INCREASING THE GENETIC DIVERSITY OF US NORTHERN CORN BELT HYBRIDS WITH TROPICAL AND TEMPERATE EXOTIC GERMPLASM

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Increasing the Genetic Diversity of US Northern Corn Belt Hybrids

With Tropical and Temperate Exotic Germplasm

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

Sharma, Santosh; MS; Department of Plant Sciences; College of Agriculture, Food Systems and Natural Resources; North Dakota State University; July 2011. Increasing the Genetic Diversity of US Northern Corn Belt Hybrids with Tropical and Temperate Exotic Germplasm. Major Professor: Dr. Marcelo J. Carena.

The NDSU EarlyGEM or the Early Germplasm Enhancement of Maize (*Zea maize* L.) is a long term incorporation program designed to increase the genetic diversity of short season hybrids. Starting in 1999, exotic GEM breeding crosses derived from temperate accessions: BR52051, CHO5015; tropical accessions: SCR01, CUBA117, FS8B; and tropical hybrid DKB844 along with late checks: B73, Mo17, and Iowa Stiff Stalk Synthetic (BSSS), were adapted to short-seasons and incorporated via a modified backcross (BC) procedure. This study was designed to assess the genetic diversity in exotic derived $BC_1:S_1$ lines and their competitive potential as sources of new and unique hybrids. Useful genetic diversity was evaluated with testers belonging to opposite heterotic groups, LH176 representing a non stiff stalk and TR3026 x TR2040 a stiff stalk testers and were tested in five North Dakota environments over two years (2009 and 2010). All the traits showed highly significant ($P<0.01$) differences across genotypes except root and stalk lodging. Among 236 experimental testcrosses, 64 were statistically not different (LSD, 0.05) to industry hybrids for grain yield. BC derived lines from BR52051, CHO5015, DKB844 showed diverse alleles for low grain moisture (below 87 relative maturity days) at harvest and high grain yield. SCRO1, BR52051, CHO5015 and CUBA117 derived lines produced hybrids with high grain oil (4.9% vs. 4.1%) and grain protein (10.4% vs. 9.1%) contents compared to top checks. The results showed that the exotic incorporations are the sources of unique new alleles for early maturing maize not present in existing US germplasms (e.g. B73, Mo17, and BSSS). Even though each exotic cross was unique to integrate diverse alleles, utilizing multiple unique exotic crosses for incorporation showed large variation for specific traits. Phenotypic correlations of traits showed grain moisture played the most important role for short season hybrid development. Exotic incorporation through NDSU EarlyGEM has shown a new way of breeding early maturing maize keeping the breeding program open and genetic diversity high.

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DEDICATION

To my lovely parents Bhubaneshor and Parvata Sharma

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

INTRODUCTION

North Dakota (ND) acreage of maize (*Zea mays* L.) had record increases from 590,000 acres of maize planted in 1997 to 2.3 million acres planted in 2011 with the record of 2.5 million acres planted in 2007 (USDA, 2011). The main reasons for this significant increase is the renewable fuel demand (Carena et al., 2009) and the change in weather pattern favoring maize production (Ransom et al., 2004). In ND, maize is expanding northward and westward to areas previously considered marginal for maize production posing significant trait challenges related to early maturity, drought tolerance, test weight and grain quality. This region has characteristic short maize growing season and cooler temperatures throughout the growing period. The large part of this region needs maize with maturity lower than 90RM (relative maturity) days (Carena et al., 2009).

Improved maize exotic germplasm can be the potential sources of significant genetic improvement and of new alleles different from B73 and other elite lines recently sequenced (Hallauer and Carena, 2009). The utilization of exotic germplasms can increase the genetic diversity of the crops for various important traits including many biotic and abiotic stresses (Goodman et al., 1990; Goodman, 1999; Uhr and Goodman, 1995; Tanskley and McCouch, 1997). Historically, Iodent derived lines (derived from I159, I198, I205, MBS847 etc.) and the Minnesota 13 line have been found to contribute to early dry down for short season hybrids (Goodman, 2005). However recently there are not many efforts to develop diverse sources contributing early maturity.

Adaptation is a unique way to move exotic germplasms to a new environment. Learning to adapt new crop varieties to changing climate is an important tool to solve the food insecurity of present world (CSSA, 2011). The biggest event in the history of maize germplasm evaluation was the Latin American Maize project (LAMP). LAMP evaluated over 12,000 maize accessions comprising 74% of the known races of maize found in Latin America and the USA. It was cooperative effort of 11 Latin American countries and USA. The evaluated accessions were the products of experiments on special traits like: drought resistance, disease and insect resistance to northern leaf blight (*Exserohilum turcicum),* army worm (*Spodoptera frugiperda*), ear worm (*Heliothis zea*) and Fusarium ear rot (*Fusarium moniliforme*), cold tolerance, and grain quality traits (Sevilla and Salhuana, 1997). The follow up of the LAMP project was the Germplasm Enhancement of Maize Project (GEM) of Iowa and North Carolina State which adapted maize to the southern temperate climate of the USA by crossing with industry lines (Pollak, 2003).

Exotic germplasm incorporation is a unique way of genetic diversification of favorable alleles to the breeding germplasms (Simmonds, 1993). The NDSU EarlyGEM (the Early Germplasm Enhancement of Maize Program) is a long-term incorporation program designed to increase the genetic diversity of short-season and short season drought tolerant hybrids. It utilizes the GEM project as an intermediate adaptation process to incorporate diverse alleles from tropical and temperate exotic germplasm.

This research study was conducted to assess the genetic diversity created by exotic GEM germplasm via an incorporation program 'NDSU EarlyGEM'. It was the first study to evaluate whether elite exotic GEM germplasm can donate the superior alleles than top popular U.S. check lines Mo17, BSSS and B73 for unique short season hybrid development. We compared the variation among the incorporations of different breeding crosses. This also helped us to identify potential EarlyGEM back cross lines for future breeding with specific quality and agronomic traits as short season early maturing hybrids.

Our hypothesis was that the improved temperate and tropical exotic germplasm can be adapted quickly and can be incorporated to create more genetic diversification than the U.S. lines Mo17, BSSS (Iowa Stiff Stalk synthetics) and B73 for many of agronomic and quality traits to develop competitive short season hybrids below 90RM days.

LITERATURE REVIEW

Use of Exotic Germplasm in Temperate Maize

Exotic germplasm include all germplasms having no immediate use without selection for adaptation to the given environments (Hallauer and Miranda, 1988). These germplasm represent potential sources of significant genetic improvement and of new alleles different from B73 and other elite lines recently sequenced (Hallauer and Carena, 2009). The utilization of exotic germplasm can increase the genetic diversity of crops for various important traits including response to many biotic and abiotic stresses (Goodman, 1999). It gives an opportunity to diversify the scope of selection for individual traits like earliness, drought tolerance, pest and disease resistance, and high quality in North Dakota (Carena et al., 2009). The potential yield of elite maize cultivars depends on identifying good heterotic combinations. New heterotic combinations can be possible with utilization of diverse exotic germplasms (Crossa et al., 1987, Parra and Hallauer, 1997).

Goodman (1999) identified three geographic types of maize germplasms exotic to temperate U.S. areas. The first types were from other temperate areas such as Argentina, Europe, and South Africa. The second types were from the lowland tropics. These represent the races or varieties such as Cuban Flint, Suwan, Tuson, and Tuxpeno. These have been used in the U.S. as source of disease and pest resistance. The third types were the least used and belong to the highland tropics. They include races like Chalqueno, Cuzco, Sabanero, or San Geromino. Their general weakness is the low tolerance to heat and other stresses.

Surveys of exotic germplasm use covering 1983 to 1996 planting seasons have indicated very little applications (Goodman, 2004). It showed for tropical germplasm sources the use was 0.1% in 1983 and 0.3% in 1996. The 1996 survey was an extensive survey including both conventional (Pioneer, DeKalb, etc) and foundation seed companies (Holden's, Illinois foundation seeds) that covered more than 90% of the maize seed sold in the USA. Goodman (2004) has reported that only two non-U.S. sources (French lines F2 and F7 from the open pollinated variety Lacauna and other source from insect resistant Argentine variety Maize Amargo via lines B64 and B68) contributed most of the exotic uses in the U.S. maize inbreds and hybrids. The French source was described as with limited use in the northern U.S. and the Argentinean source contributed small percentages (1% to 5%) of germplasm throughout all maize growing region of the U.S. The survey showed that the average percentage of temperate exotic germplasm was 2.57% while the percentage for tropical germplasm was only 0.31% of the total U.S. hybrid maize seed market. Altogether temperate and tropical exotic germplasm reported to represent only less than 3% of the U.S. market.

Exotic germplasm have been found to be a source for new and useful diversity. There are many examples of superior exotic derived lines in past. Goodman (1999) showed that exotic tropical lines could compete with domestic lines in certain tropical × domestic combinations. He showed better yields than commercial hybrid in North Carolina trials. One of temperate adapted lines, NC296A, was found to be a source for potentially new yield factors in U.S. breeding programs. It also showed gray leaf spot (*Cercospora zeae-maydis*) and southern leaf rust (*Puccinia polysora*) resistances. NC296A was a temperate-adapted line that was derived from a cross of two tropical hybrids, Pioneer X105 from Jamaica and H5 from CENTA (Centro Nacional de Tecnologia Agricola), El Salvador. The use of tropical germplasm usually introduces more lodging, higher moisture at harvest, taller plants, and susceptibility to smut (*Ustilago maydis*). However, the study found that the lines had higher yield and more gray leaf spot (*Cercospora zeae-maydis*) and southern rust resistance (*Puccinia polysora*). Tropical germplasms were found to be effective for yield improvement in the U.S. temperate hybrids (Goodman et al., 1990; Uhr and Goodman.1995, and Tarter et al., 2003). Uhr and Goodman (1995) found 17 testcrosses out of 190 to yield similar to commercial checks.

Techniques of Genetic Diversification and Evaluation

Exotic Germplasm Incorporation

Genetic enhancement through incorporation of exotic germplasm can contribute to sustainability of a plant breeding program for long term selection. It is a source of significant genetic gain when choice is successfully carried out. Simmonds (1993) described genetic incorporation as the vital part of plant breeding that develops lines which are superior to parental lines, containing high proportions of alleles not previously present in intermediate germplasm pools. He described it as a precondition for the long term progress in selection. The principles of incorporation were described as: widely based population, maximal recombination, weak selection, local adaptation, genetic isolations, quick turnover of generations aimed at producing parental stocks, economy of operations, and acceptance of long-term commitment (Simmonds, 1993). The general pattern of successful incorporation programs is characterized by enhanced variance and increased and sustained response to selection.

Long-term improvement programs need continuous resources and manpower. North Dakota environmental conditions are unique with adverse climatic conditions needing new genetic diversity for adaptation. A program of incorporation 'NDSU EarlyGEM (the North Dakota State University Early Germplasm Enhancement of Maize)' was started with partial funding from USDA-GEM (United States Department of Agriculture Germplasm Enhancement of Maize) Project and the ND Corn Utilization Council since 1999 (Carena et al., 2009).

Exotic germplasm incorporation has been extensively studied by the maize breeding program at North Carolina State University (NCSU). Incorporation of exotic tropical germplasm has been shown to be successful by many researchers. Tarter et al. (2003 and 2004) studied incorporation of 23 Latin American maize accessions, which were crossed to Mo44. The semi-exotic lines selected in temperate environments were then studied with a test cross evaluation to U.S. Corn Belt hybrid LH132 x LH51. They showed that the percentage of tropical germplasm in semi-exotic lines was not related to grain yield or grain moisture content of lines testrcossed to the Corn Belt dent tester. This indicated that the incorporation of a substantial portion of tropical germplasm in an inbred line does not necessarily impact the combining ability of the inbred for yield and grain moisture. Furthermore, they genotyped 161 semi-exotic inbreds with 51 simple sequence repeat (SSR) loci. The result was that the percentage of detectable tropical alleles was 31%. This showed that the substantial proportions of exotic germplasm were recovererd in the semi-exotic lines despite their selection in temperate environments. This research showed that the tropical maize accessions represent an important source of exotic germplasm to broaden the genetic base of temperate maize without hindering the adaptive process of agronomic traits. The result was also supported by Uhr and Goodman (1995). These finding also tried to solve the dilema, whether selection for adaptation to the target environment of exotic x adapted crosses might result in the substantial loss of exotic alleles, either due to maladaptation or to their linkeage to such alleles.

Several researchers have described the procedures of incorporation. An elite-by-unadapted cross is one of the procedures. In elite-by-unadapted crosses, the proportion of loci carrying the desirable allele from the elite parent is generally be large unless adaptation is conferred by only few genes such as genes affecting photoperiodism. In such cases one or more backcrosses to the elite parent are practiced to increase the frequency of alleles contributed by that parent before conducting selection (Isleib, 1999). Isleib (1999) showed that backcrossing the F_1 to the later parent and selecting in the $BC_1:S_1$ generation could achieve the chance of recovery. In this case, the probability of occurrence of a desirable plant would be 1.957×10^{-2} and the necessary population size would be 117.

Backcrossing has been shown to be an efficient procedure to transfer traits not only controlled by one or two genes, like qualitative traits, but also quantitative traits that are controlled by multiple genes. Theoretically, since there could be less chance of large number of genes substitutions to occur and less chance of breakage of existing recombination of desired genes while backcrossing, it can be more effective than selfing for recombination between linked alleles (Briggs and Allard, 1953).

Backcrossing is an important method to improve adaptation of exotic germplasms. This helps to create a base population that can be used to start a selection program. The first backcross is considered to be the best base population (Eberhart, 1971). The general rule is that as the degree of dominance increases and as the parents become more diverse, additional generations of backcrossing before initiation of selection are needed (Dudley, 1982). Bridges and Gardner (1987) stated the use of BC_1 is a better foundation population when the mean of the adapted population is greater than the exotic population due to a higher number of loci with favorable alleles present. They explained the F_2 as a better foundation population when the mean of the adapted and exotic population are equal and when the mean of the adapted population is greater than the mean of the exotic population due to the presence of favorable alleles at loci with a large effect.

Fisher (1930) explained that the movement of a population towards a phenotype that best fits the present environment characterizes adaptation. Hence it creates an organism that will match to the environment. Crossa (1989) showed that with one generation of backcrossing to the adapted population, the mean of the backcross generation can be increased at the same level as that of the adapted parent. Albrecht and Dudley (1987) evaluated four maize populations containing different proportion of exotic germplasm. They showed that when the proportion of exotic germplasm increased, maturity becomes increasingly important in affecting grain yield, supporting the idea that a lack of adaptability may mask the expression of favorable alleles for yield. This can be a major factor when introducing tropical germplasm to temperate environments that influence agronomic traits, for instance, including photoperiod sensitivity and other agronomic deficiencies such as high grain moisture, poor root and stalk strength, and high ear placement (Tarter et al., 2004).

Cost effective simple methods like mass selection alone can be effective for adapting exotic germplasm for use in maize breeding programs. Hallauer and Sears (1972) showed an improvement of 3.4 days per cycle after 4 cycles of mass selection for earliness in exotic ETO composite.

Exotic incorporation has been found to increase genetic variance as compared to existing U.S. temperate germplasms. Goodman (1965) studied the genetic variance of adapted U.S. Corn Belt composite and the West Indian composite adapted from West Indies. His result showed that the genetic variances were greater for the West Indian composite than for the Corn Belt composite. The expected gains from selection were also higher for the West Indian composite.

Many researchers have studied the percentage of germplasm to be maintained in the exotic x adapted crosses. Selig et al. (1999) showed that the amount of exotic germplasm incorporation into elite maize inbreds should be maintained relatively small if useful improvement is desired in the future. Their reason was the introduction of too much DNA from exotic germplasm would adversely alter elite hybrid maize genomes. Santos et al. (2000) showed that, independent of origin and production potential of each tropical population studied, backcross generations increased the mean of populations. They also suggested that the best foundation populations are obtained with incorporation of 6.25% (BC_1) or 12.5% (BC_2) exotic genomes into adapted population.

Evaluation of Useful Genetic Diversity

Testcrosses have been useful (1) for evaluating the combining ability of inbred lines in a hybrid breeding program,(2) for evaluation of breeding value of genotypes for population improvement, and (3) for evaluation of genetic diversity of lines being tested (Hallauer et al., 2010). Testcross is a type of progeny test. Allard (1960) defined progeny test as “a test of the value of a genotype based on the performance of its offspring produced in some definite system of mating.” The major disadavantage of the testcross appraoach is that it ignores new heterotic patterns which might be identified by the variety cross diallel approach (Hallauer, 1975). Hayes and Immer (1942) defined combining ability as the relative ability of a biotype to transmit desirable performance to its crosses. Testing for combining ability at early generations (S_1 and S_2) of inbreeding is desirable for a breeding program targeted for hybrid development because it permits a greater expenditure of resources on the families that are most promising (Bernardo, 2002).

