture Uptake Index	0.26			
Nitrogen Applied	0.21			
Phosphorous Applied	0.20			
Potassium Applied	0.20			

\*\* Highly significant at 0.01 level.

N ranged from 5 to 6.

TABLE G2  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx81 x Tx585 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.95*	0.94*	-0.75
Protein	0.15	0.30	-0.60	0.12
Floaters			-0.87	0.85
Grinding				-0.70
Moisture Uptake Index	-0.74			
Nitrogen Applied	0.99**			
Phosphorous Applied	0.93			
Potassium Applied	0.95			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 4 to 5.

TABLE G3  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx71 x Tx585 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.96**	0.95**	-0.78
Protein	-0.23	0.42	0.03	0.02
Floaters			-0.84*	0.65
Grinding				-0.79
Moisture Uptake Index	-0.87*			
Nitrogen Applied	0.98**			
Phosphorous Applied	0.96*			
Potassium Applied	0.97**			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 5 to 6.

TABLE G4  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx71 x Tx80 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.79	0.95	-0.91
Protein	0.73	0.19	0.57	-0.71
Floaters			-0.60	0.48
Grinding				-0.98*
Moisture Uptake Index	-0.46			
Nitrogen Applied	0.96			
Phosphorous Applied	0.98			
Potassium Applied	0.99			

\* Significant at 0.05 level

N ranged from 3 to 4.



TABLE G5  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx29A x Tx80 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floater	Grinding	Centrifugal Impacting
Density		-0.90*	0.96*	-0.92*
Protein	0.82	0.21	0.47	-0.44
Floater			-0.76	0.76
Grinding				-0.98**
Moisture Uptake Index	-0.88			
Nitrogen Applied	0.88			
Phosphorous Applied	0.86			
Potassium Applied	0.88			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 4 to 5.

TABLE G6  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx71 x Ga209 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floater	Grinding	Centrifugal Impacting
Density		-0.99*	0.94	-0.99*
Protein	0.92	0.59	-0.16	0.36
Floater			-0.88	0.95*
Grinding				-0.98*
Moisture Uptake Index	0.40			
Nitrogen Applied	0.54			
Phosphorous Applied	0.10			
Potassium Applied	0.17			

\* Significant at 0.05 level.

N ranged from 3 to 4.

TABLE G7  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx61M x Tx80 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.96**	0.89*	-0.85
Protein	0.77	-0.05	0.63	-0.54
Floaters			-0.75	0.71
Grinding				-0.98**
Moisture Uptake Index	-0.84			
Nitrogen Applied	0.73			
Phosphorous Applied	0.77			
Potassium Applied	0.77			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N ranged from 4 to 5.

TABLE G8  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for CI66 x Tx81 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.74	0.77	-0.09
Protein	0.53	-0.02	0.16	0.12
Floaters			-0.89*	0.27
Grinding				0.18
Moisture Uptake Index	0.06			
Nitrogen Applied	-0.77			
Phosphorous Applied	-0.94			
Potassium Applied	-0.92			

\* Significant at 0.05 level.

N ranged from 4 to 5.

TABLE G9  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Mol4w x Tx71 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.92*	0.85	-0.27
Protein	0.81	0.47	0.30	-0.77
Floaters			-0.59	-0.03
Grinding				-0.39
Moisture Uptake Index	-0.34			
Nitrogen Applied	0.79			
Phosphorous Applied	0.69			
Potassium Applied	0.71			

\* Significant at 0.05 level.

N ranged from 4 to 5.

TABLE G10  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx29A x Tx71 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.92*	0.90	-0.10
Protein	0.66	0.10	0.56	-0.99*
Floaters			-0.81	-0.12
Grinding				-0.53
Moisture Uptake Index	-0.75			
Nitrogen Applied	0.89			
Phosphorous Applied	0.98*			
Potassium Applied	0.98*			

\* Significant at 0.05 level.

N ranged from 3 to 5.

TABLE G11  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for CI66 x Tx80 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floater	Grinding	Centrifugal Impacting
Density		-0.96*	0.99**	-0.92
Protein	0.75	0.63	-0.67	0.46
Floater			-0.93	0.98*
Grinding				-0.91
Moisture Uptake Index	0.05			
Nitrogen Applied	0.41			
Phosphorous Applied	0.66			
Potassium Applied	0.63			

\*\* Highly significant at 0.01 level.

\* Significant at 0.05 level.

N = 4.

TABLE G12  
Correlations Between Physical and Chemical Characteristics of Grain and  
Agronomic Conditions for Tx61M x Tx71 Across Locations

Dependent Variable	Nixtamal Shear Force	Hardness		
		Floaters	Grinding	Centrifugal Impacting
Density		-0.93*	0.89*	-0.61
Protein	0.60	-0.62	0.81	-0.53
Floaters			-0.83	0.33
Grinding				-0.67
Moisture Uptake Index	-0.31			
Nitrogen Applied	0.98*			
Phosphorous Applied	0.98*			
Potassium Applied	0.98*			

\* Significant at 0.05 level.

N ranged from 4 to 5.



## VITA

Troy Marc Goldstein was born in Atlanta, Georgia, but has spent most of his life in Dallas, Texas, where he graduated from White High School in 1974. He attended Southwest Texas State University from 1974 to 1976. He then enrolled at Texas A&M University and graduated in 1979 with a B.S. degree in Food Science and Technology. Following one year of employment in Frito-Lay's Research and Development section at Irving, Texas, he returned to Texas A&M University to complete a Master of Science degree in Food Science and Technology.

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