The commonly used testers can be classified into (1) narrow genetic based testers (e.g. an inbred line or a cross of sister lines); and (2) broad genetic based tester (e.g. open pollinated cultivars, synthetic cultivars, double cross hybrids).

What is the most suitable tester for breeding programs? Suitable testers are those testers that include simplicity in use, provide information that correctly classifies relative merits of lines, and maximizes genetic gain (Hallauer, 1975). Narrow genetic based tester like Inbred line testers were considered to have higher efficiency than others for differentiating lines. Inbred testers combine well indicating selection has been effective for GCA (General Combining Ability). With use of the inbred tester the variability among testcrosses are expected to be twice as large than the one obtained with genetically broad based testers. Hallauer and Lopez-Perez (1979) compared among five testers (BSSS, BS13(S)C_1, BSSS-222, B73, and Mo17). Their result showed that at both S_1 and S_8 inbreeding levels the testers with lower frequency of favorable alleles provided greater variability among lines. They found the variability among B73 (good performance line) hybrids was less than among BSSS-222 (poor performance line) hybrids. Their result also showed that the unrelated elite line tester was as effective as the low performance tester. Thus, they suggested the unrelated elite line tester would be best to find untested lines that have good combining ability. These results were a significant finding because they demonstrated that unrelated testers (usually from the opposite heterotic group) have discriminatory power similar to using a low yielding tester.

Holland and Goodman (1995) evaluated the combining ability of 40 photoperiodic converted tropical accessions with testcrosses. They found a positive correlation of yield across testers ($r = 0.78$) ($P<0.0001$) and concluded that an initial testing of tropical accessions on a single temperate tester would be appropriate. It was also supported by Nelson and Goodman (2008).

Lile and Hallauer (1994) conducted testcross trials at four locations at the S_2 and S_8 generations and found out that genetic correlations between the S_2 and later generations were 0.97 for B13 (S_2) C_1 and 0.86 for BSCB1(R) C_7 populations, suggesting that early testing at the S_2 generation was effective in discriminating among these lines for relative combining abilities in later generations of inbreeding. However, selection of partially inbred maize lines based on early generation testcross performance involve some risk of losing lines that would eventually perform well in testcross at their homozygosity level. On the basis of expected genetic and phenotypic correlations among testcrosses at different selfing generations Bernardo (1992) calculated the conditional probability of retaining the genetically superior lines during early generation testing in maize. He showed that the expected genetic correlations between testcrosses lines at different selfing generations ranged from 0.71 to 0.99 where 0.77 was for S_1 lines. He also explained the effectiveness of early testing may be improved by increasing heritability (e. g. using more replicates, better experimental design, or other means of controlling non-genetic variance). Since the heritability depends on amount of genetic variance present, if the amount of non-genetic variance is constant, testcross heritability is likely to be lower in narrow than in broad base source populations. Hence, early generation testing may be more effective in diverse crosses or in synthetic populations than in biparental crosses between related parents.

Many U.S. northern regions, including North Dakota, need lines which are less than 80 RM day maturity. The lack of short-season industry elite testers limits the accurate differentiation of diverse elite early maturing lines for this region.

Utilizing Existing Sources of Maize Exotic Germplasm

Latin American Maize Project (LAMP)

The process of exotic maize incorporation is difficult because effective sourcing of exotic unadapted germplasm requires classification into heterotic groups, adaptation and pre-breeding that can take 25 to 30 years to accomplish. However, the Latin American Maize Project (LAMP) has alleviated much of that problem (Goodman, 1999). LAMP evaluated over 12,000 maize accessions comprising 74 percentages of the known races of maize found in Latin America and U.S. germplasm banks for use in breeding. 12 countries, which have most of the maize race diversity in the world (Argentina, Bolivia, Brazil, Colombia, Chile, Guatemala, Mexico, Paraguay, Peru, United States, Uruguay and Venezuela) had cooperated in this project (Sevilla and Salhuana, 1997). The evaluated accessions are the products of experiments on special traits like: drought resistance, disease and insect resistance to northern leaf blight (*Exserohilum turcicum),* army worm

(*Spodoptera frugiperda*), ear worm (*Heliothis zea*) and Fusarium ear rot (*Fusarium moniliforme*), cold tolerance, and grain quality traits. However, most of the LAMP germplasms are not adapted to temperate locations and require a long-term conversion and adaptation effort by maize breeders at numerous environments throughout the major growing regions of the USA.

LAMP was the most extensive evaluation of maize germplasms in the history covering a large geographical area of 11 Latin American countries and the USA. Evaluation trials were conducted in 34 regions covering most regions of the Americas where maize is grown, ranging from the 41^0 latitude in the northern hemisphere to the 34^0 latitude in the southern hemisphere and from sea level to 3,400 meters above sea level (Sevilla and Salhuana, 1997). The distribution of regions per country ranged from one in Venezuela to seven in Peru. The evaluation was a very well planned process considering geographical descriptors latitude, longitude and altitude.

In planning LAMP, different environmental conditions were recognized and five Homologous Areas (HA) were defined (Sevilla and Salhuana, 1997). The regions were grouped into these HA for germplasm interchange, testing selected accessions, and evaluating heterosis. The accessions were evaluated in the country of collection. An adaptation test was conducted to distribute to other countries. For this, a 'sample' of races from each region was sent to other regions to test for adaptation. The same evaluation descriptors were recorded in all the regions. A total of 813 accessions from 11 countries were sent to 21 different regions to test adaptation. The samples sent for the adaptation test were random samples of the countries maize races. A total of 204 races were tested in the adaptation test (Sevilla and Salhuana, 1997).

The LAMP project was carried out in five stages (Sevilla and Salhuana, 1997):

STAGE 1: Accessions from a region were planted for evaluation in a 10 m^2 plot in two replications at a single location. The location was environmentally similar to that from which the landrace accessions were originally collected. In this stage a total of 14,357 accessions were planted but due to problems with flowering and other agronomic deficiencies only 12,113 accessions were evaluated. A total of 3,094 accessions were selected.

STAGE 2: The selected, 20 percentages of accessions evaluated for agronomic performance in stage 1 was planted in two locations with two replications. The top 5 percentages were selected based on agronomic performance. Therefore, a total of 3,066 accessions were evaluated and 270 accessions were selected.

STAGE 3: The selected top 270 accessions were interchanged among regions belonging to the same homologous area. Two locations with two replications were used to test in each region. An isolated field within each region was used to make a testcross where the selected accessions from the same homologous area were crossed with the best tester of the region.

STAGE 4: Experimental Trials to test the combining ability of selected accessions with local testers were carried out with two or more replications in two locations within each region. A total of 270 elite accession were evaluated in test cross combinations.

STAGE 5: Elite accessions were integrated into breeding programs.

This evaluation process had identified unique accessions that can be used for integration to the U.S. germplasm base. For instance, BR52051 was one of the highest yielding accessions in testcrosses with tester BR105 in Brazil (Santos, 1997). CHO5015 was one of the four elite accessions selected in Chile (Paratori and Hofer, 1997). CUBA 117 and SCR01 are the elite LAMP accessions collected from HA 1 of the USA where stage four testcross experiments were conducted in Puerto Rico and Mexico. FS8B (T) accession was selected from HA 4 of the USA where more emphasis were given to value added traits to develop germplasm for improving traits related to feed and other industries (Pollak, 1997).

Salhuana et al. (1998) studied the breeding potential of maize accessions from Argentina, Chile, USA, and Uruguay. Top cross performance of these accessions with B73 x B14A, Oh43 x Mo17, and SR76 showed the top crosses were equal or superior to the performance of the checks in all four countries. The study showed the Argentinean accession had the best mean per se and top cross performance. They also suggested including these accessions for cooperative enhancement efforts.

Germplasm Enhancement of Maize (GEM) Project

The follow up of the LAMP project was the Germplasm Enhancement of Maize Project (GEM). This is a public/private effort to broaden the genetic base of U.S. maize hybrids using enhanced maize germplasms derived from selected LAMP and other elite exotic accessions (Salhuana et al., 2006). This is an active germplasm enhancement program with cooperators from all over the world including seed companies, public institutions, and international non-Government organizations (INGOs).

Breeding populations used in GEM include (1) elite germplasm accessions identified by LAMP crossed to elite, domestic private lines, (2) breeding crosses developed in (1) crossed to second elite, domestic, private lines from same heterotic groups but from the second company (Goodman, 1999). The reason behind using the adapted private lines was to make the exotic lines available to commercial progress quickly (Pollak, 2003). With this breeding protocol the program develops 50% and 25% breeding crosses and releases selected S_3 or bulked S_3 lines. Data collected on GEM germplasms are freely available. Enhanced GEM lines are also freely available through the U.S. North Central Regional Plant Introduction Station (NCPRIS) after their public release. Traits targeted by GEM program for improvement are agronomic productivity, disease and insect resistance, and value added traits.

The GEM project started with the selection of a set of 23 tropical accessions identified by LAMP project. The accessions were originally from Brazil, Mexico, Cuba, Barbados, British Virgin Islands, Dominican Republic, Puerto Rico, St. Croix, Antigua, Guatemala, and Peru. The second set consisted of seven tropical hybrids from a seed company 'DeKalb'. The third set included 27 accessions selected from temperate environments in Argentina, Chile, Uruguay and the USA. The accessions were assigned in groups of four to a total of 21 companies to make crosses with their tropical elite inbred lines. These materials were then assigned to different companies to make crosses to a second adapted inbred line (Salhuana, 1997).

GEM lines proved to have tremendous genetic potential for most important agronomic traits like yield, insect and disease resistance, and for additional traits that add value to the grain (Pollak, 2003; Salhuana et al., 2006; Carena et al., 2009). There are reports of breeding germplasms identified for better agronomic and quality traits from GEM lines. Balint-kurti et al. (2006) registered 20 GEM maize breeding germplasm lines adapted to the southern USA. The lines were described to provide a unique source of tropical x temperate maize germplasm for the development of lines with improved yield and potential disease resistance. A partial inbred germplasm line GEMS-0067 was released by Truman State University (TSU) with protocol developed by GEM project (Campbell et al., 2007). The line reported to have potential in the development of genetically diverse, elite Amylase class VII (starch amylase >70%). The modified gene and the recessive amylase extender (*ae*) allele present in the line reported to elevate starch amylase content to at least 70%.

NDSU EarlyGEM (the Early Germplasm Enhancement of Maize) Program

NDSU EarlyGEM is a continuous effort to incorporate GEM germplasm into the U.S. northern Corn Belt since 1999. One of the major goals of this program is to increase the genetic diversity of northern U.S. Corn Belt hybrids by providing unique short-season products not available in industry. The program targets the diversity present in LAMP identified accessions, which were adapted in temperate areas by United States department of agriculture (USDA) under USDA-GEM program of Iowa and North Carolina States. It utilizes USDA-GEM program as intermediate adaptation process to move GEM products northward to cooler seasons and westward to drier areas of the northern U.S. The diverse elite lines for incorporation were selected based on multi-location data of USDA-GEM testing. The NDSU EarlyGEM program initiated the adaptation process of late temperate and tropical derived GEM germplasm to North Dakota. The lines after observation in series of nurseries are converted through a backcross breeding program with adapted NDSU released lines (e.g., ND2000). The diverse $BC_1{:}S_1$ lines are then advanced and testcrossed to industry testers for potential advancement through the NDSU pedigree breeding method

(Carena et al, 2009). The NDSU EarlyGEM program was inspired by the early conversion process conducted by Dr. Pinnell in Minnesota (Rinke and Sentz, 1961).

Importance of Maize Exotic Germplasm for Value Added Traits

End users of maize in US include livestock producer-feeders, feed manufacturers, wet corn millers, dry corn millers, and alkaline corn processors (Boland et al., 1999). These different end users desire various maize properties for their uses in raw maize which increases the value of maize and, therefore, increases profit to end users. Value enhanced corn (VEC) is "maize with particular quality characteristics that add end-use value" (US Grain Council, 2006). VEC can be defined in terms of both traits and components. The traits leading to add value to maize are waxy, nutritionally dense, and high oil among others. The components are the specific value added attributes of maize like starch content, oil content and protein content (Boland et al. 1999). In 2006, 8% of the maize grown in US was VEC (US Grain Council, 2006). The reports have specified white maize, waxy maize, hard endosperm/food grade maize, high oil maze, nutritionally enhanced maize (for protein quality), high extractable starch maize, and non-GMO maize as major trait to add value.

The history of maize breeding research has shown that maize was mostly selected for high yield and agronomic traits by repeatedly using similar or narrow based germplasm without taking care of compositional properties. This had reduced the diversity in the grain quality traits (Whitt et al., 2002) making selection for these traits more difficult. Exotic germplasms were selected from a long history for indigenous uses by various cultures (for food, feed and beverage) and can be a source of diversity of new alleles for grain quality traits (Pollak, 2003) with unique groups of genetic diversity (Osorno and Carena, 2008).

The addition of new traits for grain quality related to new uses (e.g. ethanol) is important to increase the potential premium of farmers. Pollak (2003) explained that many studies indicated significant variability for quality and biomass for paper pulp production is present in exotic maize genetic resources. Greater genetic diversity for oil composition was found to be present in maize of foreign origin than in maize of U.S. origin (Milton, 1970). Higher oil content in the grain is important to increase the caloric content of the grain for animals as feeds.

Earle et al. (1946) reported mature kernels of typical Corn Belt maize are composed of 70 to 75% of starch, 8-10% protein, and 4-5% oil. By utilizing genetic variation, the composition of the kernel can be changed for both the quantity and quality (structural and chemical diversity) of starch, protein, and oil throughout kernel development (Boyer et al., 2001). Singh et al. (2001a) reported greater protein and fat contents in GEM accessions than in commercial hybrids. In testcrosses of Mo17 and B73 with 10 selected GEM accessions, Singh et al. (2001b) found increased protein content, decreased oil content, and increased absolute density and test weight. Starch yields were increased in crosses by almost five percent points, but were still lower than commercial U.S. dent hybrids. GEM x B73 crosses showed additive effects for grain protein content and fiber yield, while GEM x Mo17 crosses exhibited additive effects for absolute density, grain starch content, starch yield, and starch recovery. This showed many of the GEM accessions combined well with non-SS lines for grain starch properties.

Generally compositional properties like grain protein are considered to be negatively correlated with yield (Frey, 1951). However, Pollmer et al. (1978) showed that within the physiological limitations, through the selection of genotypes with higher nitrogen uptake and higher translocation from stover to grain, different results can be obtained. Lines with higher grain protein contents and better combining ability for agronomic traits can be obtained from simultaneous selection for both traits. They showed no significant association between grain protein and grain yield. They showed that the additive genetic variation, relative to the non-additive one was of greater importance for percent protein in the grain than for the other traits. This result showed the possibility of developing hybrids with high yield and greater protein composition. The chances for obtaining these hybrids are better with strong breeding programs with extensive testing of variable germplasm.

Maize ethanol production currently utilizes more than one third of maize produced in USA (US grain council, 2006). This is also a source of numerous bi-products like Distiller's Dried Grains with Solubles (DDGS). Dry mill ethanol plants produce the bi-product. During the fermentation process the starch is converted to ethanol and CO_2, concentrating the remaining nutrients in DDGS (Swiatkiewicz and Koreleski, 2008). As a consequence, bi-products are an excellent feedstock for livestock and animals. Hence, the ethanol industry recently is considered more sustainable for energy and feed industry. Bothast (2005) reported that most of the fuel ethanol is produced from two different milling processes of maize: 67% is produced from dry mill and 33% from wet mill process. In both methods the starch is enzymatically hydrolyzed to fermentable sugars that are fed to yeast in large fermenters. Pure (95%) ethanol is then produced after distillation. The demand of maize for ethanol is set to increase as the U.S. government has set a target of 30% transportation fuel to be used from renewable resources by the year 2030. Currently, U.S. gasoline has the option of 10% ethanol mixture and has set to increase 15% in the near future. In 2005, technology could produce 2.5 gallons from wet mill and 2.8 gallons of ethanol from dry grind process per bushel of maize (Bothast, 2005). Dry grind ethanol plants represent the fastest growing segment of the fuel ethanol industry in the USA. Bothast and Schlicher (2005) have described the need of developing hybrids with a higher fermentable starch and extractable starch content for ethanol utilization. Extractable starch is different than starch content. Extractable starch is influenced by variety, growing environments, and drying conditions (Paulsen et al., 2003).

At present there is an increasing trend of maize hybrids developed with higher extractable starch for wet mill and higher fermentable starch for dry grind process (Bothast and Schlicher, 2005). Efforts have been placed on selective and transgenic approaches of increasing these traits. The U.S. largest seed companiies Monsanto and Pioneer both have continuous research efforts to develop new hybrids with these features. The history shows the Monsanto's effort mostly have focused on the dry grind industry. They have developed the product called "processor preffered fermentable corn' (HFC) hybrids . The Processor preffered® technology of Monsanto is designed to screen maize hybrids for levels of fermentable and extractable starch. High extractable starch is important for wet millers to produce high starch yields that they can turn into products including high frutose corn syrup, corn oil, speciality starch products, commodity starches, and ethanol. Similarly, high fermentable corn is important for dry grind ethanol industry (Monsanto Company, 2011). Bothast (2005) reported that in 2004 these hybrids were offered in nearly 60 independent seed brands in additon to Monsanto, DEKALB and Asgrow brands. Pioneer Hi-Bred International also has products called 'High fermentables'(HTF) hybrids with ethanol yield up to 4% above mixed commercial grain possile. Other companies including Syngenta (under Northrup King brand), Agrigold and additional regional seed companies have also begun to market hybrids reported to enhance ethanol yields.

The NDSU EarlyGEM project is also a source of unique genetic resources for value added traits (Carena et al.,2009). Pollak (2003) reported the GEM project had evaluated many accessions and breeding materials from LAMP for grain quality and agronomic traits. These were analyzed for seed composition, wet milling characteristics, and starch quality. The GEM lines showed to have very diverse values in these compositional traits. Pollak (2003) reported a wide range of grain compositional values after screening selected GEM S_3 bulk lines from 1997 and 1998 yield tests: 1.9-5.3 for oil (% dry matter,dm), 9.4-15.1 for protein (% dm), and 64.7 -73.1 for starch (% dm).

There are recent concerns on the U.S. grain system undergoing increased product differentiation and market segmentation. The new forces including biotechnology, industrial processing innovations, logistical advances, information and measurement technologies, and consumer preferences have induced rapid market adjustment that have driven this differentiation (Elheri, 2007). As a consequence, farmers are eager to diversify their products to improve the present comodity system for the development of products with specific traits with market demand.

Maize in North Dakota

North Dakota State University (NDSU) maize breeding program is an applied maize breeding program focusing on population improvement, inbred line development, and adaptation of unique exotic germplasm to the U.S. northern Corn Belt. NDSU has over 80 years of maize breeding research history and its breeding program has released 25 maize products since 1997. ND acreage had record increases from 590,000 acres of maize planted in 1997 to 2.3 million acres planted in 2011 with the record of 2.5 million acres planted in 2007 (USDA, 2011). One of the reasons for this significant increase is the renewable fuel demand (Carena et. al., 2009). The NDSU maize breeding program is the largest in the region breeding products locally. Industry breeding centers for ND are mostly located in southern Minnesota (MN) and they do not breed locally. Therefore, the NDSU program acts as a unique genetic provider and foundation seed companies license products to retailer companies. These retailer companies sell products to ND farmers. NDSU cooperates with the United States Department of Agriculture (USDA) to increase the genetic diversity of early maturing industry hybrids and with several industry and public partners to integrate germplasm improvement with cultivar development.

The main objectives of the program are to adapt maize germplasm to the challenging environmental conditions of ND and develop lines and hybrids for industry use, focusing on early maturity, drought and cold tolerance, and grain quality. Northern U.S. farmers continue to select maize as one of their most profitable choices. However, industry hybrids are still late maturing, lack stress tolerance, are slow driers, and often end up with poor quality. One of the main reasons is that current commercial hybrids are mostly bred elsewhere (e.g. southern MN) making their adaptation to short-seasons challenging. Also, maize often needs to be harvested at moisture levels too high for safe storage and must be artificially dried for storage and transport.

OBJECTIVES

The goal of the NDSU EarlyGEM program is to increase the genetic diversity of U.S. northern Corn Belt hybrids with unique sources of germplasm currently not available in the northern U.S. industry. This research study was designed to assess the incorporation of diverse and unique favorable alleles from exotic GEM germplasms as donor for high grain quality and genetic diversity to short season hybrids. The specific objectives are:

1) To determine whether exotic GEM germplasms can donate superior alleles than popular check lines Mo17, BSSS, and B73 for important traits in North Dakota unique environments.

2) To compare the relative amount of variation within and among BC_1:S_1 populations for short season hybrid traits.

3) To identify potential EarlyGEM lines for future breeding and as new hybrid parents in the U.S. northern Corn Belt.

MATERIALS AND METHODS

Plant Materials

The plant materials initially were evaluated by LAMP project for special traits drought resistance, disease and insect resistance to northern leaf blight (*Exserohilum turcicum),* army worm (*Spodoptera frugiperda*), ear worm (*Heliothis zea*) and Fusarium ear rot (*Fusarium moniliforme*), cold tolerance, and grain quality traits after extensive evaluation of 12000 maize accessions of Latin America and USA in 12 different countries of this region (Described by Sevilla and Salhuana, 1997). Then the GEM project started with the selection of a set of 23 tropical accessions identified by LAMP project. The accessions were originally from Brazil, Mexico, Cuba, Barbados, British Virgin Islands, Dominican Republic, Puerto Rico, St. Croix, Antigua, Guatemala, and Peru. The second set consisted of seven tropical hybrids from a seed company 'DeKalb'. The third set included 27 accessions selected from temperate environments in Argentina, Chile, Uruguay and the USA. The accessions were assigned in groups of four to a total of 21 companies to make crosses with their tropical elite inbred lines. These materials were then assigned to different companies to make crosses to a second adapted inbred line (Described by Salhuana, 1997).

In 2001, 152 GEM S_3 lines from released GEM central U.S. Corn Belt sets A, B, and C derived from breeding crosses adapted to the U.S. Central Corn Belt in 1999 were obtained from GEM program of Ames, Iowa. Three sets were selected based on top ten yields. Set A was selected in 1997 yield trials tests and retested in 2000 with two different testers. Set B lines were selected in the 1998 yield trial tests and retested in year 2001 with two different testers. Set C lines were selected in the 1999 yield trial tests and retested in year 2002 with 2 different testers in Iowa (http://www.public.iastate.edu/~usda-gem/

assessed May 4, 2011) .The lines were observed for 15 adaptation traits in ND short season nursery. The best 28 (<20% of all GEM lines evaluated) adapted lines (based on earliness and agronomic data in Fargo, ND) and top yielding genotypes (based on central U.S. Corn Belt GEM trials) were selected and crossed to ND inbred line ND2000. ND inbred line ND2000 was used as recurrent parent to produce $BC_1:S_0$ source populations. Photoperiod conversion to the short season of ND was carried out by selecting the earliest flowering plants among the segregating individuals per populations. Visual selection was used to discard late lines with agronomic deficiencies (poor stands, low seedlings vigor under cold stress, drought stress, lodging, insect and disease susceptibility, and height). Only nine populations were kept to produce $BC_1:S_1$ elite early maturing early generation lines with approximately 25 % exotic GEM germplasm (approximately 12.5 % if we also consider industry germplasm used in original GEM crosses) (Fig. 1).

The recurrent parent ND2000 is a yellow-dent maize inbred line. It was released by NDSU in 2002. It was reported to have potential to produce early maturing hybrids with higher grain yield, low grain moisture at harvest, high test weight, and very good stalk and root lodging resistance in the northern U.S. Corn Belt (Carena and Wanner, 2003). This line was derived from breeding population, NDSCD (M) C_8. NDSCD is a yellow-endosperm variety that was developed by one cycle of full-sib family selection between NDSC (FS) C_1 and NDSD (FS) C_1 synthetic varieties. ND2000 reported to have good combining ability with early non-Iowa Stiff Stalk Synthetic (BSSS) industry and public testers. It was assigned to the BSSS heterotic group with simple sequence repeat (SSRs) markers.

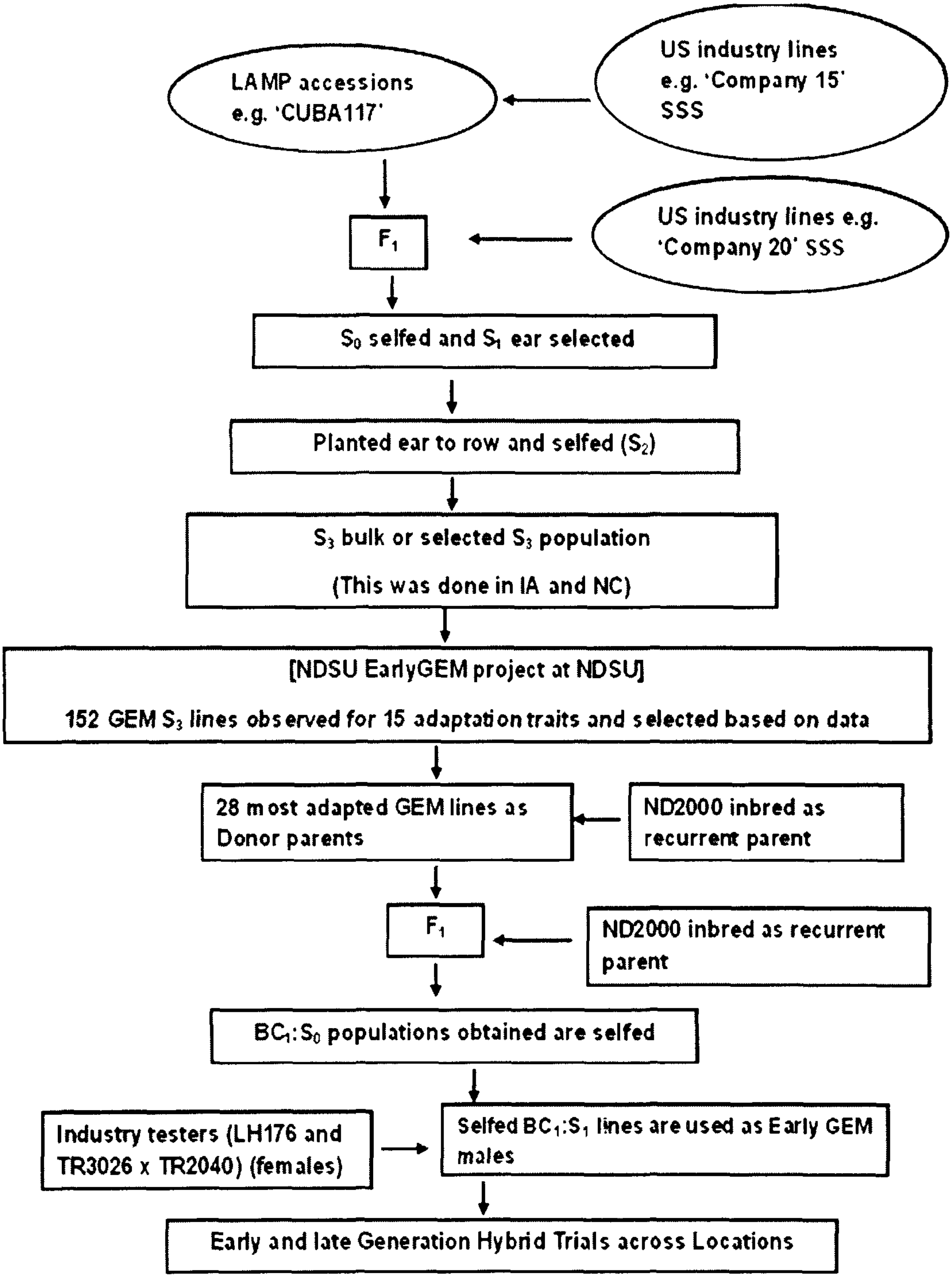

Figure 1. Protocol to develop and test EarlyGEM crosses at NDSU (adapted from Halluer et al., 2010).

METHODS

Testcrosses

Four hundred elite early maturing lines developed from nine unique BC populations were testcrossed to industry testers. $BC_1:S_1$ lines representing early versions of six GEM breeding crosses and BC check populations including B73, Mo17, and Iowa Stiff Stalk Synthetic (BSSS) as donors were selected for crossing (Table 1).

Table 1. Temperate and tropical germplasm enhancement of maize (GEM) germplasm used as donor for the development of NDSU EarlyGEM lines.

Pedigree	Name	Race	Country†	Ecological Adaptation	References
DKB844: S1601-507-1-B-B	GEM 10	Hybrid-tropical	Mexico	Tropical Exotic	(GEM, 2010)
CUBA 117:S1520-388-1-B	GEM 3	Argentino	Cuba	Tropical Exotic	(GEM, 2010)
BR52051: N04-70-1	GEM 5	Dente Amarelo	Brazil	Temperate Exotic	(GEM, 2010)
SCR01: N1310-265-1-B-B	GEM 4	St. Croix	St. Croix	Tropical Exotic	(GEM, 2010)
FS8B (T): N1802-35-1-B-B	GEM26	Mixed	USA	Tropical Exotic	(GEM, 2010)
CHO5015: N12-123-1-B-B	GEM22	Camelia	Chile	Temperate Exotic	(GEM, 2010)
BSSS (HT) C5	B73		USA	Temperate	(Russell, 1970)
C103 x187-2	Mo17		USA	Temperate	(Zuber, 1973)
16 SS lines	BSSS		USA	Temperate	(Troyer, 1999)

† Country of collection of accession and development of inbred lines and populations.

Useful genetic diversity was evaluated with testers belonging to opposite heterotic groups. LH176 is an inbred industry tester representing the non-SS heterotic group (NSS) derived from LH82, P3704 (MBS Genetics, 2010). This was crossed to BC early generation lines from GEM10, GEM3, BSSS, B73 representing the SS heterotic group (SS). TR3026 x TR2040, is a sister line industry tester representing SS heterotic group. The TR3026 was derived from B14, B73 and TR2040 was derived from B14 (MBS Genetics, 2008). This was crossed to lines from GEM26, GEM22, GEM4, GEM5, and Mo17 representing the non-SS heterotic group. Among the 400 lines tested only 140 lines from the non-SS groups and 96 from the SS were able to produce enough seeds for testing across locations and years (Table 2).

Table 2. Maize breeding crosses used for the development of exotic lines and numbers of testcrosses used for trials (No.).

SSS†	**Pedigree**	**No.**	**NSS‡**	**Pedigree**	**No.**
GEM 10	DKB844: S1601-507-1-B-B	25	GEM 5	BR52051-N04-70-1	34
GEM 3	CUBA 117:S1520-388-1-B	37	GEM 4	SCR01: N1310-265-1-B-B	30
B73	BSSS (HT) C5	12	GEM 26	FS8B (T): N1802-35-1-B-B	30
BSSS	16 SS lines	22	Mo17	C103 x187-2	15
			GEM 22	CHO5015: N12-123-1-B-B	31

† Lines representing stiff stalk synthetic heterotic groups. ‡ Lines representing non stiff stalk synthetic heterotic groups.

Testers were planted within two ranges of BC_1:S_1 lines in 2008 summer in Fargo (Fig. 2). The tester range was divided into two ranges by making a small aisle in the middle of the tester range. The tester was crossed to the adjacent BC_1:S_1 lines. This allowed utilization of BC_1:S_1 lines as males to advance one generation of selfing at the same time as crossing to industry testers. To represent the diversity present in each of the BC_1:S_1 lines a maximum number of males plants (in average 8-10) were selected for crossing to female testers within each row.

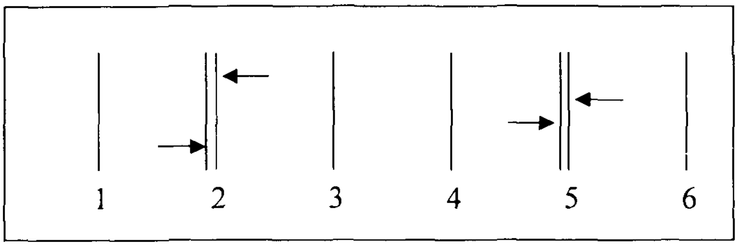

Figure 2. Diagram representing the layout of the crossing block. Ranges 2 and 5 are two female testers and ranges 1, 3, 4, and 6 represent the BC_1:S_1 lines utilized as males.

Yield Trials

The progeny produced from each female row was shelled in bulk and it was the source for testing in multi-location trials across ND environments. Trials were conducted with testcross hybrids from each tester as a single experiment for a total of two experiments per location. Experiments were arranged in 12 × 12 partially balanced lattice designs with two replicates in each location for non-SS groups of lines. Experiments were arranged in 10 × 10 partially balanced lattice designs with two replicates in each location for the SS groups of lines. In 2009 both experiments were placed in 4 locations (Barney, Casselton, Prosper and Larimore) but due to the very short and cool growing season only Prosper and Casselton for testcrosses with SS group of lines and Prosper, Casselton and Barney for non-SS group of lines were harvested. In 2010, the SS testcrosses were placed in three locations (Casselton, Prosper and Larimore) and the non-SS testcrosses were placed in four locations (Prosper, Casselton, Barney and Larimore). Flowering notes were taken only in two locations (Fargo and Casselton) for two years. In 2010, all locations were harvested. Four popular top performing industry hybrids representing the maturity range of ND hybrids were used as checks (Table 3). Plots were 7 m long row and 0.76 m between rows. Each plot was planted with 45 seeds which were thinned to 40 plants per plot at the four leaf stage after germination notes to maintain the population size of 86,110 plants per hectare.

Table 3. List of maize hybrids utilized as checks.

Checks	**Company**	**RM†**
DKC33-54	Monsanto Co.	83
Pioneer 39D85	Pioneer Hi-Bred	87
NP2623CBLL X TR3030	Thurston Genetics	90
TR3127GT x TR3621CBLLRW	Thurston Genetics	92

† Relative Maturity (RM) provided by respective companies based on average North Dakota growing degree days.

Data Collection

Emergence (%)

The germination count was taken 30 days after planting. Data on emergence were collected as a percentage of the number of plants germinated and emerged of the total 45 seeds planted per plot.

Days of Anthesis and Silking (days)

Both days to anthesis and silking were taken relative to the days after planting. Days to anthesis was noted when at least 50% of the plants in the plot were shedding pollen with at least 50% of the anthers emerged. Days to silking were noted when at least 50% of the plants in the plot were displaying visible silks.

Plant and Ear Height (cm)

Maize plant reaches maximum height only after tasseling so all the height notes were taken after complete tassel development. Mean plant height (cm) at maturity was measured as height from the ground to the terminal node of 10 competitive plants per plot. Mean ear height (cm) was measured as height from the ground to node of uppermost ears in the same sample utilized for plant height.

Root and Stalk Lodging (%)

Root lodging (%) was measured as the percentage of plants leaning greater than 30° from vertical with intact stalks. Stalk lodging (%) was measured as the percentage of plants broken below the ears.

Grain Moisture Content (%) and Test Weight (lb bu^{-1}) at Harvest

Grain moisture (%) and test weight (lb bu^{-1}) at harvest were measured by a moisture blade and a test weight chamber located in the combine harvester.

Grain Yield (t ha^{-1})

Grain yield (t ha^{-1}) was obtained through the collection of plot wet weights which was transferred from pound per plot to tons per hectare (t ha^{-1}) adjusted to 15.5% grain moisture basis.

Grain Quality Traits Screening

A sub sample of 500 g of kernels was collected from every plot from all environments and used to measure the grain quality of all the genotypes. Near Infrared Transmittance (NIT) was used as a rapid and non-destructive measure of analyzing quality parameters in maize grains. The Infratec^{TM} 1241 Grain Analyzer was used in cooperation with Monsanto. This equipment was used to analyze the following quality parameters: grain protein, grain moisture, grain starch, grain oil, grain Extractable Starch (ES) and grain High Fermentable Corn (HFC) contents in percentage of dry matter of total sample of grain.

Statistical Analysis

Data from each of the environments were analyzed by SAS version 9.2 (SAS Institute, 2008). Homogeneity of error variance across environments was analyzed using the procedure described by Patterson and Silvey (1980). They stated that 'combined analyses across environments are possible if the largest error mean square is no more than 10 times larger than the smallest'. The rule is also called '10X rule of thumb'. The argument of this rule is that the analyses of variances are robust enough to tolerate a certain level of heterogeneity of the variance and still show significant differences at the desired probability level, especially when sample sizes are equal as described by Geng et al. (1982). Analyses of variance for each location were performed using the PROC LATTICE procedure from SAS 9.2 (Table 4). Entries were considered as a fixed factor whereas replicates, blocks and environments were treated as random. The relative efficiency of the lattice design with the randomized complete block design (RCBD) was calculated for each trait. If the relative efficiency was higher than 105%, means were adjusted by incomplete blocks. If the efficiency was lower than 105% means were not adjusted. For high efficiency traits the effective error (average of the variance) was used as denominator in the F-test instead of the RCBD error mean square. The environments with homogeneous variance were considered for combined analysis for each trait. Each location by year combination was considered as an environment. PROC MIXED procedure with default REML in SAS was used to combine analysis using adjusted means for lattice effect from each traits and environments. Treatments (testcross entries and check entries) were considered as fixed and environments, replications (environments), block (replications x environments) and treatments x environments were considered as random. The treatment x environments mean square error was used as the error term. Fisher Protected Least Significant Differences (FLSD) was used to compare the differences among genotype means at <0.05 level of significance.

Table 4. Sources of variation and degrees of freedom for the lattice incomplete block experimental design utilized in the maize hybrid experiments.

Source of Variation	Degrees of freedom
Replications	(r-1)
Blocks within Replications (Adjusted)	r(k-1)
Treatments (Unadjusted or adjusted based on efficiency)	(k^2-1)
Intra-block Error	(k-1) (rk-k-1)
Randomized Complete Block Error	(t-1)(r-1)
Total	(k^2r-1)

*r, k and t are the number of replications, blocks, and treatments (genotypes), respectively.

The mean of the testcrosses were considered as the means over environments adjusted for lattice effects. Entry x environment interaction error was used to calculate the LSD comparing entry means (checks and testcrosses) as follows:

$$t\ (0.05/2,\ \text{Error df}).\sqrt{\frac{2MSE_{(TreatmentsXEnvironment,lattice)}}{Environments}}$$

To determine correlation of rank of genotypes in different environments Spearman's coefficient of rank correlation was calculated by using PROC CORR with the SPEARMAN option in SAS. The phenotypic correlations (r_p) of the different traits were calculated using Pearson's correlation using PROC CORR with the PEARSON option.

RESULTS AND DISCUSSION

Several experimental testcross hybrids with exotic genetic background were statistically not different (LSD, 0.05) to the top industry check hybrids for grain yield and other economically important traits (Table 12, 13, 14 and 15). The LSD (0.05) criteria can be more stringent to truly define useful genetic diversity. Since the lines have diverse genetic background (Table 1), maintaining the relaxed culling level to accurately identify potential of lines for useful genetic diversity can be true (Holland et al., 1996; Bernardo, 1996).

It is important to note that environmental conditions were not normal especially in 2009. The 2009 year was a shorter season than 2010.The year 2009 was characterized by a wet spring leading to delayed planting. In addition, cool air temperature was present during the whole season. The growing degree days (GDD) heat unit was less than 100 than the normal maize growth in different ND locations (NDAWN, 2009). The relative performance across genotypes for traits has exposed the weaknesses and strengths of hybrids; often the overall mean did not represent the normal values for traits. These seasons were extremely important for breeding purposes as they allowed us to clearly differentiate between strong and weak lines for adaptation. A challenging environment for producers became an extremely useful environment for selection of adapted lines.

Experiment I: Testcross Evaluation of Non Stiff Stalk Groups of Backcross Lines

All the traits showed highly significant ($P<0.01$) differences across genotypes and five ND environments except for root lodging ($P<0.23$) and stalk lodging ($P<0.06$) (Table 12 and Table 13). The root lodging and stalk lodging were below 3% except one testcross TR3026 x TR2040 x [(GEM 5 x ND 2000) x ND 2000)-I]-13 with 11.8% stalk lodging (data not shown). The non-significant differences with industry check hybrids and check US lines with less lodging showed these hybrids did not have lodging problems even though exotic tropical and late temperate germplasm were incorporated. The series of nursery observation and screening across inbreeding generations while incorporation was efficient in selecting lodging resistant lines and hybrids. Easy improvement of lodging in incorporation of tropical exotic germplasm through visual selection was also reported by Holly and Goodman (1988).

The plant height of most of the checks was taller or within the range of rest of the testcross hybrids (Fig. 3). There was a significant reduction in plant height in hybrids derived from exotic germplasm as compared to their initial stage of adaptation. This showed that it is simple to decrease the height of exotic hybrids with visual selection in breeding nurseries. Similar results were also showed by Holly and Goodman (1988). They reported the ear height of tropical exotics derived from 100% tropical lines adapted to NCSU were within the range of commercial hybrids.

Many early flowering lines were recovered from late exotic incorporations. There were 99 testcrosses statistically not different (LSD, 0.05) to earliest check DKC 33-54 for days of silking (Table A1, A2, A3, A4, and A5). The evidence showed the large standing variation in flowering time (Coles et al, 2011; Coles et al, 2010; Buckler et al., 2009) can be exploited for adaptation to early flowering with selection of earliest flowering plants in a population. This found to be successful by crossing with adapted parents and testing in unique short season environments. Successful development of relatively photoperiod insensitive inbred from tropical germplasm was also reported by Holly and Goodman (1988). They reported the days to flowering of exotics derived from 100% tropical and adapted in North Carolina (NC) were within the range of commercial hybrids.

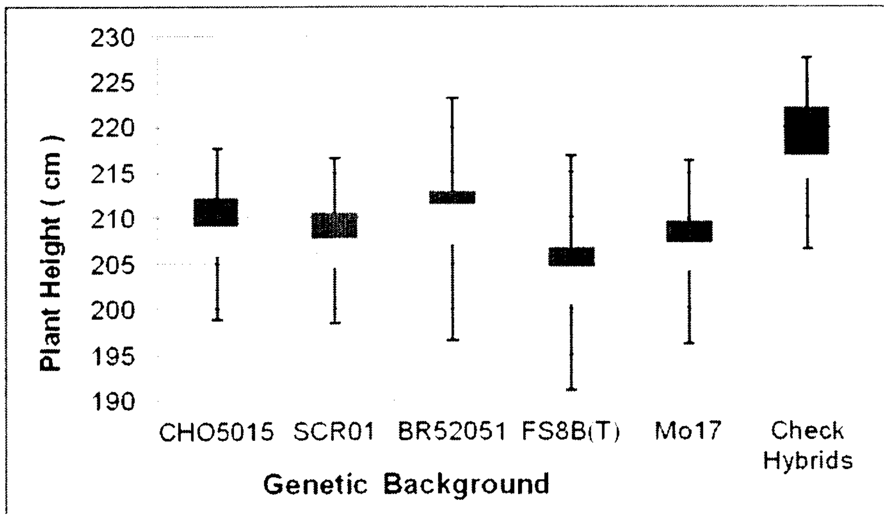

Figure 3. Box plot of the distribution of mean plant heights of maize testcross hybrids representing different non stiff stalk synthetic (NSS) genetic backgrounds and industry checks.

For grain moisture at harvest there were 32 testcrosses statistically not different (LSD, 0.05) than driest 83 RM day check DKC33-54 (Table A1, A2, A3, A4, A5). This result clearly showed us the possibility of producing many hybrids below 85RM days for short season ND environments. Only one backcross generation with elite exotic germplasm as donor was sufficient to develop early lines from late exotic germplasms.

The exotic incorporation was found important for yield improvement. There were 45 testcrosses out of 144 entries, which were not statistically different (LSD, 0.05) than the top industry check hybrid NP2623CBLL x TR3030 for grain yield (Table A1, A2, A3, A4, and A5). Many of the testcrosses showed outstanding lines can produce exotic derived hybrids with high yield in short-season environments. The yield advantage with tropical exotic incorporation was also reported by Holland and Goodman from NCSU (1995). There were 54 testcrosses not significantly different than the top industry check hybrid DKC33-54 (Table A1, A2, A3, A4, and A5). Since the Pearson's correlation between moisture and test weight was large ($r_p = -0.559$) ($P <. 0001$) (Table 16), the low test weight observed in the experiment may be related to grain moisture at harvest.

Many non-stiff stalk lines with unique quality characteristics were identified. For high fermentable corn (HFC) content in grain, 90 entries were statistically not different (LSD, 0.05) than the top check DKC33-54 (Table A1, A2, A3, A4, A5). We expected DKC33-54 to be on top of the rank for this trait as it has been reported as a processor preferred hybrid for HFC (Monsanto co., 2011). Hence, testcross hybrids, which were not different to DKC33-54, showed that they had useful variability for ethanol utilizations. For grain starch, 23 testcrosses were statistically not different than the top check Pioneer 39D85 (Table A1, A2, A3, A4, and A5). Grain starch content was found to be negatively correlated with protein and oil content ($r_p = -0.63$ and -0.52 respectively) ($P <. 0001$) (Table 23). Hence, as most of the lines showed higher protein and oil content in hybrid combinations they also showed average grain starch content.

There were 12 hybrids with mean value statistically not different than the top entry for grain oil content not including any commercial checks and testcross hybrids from check population Mo17 derived lines (Table A1, A2, A3, A4, and A5). Grain oil is one of the most important traits increasing the energy value of animal feeds. Values above 4.6% significantly change the price of maize for feeding purposes (NCSU cooperative extension, 2001). For Grain protein content thirty entries were statistically not different to the top entry, not including any of the industry checks used and including two lines TR3026 x TR2040 x [(MO 17 x ND 2000) x ND 2000)-1]-103 and TR3026 x TR2040 x [(MO 17 x ND 2000) x ND 2000)-1]-39 from Mo17 genetic background. The high grain protein content in many of the exotic derived hybrids showed the exotic incorporation can be an important source for high grain protein in ND short seasons, not found in the existing US commercial hybrids and line Mo17. There were 13 testcrosses not different than the top industry check DKC 33-54 not including lines from Mo17 for extractable starch content (Table A1, A2, A3, A4, and A5). This showed the potential for making future significant improvements in the hybrids for the high extractable starch content useful for wet milling industries.

Comparing Among Non Stiff Stalk Groups of Donor Parents

GEM 22 (CHO5015:N12-123-1-B-B)

Nine testcrosses were statistically not different (LSD, 0.05) to top industry check hybrid NP2623CBLL x TR3030 for grain yield (Table A1). The incorporation of tropical and temperate exotic lines had provided, with only one backcross generation, elite and unique lines and hybrids with adequate maturity for ND. There were ten test crosses from GEM22 not different than driest hybrid DKC33-54 for grain moisture at harvest. The grain oil content was higher than the top check NP2623CBLL x TR3030 (4.9% vs. 4.6%). The protein content was also high in GEM22 testcross 9.9% vs. 8.87% in highest check DKC 33-54. The average starch properties and high protein and oil content in GEM22 derived testcrosses showed the incorporation of exotic germplasm had donated superior alleles for these quality characteristics. The lines obtained, therefore, can be an improved source of high grain oil and grain protein content for short-season hybrids (<90RM). In past, low mean grain moisture and comparable grain yield were also reported from Chilean accession groups compared to accessions from Argentina, Uruguay and USA (Salhuana et al., 1998).

GEM 4 (SCR01:N1310-265-1-B-B)

There were nine out of 34 testcrosses tested that were statistically not different (LSD, 0.05) to the driest hybrid DKC 33-54 for grain moisture at harvest (Table A2). Many of these testcrosses with high yield and intermediate moisture at harvest showed this incorporation was successful to produce many lines that can produce hybrids with less than 87RM. Testcrosses with [(GEM 4 x ND 2000) x ND 2000)-1]-115 (4.8%) had the highest grain oil content followed by [(GEM 4 x ND 2000) x ND 2000)-1]-131 (4.7%) as compared to the top industry check NP2623CBLL x TR3030 with grain oil content of 4.6%. Testcross hybrid with exotic line [(GEM 4 x ND 2000) x ND 2000)-1]-53 (9.49%) had the highest protein content vs. 8.87% in top industry check DKC33-54. For extractable starch content there were four testcrosses not different (LSD, 0.05) than the top check hybrid DKC 33-54. There were 22 testcrosses not different to the earliest hybrid DKC 33-54 for days of silking. Testcross with [(GEM 4 x ND 2000) x ND 2000)-1]-45 (64.9 days) flowered earliest. Testcross with [(GEM 4 x ND 2000) x ND 2000)-1]-90 proved to be not only early flowering with 65.6 days of silking but also high yielding (7.1t/ha). This source of lines can be a factor for high grain oil and grain protein content combined with high yield.

The major disadvantages of exotic incorporation from tropical areas were reported to be high grain moisture content and late flowering (Goodman, 1999). The evidence showed that the tropical accession SCRO1 derived lines produced hybrids that can flower early and have low grain moisture at harvest. This is especially important for short season environments of ND where not many tropical sources of earliness and genetic diversity are available. In past researches the hybrids with 10-60% tropical genetic background were found to be competitive in yield with popular commercial hybrids in North Carolina (Tallury and Goodman, 1999). The result we obtained was that the high yield from unique tropical germplasms can also be obtained for short season hybrids.

GEM 5 (BR52051:N04-70-1)

There were 13 out of 34 testcrosses statistically not different (LSD, 0.05) to the driest hybrid for grain moisture content at harvest (Table A3). Testcrosses with [(GEM 5 x ND 2000) x ND 2000)-1]-9 (21.8%) and [(GEM 5 x ND 2000) x ND 2000)-1]-24 (21.8%) exotic lines had the lowest grain moisture at harvest of all the entries of the experiment. Both testcrosses also had high yield of 7.2 and 6.8 t/ha respectively. There were 16 additional testcrosses that were statistically similar to the top industry check hybrid NP2623CBLL x TR3030 for grain yield (Table A3). Many of the testcrosses represented in this particular group had high yield, low grain moisture at harvest, and high test weight (Table 7). These traits in hybrids are most desirable for short season environments like ND (Carena et. al, 2009).

Days to silking means of GEM 5 derived testcross hybrids (Table A3) showed 17 testcrosses not different to the earliest industry hybrid check DKC 33-54. Specifically, the testcross with [(GEM 5 x ND 2000) x ND 2000)-1]-9 BC line showed low grain moisture at harvest, high grain yield, and earliest flowering in hybrid combination having the greatest potential to be used as a unique source for excellent short season hybrids. Therefore, NDSU, with [(GEM 5 x ND 2000) x ND 2000)-1]-9, is a unique genetic provider for earliness with yield. The finding also rejects the general hypothesis that high yielding genotypes are not found in earlier hybrids (Howbaker et al., 1997). If more efforts were put into breeding genotypes for short season environments the relationship between moisture and yield would change even faster. The lines from BR52051 can also be the source of high grain protein and grain oil content. The grain protein was 9.6% vs. the 8.87% in top industry check DKC33-54. Many lines also had high grain oil content as compared to top check hybrid NP2623CBLL x TR3030. This late temperate exotic germplasm from Brazil showed a great promise to develop high quality short season hybrids.

GEM 26 (FS8B (T): N1802-35-1-B-B)

There were six testcrosses statistically not different than faster drying hybrid DKC 33-54 for grain moisture at harvest (Table A4). For grain yield, there were nine testcrosses not different than the top industry check hybrid NP2623CBLL x TR3030. Testcross with [(GEM26 x ND2000) x ND2000)-1]-32 line had the highest hybrid yield with 7.2 t/ha. Many testcrosses hybrids were poses test weight within the range of commercial hybrids. The lines showed to be important for starch properties. There were 17 testcrosses not different (LSD, 0.05) than the earliest hybrid DKC 33-54 based on days of silking. The backcross line [(GEM26 x ND2000) x ND2000)-1]-44 proved to be a unique new source for early maturing hybrids (e.g., early flowering and low moisture) and high yield. The accession FS8B (T) from southern U.S. was selected for special value added traits (Pollak, 2003) in GEM program.

Early Mo17 Testcrosses

Only one (Mo17 x ND2000) x ND2000 S_1 testcross was similar statistically to the driest hybrid DKC 33-54 for grain moisture at harvest (Table A5). Test weight means were within the range of commercial hybrids. Six testcrosses were not different to earliest industry check hybrid DKC33-54 for grain moisture at harvest. The incorporation and adaptation of Mo17 provided alleles for HFC and starch contents. However, results showed that no unique alleles were found for maturity and yield. In addition, this source of germplasm would not be chosen over others for grain quality traits. The major constraint of these BC lines to use in short season environment is their lateness. Even though six lines had better DS, their grain moisture at harvest was higher than the intermediate maturity industry checks, showing the greater importance of dry down over the one for early flowering. The adaptation process was effective to produce earlier flowering versions of Mo17. However, these hybrids needed longer time to dry down leading to high grain moisture at harvest.

Experiment II: Testcross Evaluation of Stiff Stalk Groups of Backcross Lines

Many of the exotic derived lines were adapted to ND short seasons that could produce adapted hybrids with testers. Stalk lodging was under 3% and root lodging was under 1.8% for all entries grown across ND environments (Table B1, B2, B3 and B4). Stalk lodging and root lodging were not significantly different than top industry check hybrids and lines derived from U.S. germplasm. Industry checks were taller or within the range of GEM-derived testcrosses.

There were 30 testcrosses those were not significantly different (LSD, 0.05) than the driest check DKC33-54 for days of silking (Table B1, B2, B3 and B4). However, several testcrosses obtained had medium to late maturity. The correlation between flowering time and grain moisture at harvest was not large ($r=0.48$, $P<0.0001$). Only two testcrosses were statistically not different (LSD, 0.05) than the driest hybrid DKC33-54 for grain moisture at harvest. The result showed that the SS lines represents medium to late maturity (more than 83 RM).

The exotic derived lines had added high yielding alleles to the NDSU germplasm base. For grain yield 23 testcrosses were statistically not different to the highest check NP2623CBLL x TR3030 including 5 lines from B73 genetic background (Table B1, B2, B3 and B4). The B73 showed still good yield including many exotic derived lines. However the hybrids derived from B73 were late and had high grain moisture at harvest (Table B1). There were 12 testcrosses not different than the DKC33-54 for test weight. There were 64 testcrosses not different than the top check DKC 33-54 and Pioneer 39D85 (Table B1, B2, B3 and B4) for high fermentable corn content (HFC). There were 49 testcrosses not different than the top check Pioneer 39D85 for grain starch content (Table B1, B2, B3 and B4). Many of the lines showed better combining ability for starch properties in testcross combinations.

Gem 3, BSSS and B73 showed high grain oil content as compared to top industry check NP2623CBLL x TR3030 (4.8% vs. 4.4%) (Table B1, B2, B3 and B4). Many of the lines derived from GEM 3 had high grain oil content as compared to industry checks and check population. Some of the lines from BSSS were also found to have high grain oil content. GEM 3 and BSSS derived lines were also found to produce testcrosses with high grain protein content as compared to other populations and top check industry hybrid TR3127GT x TR3621CBLLRW (10.4% vs. 9.3%).

Comparing Among Stiff Stalk Groups of Donor Parents

Early B73 Testcrosses

The grain moisture at harvest of most early B73 testcrosses was high (Table B1). Eight testcrosses were not statistically different (LSD, 0.05) than the earliest flowering hybrid DKC 33-54. There were only four testcrosses not different than the highest yielding industry check NP2623CBLL x TR3030. The testcross with [(B73 x ND2000) xND2000-1]-41 was ranked second for HFC (48.32%) and 11 testcrosses were not different than the top one industry DKC 33-54 and Pioneer 39D85 for HFC. There were seven testcrosses not different than the top entry Pioneer 39D85 for starch content but none of them for extractable starch content. This clearly states that the relationship between starch content and extractable starch should be further investigated for the best economic return. The lines did not produce hybrids with high grain protein and grain oil content. Based on our data, the early B73 lines derived from incorporation do not have the ability to produce early hybrids for short season environments. An additional BC generation might be needed to adapt B73. However, no special quality characteristics were observed either. Therefore, B73 might not be a good donor for short-season environments.

Early BSSS Testcrosses

Grain moisture at harvest was high for early BSSS $BC_1:S_1$ testcrosses than medium maturity check Pioneer 39D85 (Table B2). As expected, the yield was low as compared to the top industry check. The highest yielding early BSSS testcross was 6.7 t/ha vs. the lowest check with 8.2 t/ha. Some testcrosses had better starch contents though but not significantly high grain oil, protein, and extractable starch contents. However one of the testcross hybrid LH176 x [(BSSS x ND2000) xND2000-1]-10 had the highest grain oil content (4.8% vs. .4.4%) as compared to top grain oil hybrid NP2623CBLL x TR3030. Early BSSS testcrosses were late for ND short season environments making them unacceptable to increase the genetic diversity of short season hybrids. Low yields were observed with high moisture levels. Additional backcross generations would be used in the case BSSS was desirable for specific traits in short-season environments. High grain oil content in specific lines could be used.

GEM 10 (DKB844:S1601-507-1-B-B)

These testcrosses were similar or have high moisture at harvest than 87 RM days check Pioneer 39D85 for grain moisture at harvest (Table B3). There were 11 high yielding testcrosses not different than the top yielding industry check NP2623CBLL x TR3030. There were 22 testcrosses with highest HFC including the three commercial hybrid checks used and 17 testcrosses with highest starch content including top check Pioneer 39D85. Many of the hybrids had similar plant height and ear height to the top checks. There were 10 testcrosses with similar low days of anthesis (DA) while there were 27 testcrosses early for days of silking (DS) compared to top earliest hybrid industry check DKC 33-54.

This breeding cross can be a source of hybrids with intermediate maturity, high yield, and high extractable starch content for wet mill ethanol production efficiency. The incorporation of exotic alleles from this germplasm will be important to select hybrids for ethanol production and other starch properties.

GEM 3 (CUBA 117:S1520-388-1-B)

Several testcrosses were medium to late maturing with grain moisture at harvest higher than 87RM day check Pioneer 39D85 and there were nine testcrosses not different than the highest yielding check NP2623CBLL x TR3030 (Table B4) for grain yield. There were 13 testcrosses with lowest DA and 33 with lowest DS not different than the earliest flowering industry check hybrid DKC 33-54. These testcrosses were mostly medium maturity representing more than 87RM group with premium grain quality. GEM 3 derived from a tropical exotic breeding cross and one of its derived early versions: [(GEM 3 x ND2000) x ND2000-1]-30 produced testcrosses with intermediate grain moisture at harvest and highest yield. The lines although had medium maturity range, it had high grain protein and oil characteristics.

Diversity Within and Among Exotic Incorporations

We refer useful genetic diversity as only the subset of diversity that is important for the particular regions targeted by a breeding program. The total sample size of lines recovered from an incorporation program in ND was different due to lateness of exotic germplasms and the other undesirable traits present in the exotic germplasms (Table 2). This showed the equal importance of adaptation and diversity for improvement of traits. Exotic germplasms are the sources of genetic diversity required to diversify selection and in our case it was an elite sub-sample obtained through backcrossing with an elite ND line: ND2000.

Similar large distributions of means were observed in the lines derived from single incorporation process of exotic crosses (Fig. 4, 5, 6, 7, 8, 9, 10 and 11). Hence each exotic incorporation was unique to integrate diverse alleles to the back cross lines. However, in comparing trait means it showed that utilizing multiple exotic incorporations is important to identify lines with specific traits. For example, the range for grain moisture at harvest was 21.8% to 27.6 % for BR52051 derived testcross hybrids (Fig. 4). The probability of extracting early maturing hybrids was higher for BR52051 than for CHO5015 with mean range of 23.0% to 28.1%. The box plots (Fig. 4)) showed that most of the lines in BR52051 included in the lower quartile (25-50 percentile) of grain moisture contents distribution. And the huskers showed possibilities of extreme phenotype with grain moisture content even lower than the earliest check hybrid DKC 33-54. Accession BR52051 (GEM5) followed by CHO5015 (GEM 22) and FS8B (GEM26) derived lines had donated alleles for earliness to produce high yielding hybrids (Table A5). Among SS group of lines, the overall means for grain moisture at harvest of DKB844 derived testcrosses were lower than the other populations followed by BSSS (Fig. 5). Hybrids derived from B73 and CUBA117 incorporations are later than 87RM day check Pioneer 39D85. The possibility of extracting medium maturity (similar to 87RM Pioneer 39D85) with high yield from the tropical accession SCRO1 (GEM4) and tropical hybrid DKB844 derived lines has special significance with diverse alleles from tropical regions.

Historically, Iodent derived lines (derived from I159, I198, I205, MBS847 etc.) and Minnesota 13 line have been found to contribute for early dry down for short season hybrids (Goodman, 2005). However recently there are very few diverse sources for contributing to early maturity. The source of early maturity as lines from the exotic sources can play a significant role to develop short season hybrids.

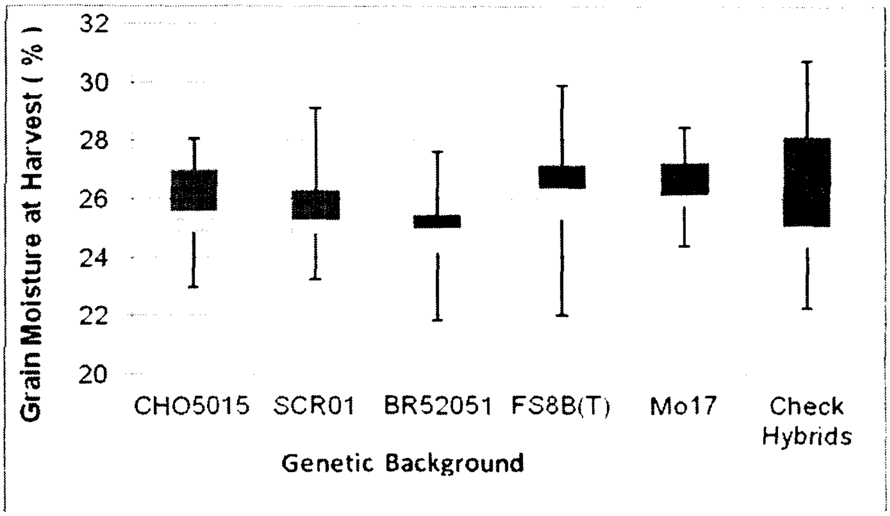

Figure 4. Box plot of the distribution of grain moisture contents of maize testcross hybrids representing different non stiff stalk synthetic (NSS) genetic backgrounds and industry checks.

Means of grain yield for non-SS lines (Fig. 6) showed that many exotic backcross (BC) lines produced testcrosses with high yield. BR52051 derived lines had many testcrosses, which were high yielding, followed by FS8B and SCRO1 derived testcross hybrids. Among SS group of lines DKB844, B73 and CUBA117 derived testcrosses produced higher yielding hybrids (Fig. 7). High yield observed in the exotic hybrids than the US lines early BSSS, early Mo17 derived testcrosses had shown many of these exotic lines can produce hybrids with high yield than the most exploited US lines. In past the West Indian composite, an adapted exotic composite from varieties of West Indies, was reported to have higher genetic variance than the Corn Belt composites for many agronomic traits like number of ears and grain yield (Goodman, 1965).

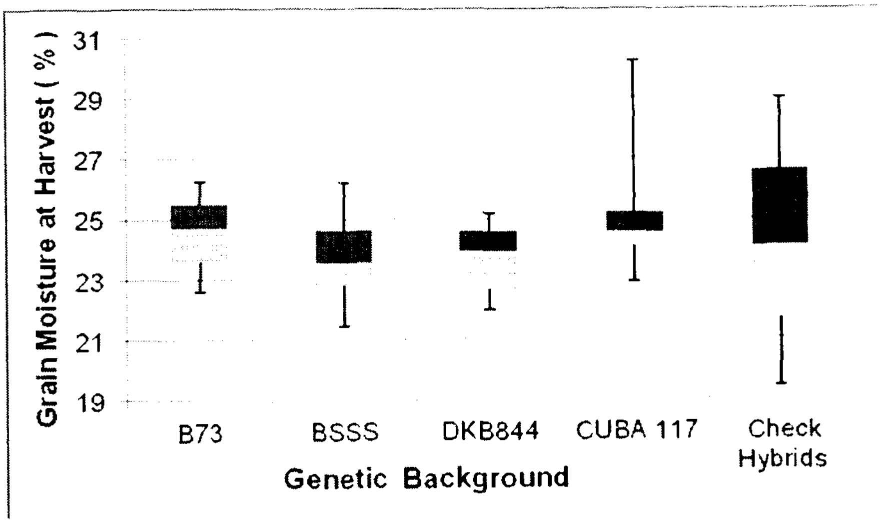

Figure 5. Box plot of the distribution of grain moisture contents of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

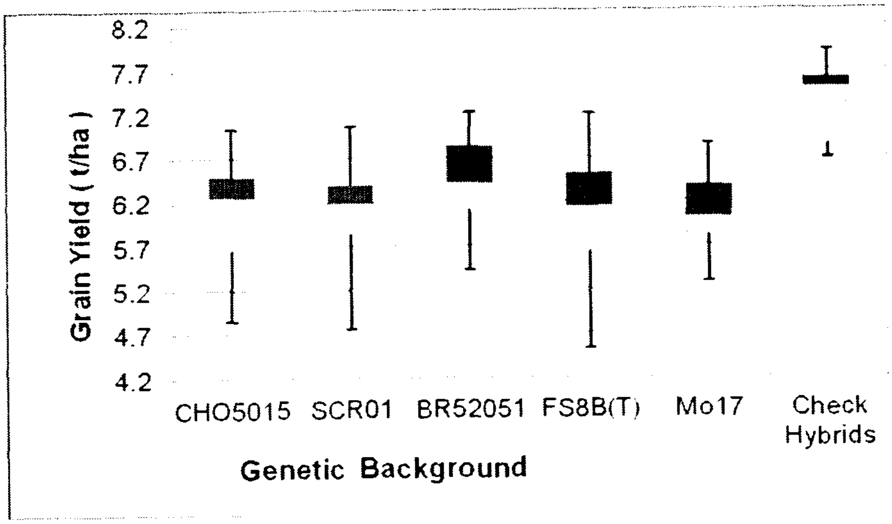

Figure 6. Box plot of the distribution of grain yield of testcross maize hybrids representing different non stiff stalk synthetic (NSS) genetic backgrounds and industry checks.

Mean of hybrids for grain oil content showed that the CHO5015 derived lines had produced hybrids with higher grain oil content followed by BR52051 (Fig. 8). Many testcrosses with similar high level of oil content were also observed in SCRO1 derived testcrosses as shown by larger area of 50-75 percentile quartile regions in box plot (Fig. 8). The U.S. originated FS8B and Mo17 derived testcrosses were less frequent in higher grain oil range than others.

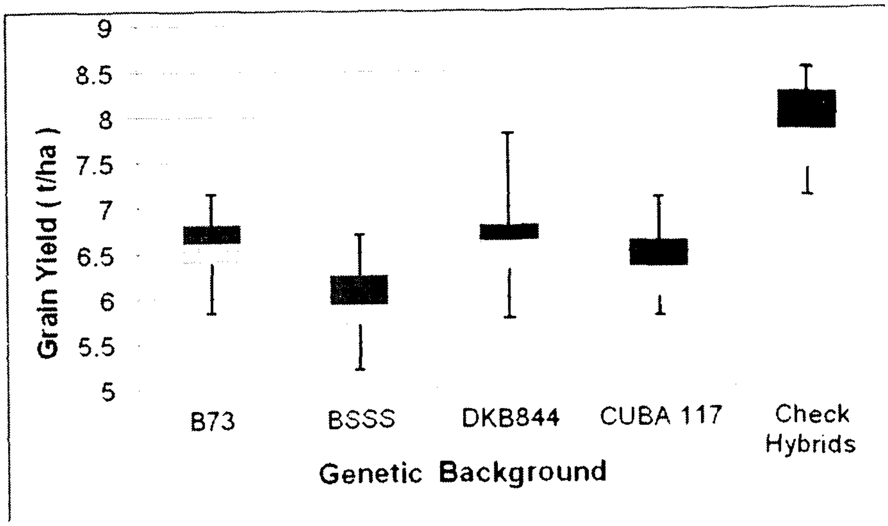

Figure 7. Box plot of the distribution of grain yield of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

Greater genetic diversity for oil composition presents in maize of foreign origin than in maize of U.S. origin was also reported by Milton (1970). The relation was also true in the short ND environments. CHO5015 (GEM22) followed by BR52051 (GEM5) and SCRO1 (GEM4) derived BC lines were unique to provide testcrosses with high grain oil and high yield (Table 6). Among SS group, several testcrosses were obtained with high grain oil content from CUBA117 derived exotic lines followed by B73 and BSSS derived early lines (Fig. 9). CUBA117 (GEM3) derived testcrosses were especially excellent for grain oil content and yield (Table 9).

CHO5015 derived lines followed by FS8B and BR52051 derived exotic lines were unique to produce testcross hybrids with higher grain protein contents (Fig. 10). Lines with

1-2% higher protein content than the famous checks have shown these base populations can be the source of alleles for high grain protein in short season hybrids. High protein content in non-SS group of GEM accessions was also reported by Singh et al. (2001b). Among SS group of lines, Higher grain protein was obtained in CUBA117 derived testcrosses followed by early BSSS and DKB844 derived testcross hybrids (Fig. 11).The incorporation with CUBA117 was unique to introduce high genetic diversity for grain protein. A high frequency of CUBA117 (GEM3) derived testcrosses can be expected to carry alleles for high protein content in addition to high grain yield (Table 10).

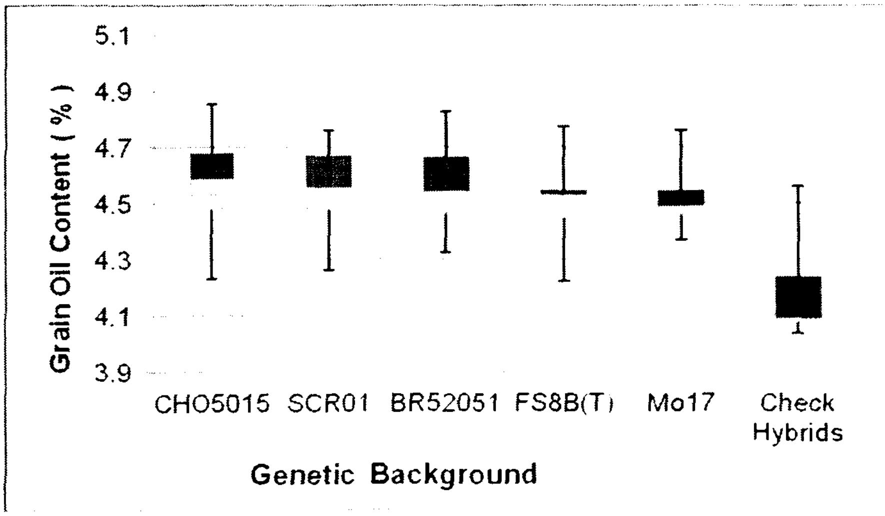

Figure 8. Box plot of the distribution of grain oil contents of testcross maize hybrids representing different non stiff stalk synthetic (NSS) genetic backgrounds and industry checks.

DKB844 derived testcross hybrids also showed high extractable starch content followed by BSSS and B73 derived testcross hybrids (Fig. 12). DKB844 derived testcrosses also showed high fermentable corn (HFC) content followed by B73 and BSSS derived testcross hybrids (Fig. 13). There were many hybrids with high grain yield; low grain moisture and high HFC from DKB844 derived exotic lines compared to others (Table B3). Many of these DKB844 derived testcrosses had shown above average yield, earliness, and good extractable starch contents (Table B3).

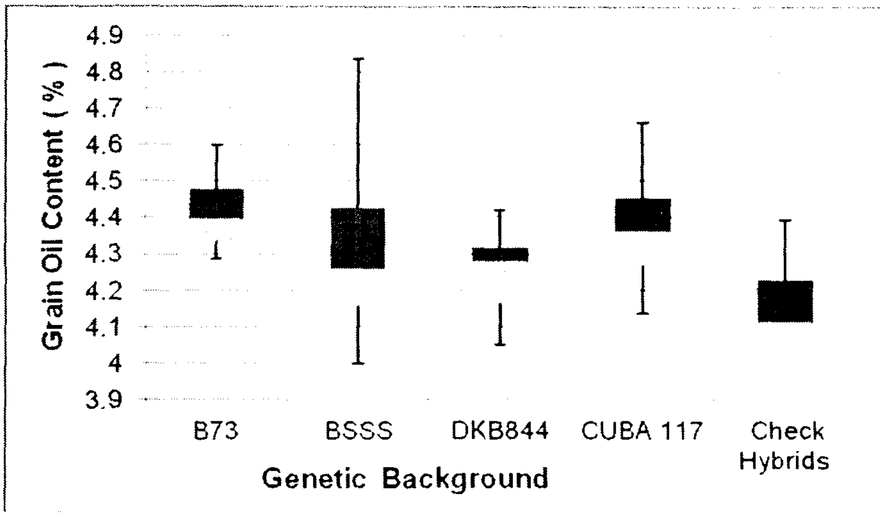

Figure 9. Box plot of the distribution of grain oil contents of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

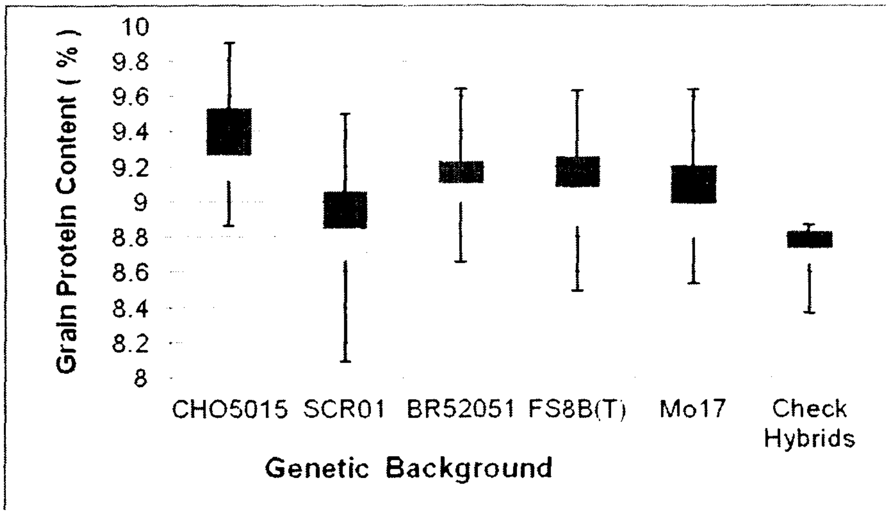

Figure 10. Box plot of the distribution of grain protein contents of testcross maize hybrids representing different non stiff stalk synthetic (NSS) genetic backgrounds and industry checks.

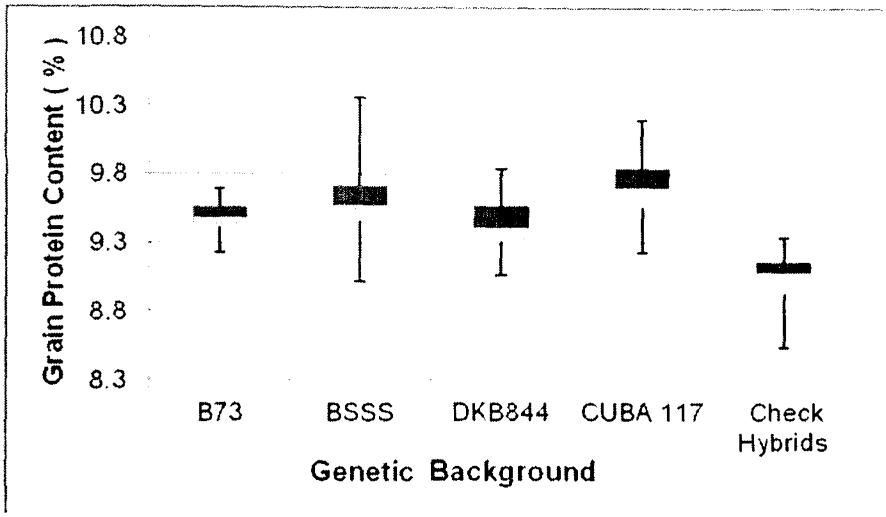

Figure 11. Box plot of the distribution of grain protein contents of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

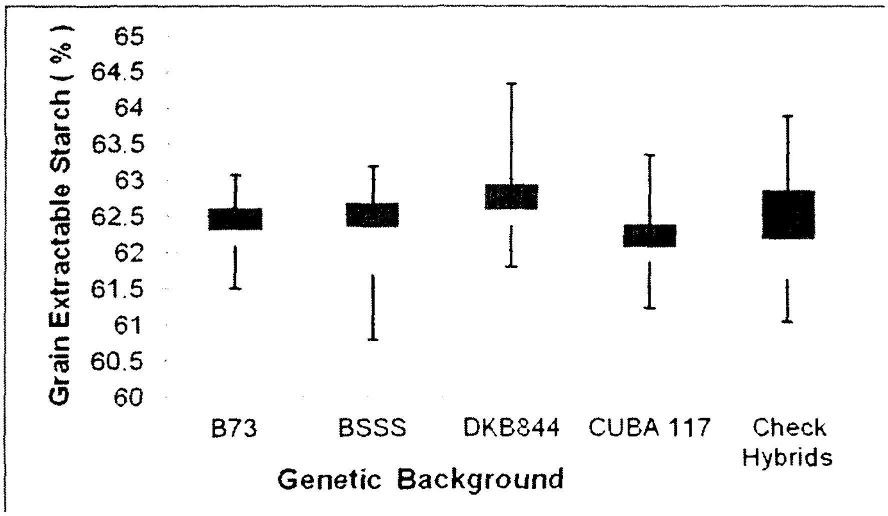

Figure 12. Box plot of the distribution of grain extractable starch contents of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

The results showed that the probability of identifying lines with unique alleles was high with selecting across exotic germplasms crosses than selecting within single exotic cross. Incorporating multiple exotic germplasms had provided desirable traits with unique alleles not present in current sequenced genomes (B73 and Mo17 etc.). This result also supports giving priority to sampling across rather than within populations in order to maximize utilization of genetic diversity. The results agree with Holland and Goodman (1995) in considerations for yield and Uhr and Goodman (1995) for yield, standability and grain moisture.

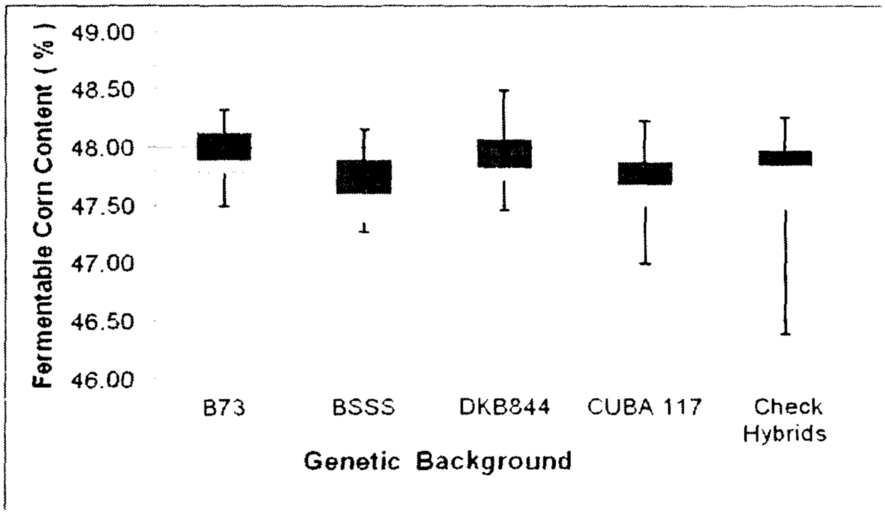

Figure 13. Box plot of the distribution of high fermentable corn (HFC) contents of testcross maize hybrids representing different stiff stalk synthetic (SS) genetic backgrounds and industry checks.

Recent commercial hybrids are mostly dependent on B73 or Mo17 derived inbreds (Mikel, 2008, Mikel and Dudley, 2006). Our results showed incorporation with B73, Mo17 and BSSS lines in ND environments produced many BC testcross hybrids which were later than medium maturity (87RM) hybrid Pioneer 39D85 as represented by grain moisture at harvest and days of silking and yield (Fig. 4 and Fig. 10). Therefore, existing sources of U.S. germplasm may not provide the favorable alleles to develop below 90RM day hybrids that are required for short season environments like ND. The earliness, and higher quality characteristics observed in the exotic testcross hybrids at similar levels of check yields had shown the exotic germplasm had added new unique alleles to these breeding lines to improve the genetic diversity of future hybrids for this region. Exotic germplasms has diversity to move maize to more marginal areas of ND. This can be achieved utilizing more unique exotic germplasm sources like BR52051, SCR01, CHO5015 and DKB844.The incorporation with the existing sources also did not had potential to produce testcrosses with value added traits compared to commercial hybrids and exotic testcrosses.

Grain moisture at harvest is major concern of ND farmers even cost wise. The short and cool ND seasons often lead to high grain moisture in hybrids resulting in significant crop losses and/or extra cost in drying for farmers. In addition, faster drying hybrids can benefit farmers across the U.S. Midwest. Previous research showed that agronomically competitive inbred lines with acceptable grain moisture content at harvest were derived from 100% tropical exotic germplasm sources (Hawbaker et al., 1997). Our results also showed that diverse short season hybrids with comparable yield with commercial checks can be produced with exotic derived lines.

In the past researches, exotic germplasms were found to be useful in breeding temperate maize. Uhr and Goodman (1995) studied the group of 190 lines derived from seven tropical commercial hybrids. In top cross combination with tester they found 16 testcrosses within the LSD (0.05) of the commercial checks for yield, standability and grain moisture. Similarly, the testcross trials for 33 selected semiexotic lines in North Carolina State had showed significant greater grain yield than the testcross with the Mo44, which were similar or better than commercial hybrids for grain moisture and lodging resistance. Our results also showed that diverse short season hybrids with similar yield with commercial checks can be produced with exotic derived lines. High yield from 50% tropical lines such as NC312 to NC316 was reported from NCSU (Lewis and Goodman, 2003). These lines were reported to have important for disease that affect the entire elite US germplasm base like streak virus of maize. Many of the exotic testcross hybrids from the EarlyGEM BC lines in the year of 2009 were also resistant to level of mold (*Diplodia maydis*) than the other many of the trial hybrids originated from the narrow based US germplasms. The lines can be significant source for mold resistance, which is prevalent in cooler region especially in cooler year like 2009, if further screening is carried out.

Grain quality is another concern for short season hybrids. Many of the exotic derived lines from SCRO1 and CHO5015 and CUBA117 with high grain oil and grain protein content and high yield on testcross combination had donated the exotic alleles to increase the genetic diversity of adapted exotic lines for these quality traits to produce below 90RM day hybrids for this region (Fig. 8, Fig. 9, Fig.10, and Fig. 11). Higher grain protein and fat contents in GEM accessions than commercial hybrids were also reported by Singh et al. (2001a). The higher grain protein and grain oil content in many BC lines can be important to develop hybrids with high yield and high protein with simultaneous selection of both traits as discussed by Pollmer et al. (1978). The unique genetic diversity created for quality traits can be a unique way to add value to the short season hybrids of northern Corn Belt. U.S. grain system is undergoing increased product differentiation and market segmentation (Elheri, 2007). These unique value added traits can fulfill the aspirations of farmers to diversify their products with specific traits and market demand. Renewable fuel demand as ethanol is major driver of increased corn production in North Dakota (Carena et al., 2009). Higher HFC and extractable starch observed from DKB844 derived testcross hybrids showed this exotic derived lines can be the factor to increase these ethanol properties in future hybrids.

High yield observed in both heterotic groups (Fig. 6, Fig. 7) had shown that exotic alleles were retained well throughout the incorporation process. Other researchers also reported the retention of higher numbers of exotic alleles, while incorporation. Tartar et al. (2003 and 2004) had showed 31% of detectable tropical alleles retained after incorporation of 23 Latin American maize accessions by crossing with U.S. line Mo44. The result was based on genotyping 161 semiexotic inbreds at 51 simple sequence repeat (SSR) loci that permitted the classification of their alleles to be either Mo44 or tropical. The result also showed that the high genetic diversity observed in early generation of incorporations can be maintained throughout the whole inbreeding period in line development. Many of the hybrids especially from advanced BR52051 and SCR01 derived lines with top yield and low moisture in 2010 ND trials had also shown the careful selection can lead to desired cultivars in later generations as well (data not shown).

Selection of testcrosses in multiple environments for multiple years is a successful way to differentiate lines from exotic incorporations targeting specific traits of short season hybrids. It needs more money and effort to screen testcrosses based on multiple molecular markers which may not be present in diverse germplasm due to difference in allelic combinations due to lost alleles during selection and early diversification of germplasms (Whitt et. al, 2002). The research also showed as molecular markers data and better statistical procedure always assists but for best evaluation of useful genetic diversity there is no substitute for quality, well-replicated field trials (Goodman, 2005). The efficient screenings of diversity in this study comply with Bernardo (1992) as he discussed the early generation evaluation to be more efficient in diverse crosses and synthetic populations wherein genetic variance is large and testcross heritability is high. The results also showed exploiting ND environments with diversity in maize maturity zones and abiotic stresses can efficiently screen unique exotic backcross lines.

The results showed that the exotic germplasm incorporation through NDSU EarlyGEM can be a new way of adapting exotic germplasm to the changing climate of North Dakota. The research have given new insight for learning to adapt new crop varieties to changing climate of upper northern corn belt, which have been discussed to be crucial to ensure the food security (CSSA, 2011).

NDSU EarlyGEM Lines as Parents in Future Breeding Programs

The exotic incorporation is a unique way to derive lines, which can combine higher yield and other agronomic and quality traits in same hybrid. These selections are important to differentiate lines for many grain quality and agronomic traits for a breeding program. The rank of the adjusted means for lattice effects combined over environments was used to select back cross (BC) lines for specific grain quality traits, yield, and earliness. Most of the selected lines were at least earlier and higher yielding than or similar to 87 RM day hybrids check Pioneer 39D85.The selected lines and their testcross combination are given in Table 5 to Table 11.

$BC_1:S_1$ lines were differentiated according to their merit for different traits and forwarded to develop six breeding populations in 2011 summer nursery. These included the lines derived from BR52051 (below 83RM group and high grain protein), CHO5015 (early maturing and high protein), SCR01 (High oil lines), CUBA117 (High protein), FS8B (High starch), and tropical hybrid DKB844 (High starch). The procedure will follow with recombination in bulk entry method and selection in a recurrent selection program in North Dakota. The lines under top one LSD (0.05) in ranking for grain yield and grain moisture at harvest from the breeding incorporations were forwarded for inbred line developments to develop diverse early maturing inbreds with value added traits.

Selection of Non Stiff Stalk Groups of Backcross Lines as Parents

Table 5. Means† of selected non stiff stalk synthetic parents in testcross combination for early maturing hybrids with high grain yield.

Pedigree	Moisture	Yield	TWT¶	DS#	PH††
	(%)	(t/ha)	(lb/bu)	(days)	(cm)
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-9	21.8	7.2	52.2	64.8	207.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-24	21.8	6.8	52.3	65.5	212.5
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-44	22.0	6.6	53.0	65.0	197.5
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-45	23.0	6.5	53.1	65.3	214.1
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-33	23.2	6.8	52.0	66.5	212.8
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-42	23.6	6.6	53.6	66.4	202.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-19	23.7	6.5	53.4	65.1	206.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-219	24.1	7.0	52.7	65.5	208.6
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-54	24.2	6.8	51.0	66.9	223.1
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-98	24.3	6.5	51.6	66.2	209.9
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-47	24.4	6.5	51.9	65.7	210.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-51	24.5	6.9	52.5	66.8	216.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-108	24.6	6.5	52.0	65.3	205.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-67	24.7	6.6	51.2	65.7	210.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-39	25.0	6.8	52.1	65.7	208.1
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-35	25.0	6.5	53.3	65.6	200.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-25	25.2	6.8	51.6	67.5	212.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-186	25.2	6.7	51.3	66.3	212.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-74	25.2	6.5	53.0	65.6	198.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-97	25.3	7.0	51.7	66.2	212.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-183	25.3	6.9	51.3	66.7	216.2
DKC33-54 (83RM)	22.2	6.9	52.3	65.8	206.5
Pioneer 39D85 (87RM)	25.1	7.5	51.9	68.4	216.9
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	70.4	227.6
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	70.5	220.4
Experimental Mean	25.8	6.2	51.8	66.5	207.9
LSD (0.05)	2.9	1.4	1.9	1.7	8.3
CV%	9.1	18.1	3.0	1.8	3.5

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest. # Days after planting to 50% plants with visible silk. †† Plant Height.

Table 6. Means† of selected non-stiff stalk synthetic parents in testcross combination for early maturing hybrids with high grain yield and grain oil content.

Pedigree	Moisture‡	Yield§	TWT¶	Starch	Oil	Protein
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-62	24.8	6.3	53.3	69.2	4.9	9.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-18	26.5	6.6	51.1	69.2	4.8	9.2
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-50	25.9	6.6	52.3	69.1	4.8	9.5
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-115	25.8	6.0	51.3	69.3	4.8	8.9
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-24	21.8	6.8	52.3	69.3	4.7	9.2
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-30	25.7	6.6	52.0	69.0	4.7	9.4
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-90	26.4	7.1	51.2	69.8	4.7	8.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-141	24.3	6.3	52.6	69.2	4.7	9.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-25	25.2	6.8	51.6	69.7	4.7	8.7
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-21	23.3	6.3	50.9	69.9	4.7	8.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-63	25.1	6.4	50.9	69.4	4.7	9.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-15	23.6	6.1	51.2	69.4	4.7	9.1
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-115	25.0	6.1	52.5	69.3	4.7	9.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-162	25.2	6.0	52.4	69.6	4.7	9.0
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-30	25.3	6.4	52.8	69.4	4.7	9.1
DKC33-54 (83RM)	22.2	6.9	52.3	70.3	4.0	8.9
Pioneer 39D85 (87RM)	25.1	7.5	51.9	70.7	4.1	8.7
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	69.7	4.6	8.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	70.0	4.1	8.8
Experimental Mean	25.8	6.2	51.8	69.7	4.5	9.1
LSD (0.05)	2.9	1.4	1.9	0.8	0.2	0.6
CV%	9.1	18.1	3.0	0.9	4.3	5.1

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.

Table 7. Means† of selected non stiff stalk synthetic parents in testcross combinations for early maturing hybrids with high grain yield and high grain protein content.

Pedigree	Moisture‡	Yield§	TWT¶	Starch	Oil	Protein
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-39	25.0	6.8	52.1	69.4	4.6	9.9
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-103	25.4	6.8	52.3	69.5	4.5	9.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-141	24.3	6.3	52.6	69.2	4.7	9.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-44	22.0	6.6	53.0	69.6	4.5	9.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-75	25.9	6.3	52.3	70.0	4.2	9.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-50	25.9	6.6	52.3	69.1	4.8	9.5
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-35	25.0	6.5	53.3	69.9	4.5	9.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-67	24.7	6.6	51.2	69.7	4.5	9.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-98	24.3	6.5	51.6	69.9	4.5	9.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-181	24.8	6.4	51.4	69.5	4.4	9.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-30	25.7	6.6	52.0	69.0	4.7	9.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-54	24.2	6.8	51.0	69.7	4.5	9.3
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-183	25.3	6.9	51.3	69.7	4.5	9.3
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-74	25.2	6.5	53.0	70.0	4.2	9.2
DKC33-54 (83RM)	22.2	6.9	52.3	70.3	4.0	8.9
Pioneer 39D85 (87RM)	25.1	7.5	51.9	70.7	4.1	8.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	69.7	4.6	8.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	70.0	4.1	8.8
Experimental Mean	25.8	6.2	51.8	69.7	4.5	9.1
LSD (0.05)	2.9	1.4	1.9	0.8	0.2	0.6
CV%	9.1	18.1	3.0	0.9	4.3	5.1

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.

Selection of Stiff Stalk Groups of Backcross Lines as Parents

Table 8. Means† of selected stiff stalk synthetic parents in testcross combinations for early maturing hybrids with high grain yield.

Pedigree	Moisture‡	Yield§	TWT¶	PSL#	PRL††	PH§§	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(cm)	(days)
LH176 x[(GEM 10xND2000)xND2000-1]-49	22.3	6.3	51.6	1.1	0.0	193.3	69.2
LH176 x[(GEM 10xND2000)xND2000-1]-31	22.5	7.2	50.4	0.7	0.0	198.2	67.8
LH176 x[(GEM 10xND2000)xND2000-1]-22	22.6	6.9	51.1	0.8	0.7	199.6	68.3
LH176 x[(GEM 10xND2000)xND2000-1]-42	22.6	7.8	51.6	0.0	0.0	194.8	67.0
LH176 x[(BSSS x ND2000)xND2000-1]-40	22.7	6.7	50.0	1.5	1.1	188.6	69.1
LH176 x[(BSSS x ND2000)xND2000-1]-24	22.8	6.7	50.6	0.0	0.0	195.3	67.3
LH176 x[(GEM 10xND2000)xND2000-1]-34	22.9	6.5	50.7	1.0	0.0	194.9	68.4
LH176 x[(B73 x ND2000)xND2000-1]-70	23.4	6.8	51.4	0.0	0.0	187.7	66.1
LH176 x[(GEM 10xND2000)xND2000-1]-17	23.5	7.1	50.8	1.2	0.0	197.5	67.5
LH176 x[(GEM 3xND2000)xND2000-1]-30	23.6	6.8	50.1	0.0	0.0	192.2	68.2
LH176 x[(GEM 3xND2000)xND2000-1]-77	23.8	6.7	50.5	0.0	0.0	190.8	66.8
LH176 x[(GEM 3xND2000)xND2000-1]-2	23.8	6.5	50.2	0.3	0.0	198.6	68.5
LH176 x[(GEM 3xND2000)xND2000-1]-116	23.8	6.6	51.2	0.4	0.0	199.0	67.8
LH176 x[(GEM 10xND2000)xND2000-1]-9	23.9	6.9	50.6	2.2	0.0	199.2	69.3
LH176 x[(GEM 3xND2000)xND2000-1]-94	24.0	6.6	51.6	2.3	1.8	201.0	68.0
LH176 x[(GEM 3xND2000)xND2000-1]-67	24.0	6.6	50.0	2.2	0.0	192.8	68.6
LH176 x[(B73 x ND2000)xND2000-1]-12	24.2	7.0	50.5	0.3	0.0	193.6	68.9
DKC33-54 (83RM)	19.4	7.1	53.3	0.0	0.3	193.4	66.0
Pioneer 39D85 (87RM)	22.4	7.5	51.5	2.9	0.0	204.5	67.8
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	0.3	0.7	214.3	71.4
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	0.0	0.3	210.6	70.2
Experimental Mean	24.3	6.4	49.8	0.7	0.2	195.5	68.3
LSD (0.05)	2.3	1.8	2.0	2.2	1.2	9.0	1.9
CV%	6.9	17.6	9.2	250.3	554.9	3.7	2.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.# Percentage stalk lodge.†† Percentage root lodge.‡‡ Days after planting to 50% plants with visible silk.§§ Plant Height

Table 9. Means† of selected stiff stalk synthetic parents in testcross combinations for early maturing hybrids with high grain yield and grain oil content.

Pedigree	Moisture‡	Yield§	TWT¶	Starch	Oil	Protein
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)
LH176 x[(GEM 3xND2000)xND2000-1]-97	23.4	6.7	49.9	69.0	4.6	9.6
LH176 x[(GEM 3xND2000)xND2000-1]-116	23.8	6.6	51.2	69.4	4.6	9.5
LH176 x[(B73 x ND2000)xND2000-1]-68	25.1	7.0	49.5	69.5	4.6	9.7
LH176 x[(GEM 3xND2000)xND2000-1]-27	22.9	6.4	49.6	69.2	4.5	10.2
LH176 x[(GEM 3xND2000)xND2000-1]-47	24.4	6.4	49.1	69.9	4.5	9.6
DKC33-54 (83RM)	19.4	7.1	53.3	69.8	4.0	9.1
Pioneer 39D85 (87RM)	22.4	7.5	51.5	70.8	4.1	9.1
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	69.9	4.4	8.5
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	69.3	4.2	9.3
Experimental Mean	24.3	6.4	49.8	69.9	4.3	9.6
LSD (0.05)	2.3	1.8	2.0	0.9	0.3	0.6
CV%	6.9	17.6	9.2	0.9	5.2	3.7

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.

Table 10. Means† of selected stiff stalk synthetic parents in testcross combination for early maturing hybrids with high grain yield and grain protein content.

Pedigree	Moisture‡	Yield§	TWT¶	Starch	Oil	Protein
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)
LH176 x[(GEM 3xND2000)xND2000-1]-73	24.3	6.7	49.8	70.1	4.3	10.2
LH176 x[(GEM 3xND2000)xND2000-1]-94	24.0	6.6	51.6	69.4	4.3	10.2
LH176 x[(GEM 3xND2000)xND2000-1]-27	22.9	6.4	49.6	69.2	4.5	10.2
LH176 x[(GEM 3xND2000)xND2000-1]-50	24.1	6.5	49.7	69.7	4.3	10.0
LH176 x[(GEM 3xND2000)xND2000-1]-74	24.6	6.3	49.1	69.5	4.4	9.9
LH176 x[(GEM 3xND2000)xND2000-1]-77	23.8	6.7	50.5	69.4	4.4	9.9
LH176 x[(GEM 3xND2000)xND2000-1]-81	24.6	7.1	49.5	70.0	4.2	9.9
LH176 x[(GEM 10xND2000)xND2000-1]-42	22.6	7.8	51.6	70.1	4.1	9.8
LH176 x[(GEM 3xND2000)xND2000-1]-67	24.0	6.6	50.0	69.6	4.4	9.8
LH176 x[(GEM 3xND2000)xND2000-1]-54	24.4	7.0	50.0	69.5	4.4	9.8
LH176 x[(GEM 10xND2000)xND2000-1]-22	22.6	6.9	51.1	69.7	4.3	9.7
LH176 x[(GEM 10xND2000)xND2000-1]-39	24.2	6.7	49.5	69.9	4.2	9.7
DKC33-54 (83RM)	19.4	7.1	53.3	69.8	4.0	9.1
Pioneer 39D85 (87RM)	22.4	7.5	51.5	70.8	4.1	9.1
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	69.9	4.4	8.5
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	69.3	4.2	9.3
Experimental Mean	24.3	6.4	49.8	69.9	4.3	9.6
LSD	2.3	1.8	2.0	0.9	0.3	0.6
CV%	6.9	17.6	9.2	0.9	5.2	3.7

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.

Table 11. Means† of selected stiff stalk synthetic parents in testcross combinations for early maturing hybrids with high grain yield and high grain extractable starch content.

Pedigree	Moisture‡ (%)	Yield§ (t/ha)	TWT¶ (lb/bu)	Starch (%)	Oil (%)	Protein (%)	ExStarch# (%)
LH176 x[(GEM 10xND2000)xND2000-1]-49	22.3	6.3	51.6	70.3	4.1	9.2	64.3
LH176 x[(GEM 10xND2000)xND2000-1]-31	22.5	7.2	50.4	70.4	4.2	9.2	63.2
LH176 x[(B73 x ND2000)xND2000-1]-70	23.4	6.8	51.4	70.3	4.4	9.4	63.1
LH176 x[(BSSS x ND2000)xND2000-1]-24	22.8	6.7	50.6	69.6	4.4	9.5	63.0
LH176 x[(GEM 10xND2000)xND2000-1]-32	24.0	6.4	49.3	70.4	4.2	9.5	62.8
LH176 x[(GEM 10xND2000)xND2000-1]-17	23.5	7.1	50.8	69.9	4.4	9.7	62.8
LH176 x[(GEM 10xND2000)xND2000-1]-33	24.6	7.1	49.0	70.3	4.1	9.5	62.7
LH176 x[(BSSS x ND2000)xND2000-1]-40	22.7	6.7	50.0	70.6	4.1	9.5	62.7
LH176 x[(B73 x ND2000)xND2000-1]-45	24.6	7.1	50.6	70.2	4.3	9.2	62.6
LH176 x[(B73 x ND2000)xND2000-1]-75	22.6	6.5	49.8	70.0	4.6	9.5	62.6
LH176 x[(GEM 3xND2000)xND2000-1]-116	23.8	6.6	51.2	69.4	4.6	9.5	62.6
LH176 x[(GEM 10xND2000)xND2000-1]-1	24.3	6.7	51.5	70.6	4.3	9.3	62.6
LH176 x[(GEM 10xND2000)xND2000-1]-42	22.6	7.8	51.6	70.1	4.1	9.8	62.6
LH176 x[(GEM 10xND2000)xND2000-1]-47	24.8	6.8	50.1	70.0	4.3	9.1	62.6
LH176 x[(GEM 3xND2000)xND2000-1]-77	23.8	6.7	50.5	69.4	4.4	9.9	62.5
DKC33-54 (83RM)	19.4	7.1	53.3	69.8	4.0	9.1	63.9
Pioneer 39D85 (87RM)	22.4	7.5	51.5	70.8	4.1	9.1	61.8
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	69.9	4.4	8.5	62.5
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	69.3	4.2	9.3	61.0
Experimental Mean	24.3	6.4	49.8	69.9	4.3	9.6	62.3
LSD	2.3	1.8	2.0	0.9	0.3	0.6	1.2
CV%	6.9	17.6	9.2	0.9	5.2	3.7	1.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight of grain at harvest.# Extractable starch percentage in grain.

Genotype and Environment Interaction (G x E)

Since economically important traits are quantitative in nature, they are genetically controlled by the combination of many genes. Quantitative traits are often exposed to high G × E interactions due to different genes reacting differently in different environments across years and across locations (Falconer and McKay, 2004).

G × E Interaction for Experiment I

Contrary to expected, G × E interaction was not observed for agronomic traits except for days of anthesis and ear height ($P < 0.05$) (Table 12). However, Significant G × E interactions were observed for all the grain quality traits (Table 13). Among the traits with significant G × E interaction, the Spearman's rank correlation was large for extractable starch, grain oil, and grain protein contents than the HFC and starch contents across environments (Table C1). High G × E interaction for maize kernel oil, protein and starch concentrations were also reported by Wassom et al. (2008) among BC_1:S_1 lines derived from Illinois high oil backcross lines.

Table 12. Fishers F-test and genotype (G) × environment (E) interaction for maize agronomic traits collected across five North Dakota environments.

Tests	**Moist†** (%)	**Yield‡** (t/ha)	**TWT§** (lb/bu)	**Stand** Plants/ha	**Stalk lodge** (%)	**Root lodge** (%)	**EH¶** (cm)	**PH#** (cm)	**DA††**	**DS‡‡**
G x E (PR > F)	0.108	0.075	0.351	0.620	0.630	0.630	0.040	0.050	0.005	0.080
F- test (G)	<.0001	0.005	<.0001	0.005	0.065	0.234	<.0001	<.0001	<.0001	<.0001

† Gain moisture at harvest. ‡ Grain yield adjusted at 15.5% grain moisture. § Test weight of grain at harvest. ¶ Ear height. # Plant height. †† Days after planting to 50% of plants shedding pollen. ‡‡ Days after planting to when 50% plants with visible silk.

Table 13. Fishers F-test and genotype (G) × environment (E) interaction for maize grain quality traits collected across five North Dakota environments.

Tests	**HFC†** (%)	**Starch** (%)	**Oil** (%)	**Protein** (%)	**ExStarch‡** (%)
G x E (PR > F)	0.002	0.020	0.001	0.004	<0.0001
F-test (G)	0.013	<.0001	<.0001	<.0001	<.0001

† High fermentable corn in grain. ‡ Extractable starch in corn.

G × E Interaction for Experiment II

G × E interaction was significant for several agronomic and grain quality traits (Tables 14 and 15). The Spearman's coefficient of rank correlation was calculated across different environments for the trait with significant G × E interactions. Low correlation between environments can be important for this kind of screening research in a breeding program to know if different genes could be active in different environments. The Spearman's correlation coefficient was high for grain moisture (range 0.26 to 0.63) compared to yield (-0.05 to 0.34) and quality traits (Table C2).

Table 14. Fishers F-test and genotype (G) × environment (E) interaction for maize agronomic traits collected across six North Dakota environments.

Tests	**Moist†** (%)	**Yield‡** (t/ha)	**TWT§** (lb/bu)	**Stand** Plants/ha	**Stalk lodge** (%)	**Root lodge** (%)	**EH¶** (cm)	**PH#** (cm)	**DA††**	**DS‡‡**
G x E Pr > F	<0.0001	<0.0001	0.004	0.006	0.020	0.205	0.103	0.440	0.009	0.380
F-test (G)	<.0001	<.0001	<.0001	<.0001	0.090	0.650	<.0003	<.0004	<.0005	<.0006

† Grain moisture at harvest. ‡ Grain yield adjusted at 15.5% grain moisture. § Test weight of grain at harvest. ¶ Ear height. # Plant height. †† Days after planting to 50% of plants shedding pollen. ‡‡ Days after planting to when 50% plants with visible silk.

Table 15. Fishers F-test and genotype (G) × environment (E) interaction for maize quality traits collected across five North Dakota environments.

Tests	**HFC†** (%)	**Starch** (%)	**Oil** (%)	**Protein** (%)	**ExStarch‡** (%)
G x E Pr > F	0.850	0.010	0.407	<0.0001	<0.0001
F-test (G)	<.0001	<.0001	<.0001	<.0001	<.0002

† High fermentable corn in grain. ‡ Extractable starch in corn.

Phenotypic Correlation of Traits (r_p)

The Pearson's correlation coefficient (r_p) was large between TWT and grain moisture at harvest: (r_p = -0.559, P <. 0001) in non-SS group of testcrosses (Table 16) and (r_p = -0.6489, P <. 0001) in SS group of testcrosses (Table 17). A medium to large negative correlation was observed between grain protein and grain starch (r_p = -0.53, P <. 0001), and grain oil and grain starch content (r_p = -0.64, P <. 0001) in non-SS group of testcrosses. Similar large medium to large correlation was observed in SS group of testcrosses between grain starch and protein contents (r_p = -0.53, P <. 0001) and grain starch and oil contents (r_p

$= -0.62$, $P <. 0001$). The strong negative phenotypic correlation among testcrosses between oil and protein with starch was also reported by Wassom et al. (2008) in $BC_1:S_1$ lines derived from Illinois high oil x B73, where B73 was used as recurrent parent. The correlation between extractable starch and starch was medium in both non-SS ($r_p = 0.41$, $P <. 0001$) and SS ($r_p = 0.55$, $P <. 0001$) group of testcrosses where high extractable starch content in grain was correlated with low protein content ($r_p = -0.554$, $P <. 0001$) for non-SS and for SS ($r_p = -0.46$, $P <. 0001$) groups of testcrosses and checks. The correlations between days of anthesis (DA) with moisture ($r_p = 0.49$, $P <. 0001$) and days of silking (DS) with moisture ($r_p = 0.47$, $P <. 0001$) among SS group of testcrosses and DA with moisture ($r_p = 0.38$, $P <. 0001$) and DS with moisture ($r_p = 0.53$, $P <. 0001$) among non-SS group of testcrosses was not high enough to obtain early maturing hybrids only based on early flowering. Nursery observation based on field dry down of grains will be more important in incorporation for early maturity of short season maize than only based on early flowering.

Table 16. Pearson correlation across mean of traits among non-stiff stalk synthetic group of testcross hybrids and industry check hybrids in experiment I.

	Moist‡ (%)	**Yield§ (t/ha)**	**TWT¶ (lb/bu)**	**HFC# (%)**	**Starch (%)**	**Oil (%)**	**Protein (%)**	**ES†† (%)**	**DA§§**	**DS‡‡**
Moisture	1.00	-0.166†	-0.56	-0.27	-0.20	0.11	0.07	-0.32	0.39	0.53
		0.05¶¶	<. 0001	0.00	0.02	0.20	0.41	0.00	<. 0001	<.0001
Yield		1.00	-0.07	0.10	0.03	-0.02	0.01	0.11	-0.09	0.02
			0.42	0.22	0.71	0.77	0.92	0.19	0.30	0.80
TWT			1.00	0.12	0.12	-0.20	0.03	0.12	-0.30	-0.51
				0.17	0.16	0.02	0.69	0.15	0.00	<.0001
HFC				1.00	0.37	-0.24	0.35	-0.08	0.02	-0.05
					<.0001	0.00	<.0001	0.35	0.86	0.56
Starch					1.00	-0.64	-0.53	0.41	-0.04	0.06
						<.0001	<.0001	<.0001	0.64	0.47
Oil						1.00	0.10	-0.16	0.06	-0.04
							0.22	0.06	0.49	0.66
Protein							1.00	-0.55	0.09	-0.06
								<.0001	0.30	0.47
ExStarch								1.00	-0.16	-0.24
									0.05	0.00
DA									1.00	0.69
										<.0001
DS										1.00

†Pearson correlation (r_p). ‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain. ‡‡ Days after planting to 50% plants with visible silk. §§ Days after planting to 50% tassels shedding pollens. ¶¶ Probability > |r| under H_0: Rho=0.

Table 17. Pearson correlation across mean of traits among stiff stalk synthetic group of testcross hybrids and industry check hybrids in experiment II.

	Moist‡ (%)	Yield§ (t/ha)	TWT¶ (lb/bu)	HFC# (%)	Starch (%)	Oil (%)	Protein (%)	ES†† (%)	DA§§	DS‡‡
Moisture	1.00	0.12†	-0.65	-0.25	-0.11	0.26	0.05	-0.34	0.49	0.48
		0.24¶¶	<.0001	0.01	0.28	0.01	0.65	0.00	<.0001	<.0001
Yield		1.00	-0.03	-0.02	0.01	-0.03	-0.26	0.02	0.20	0.19
			0.75	0.86	0.90	0.75	0.01	0.83	0.05	0.06
TWT			1.00	0.27	0.10	-0.23	0.00	0.40	-0.42	-0.46
				0.01	0.35	0.02	0.97	<.0001	<.0001	<.0001
HFC				1.00	0.51	-0.17	0.02	0.27	-0.23	-0.25
					<.0001	0.08	0.85	0.01	0.02	0.01
Starch					1.00	-0.62	-0.53	0.55	0.04	0.04
						<.0001	<.0001	<.0001	0.73	0.69
Oil						1.00	0.23	-0.49	-0.05	-0.03
							0.02	<.0001	0.63	0.77
Protein							1.00	-0.47	-0.09	-0.11
								<.0001	0.36	0.26
ExStarch								1.00	-0.18	-0.26
									0.07	0.01
DA									1.00	0.95
										<.0001
DS										1.00

†Pearson correlation (r_p).‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain. ‡‡ Days after planting to 50% plants with visible silk. §§ Days after planting to 50% tassels shedding pollens. ¶¶ Probability > |r| under H_0: Rho=0.

CONCLUSIONS

Increasing genetic diversity of maize hybrids by incorporating tropical and temperate exotic germplasm is a unique way to develop short-season hybrids with improved grain yield and grain quality. The adaptation of unique exotic germplasm in unique screening environments through incorporation can be a rapid way of evolution of new and desirable traits in cultivars. The existing U.S. germplasms (B73, Mo17 and BSSS) did not found have diverse alleles for short season hybrid development or may need more backcrossing for adaptation. The useful genetic diversity generated by the NDSU EarlyGEM program is a new source of diverse tropical and temperate alleles for yield and quality under abiotic stresses for short season hybrids not present in the hybrids offered to farmers by the U.S. industry (e.g., lines recycled and derived from B73, Mo17, where most DNA sequences are known). The NDSU EarlyGEM program has generated a unique pool of short-season germplasms represented in below 90RM group. The incorporation of unique exotic germplasm is not a popular practice by either seed companies or US universities. The results have shown the improved exotic germplasms from public breeding programs through multistage incorporations from LAMP, GEM and NDSU EarlyGEM can be valuable resource to increase the genetic diversity of breeding programs and hybrids on farms. This has shown the importance of public breeding programs to evaluate and improve more exotic germplasms for selection in more diverse environments and for multiple traits in future.

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APPENDICES

Appendix A

Table A1. Means† of test crosses with GEM22 $BC_1:S_1$ maize lines evaluated across five North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-13	27.8	7.0	51.0	48.4	69.3	4.6	9.8	60.4	66.8
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-51	24.5	6.9	52.5	48.5	70.1	4.4	9.0	61.7	66.8
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-39	25.0	6.8	52.1	48.4	69.4	4.6	9.9	60.2	65.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-42	23.6	6.6	53.6	48.6	69.8	4.6	9.1	61.4	66.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-30	25.7	6.6	52.0	47.8	69.0	4.7	9.4	61.0	66.9
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-67	24.7	6.6	51.2	48.3	69.7	4.5	9.4	60.9	65.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-50	25.9	6.6	52.3	48.0	69.1	4.8	9.5	61.1	66.2
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-45	23.0	6.5	53.1	47.8	69.6	4.6	8.9	61.8	65.3
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-98	24.3	6.5	51.6	48.6	69.9	4.5	9.4	61.8	66.2
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-11	25.6	6.3	52.8	48.7	70.1	4.4	9.2	60.8	66.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-36	24.2	6.3	53.5	48.1	69.7	4.4	9.1	61.6	66.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-75	25.9	6.3	52.3	48.6	70.0	4.2	9.6	61.7	66.3
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-65	25.1	6.3	52.5	48.1	69.8	4.6	9.0	62.3	66.9
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-62	24.8	6.3	53.3	47.8	69.2	4.9	9.2	61.7	67.0
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-87	25.9	6.3	50.3	48.4	69.9	4.6	9.1	62.4	66.0
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-107	25.5	6.3	52.8	48.9	70.5	4.4	9.2	62.0	67.5
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-115	25.0	6.1	52.5	47.6	69.3	4.7	9.4	61.0	66.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-78	25.2	5.8	51.6	48.0	69.4	4.8	9.3	60.4	67.3
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-46	27.4	5.8	51.8	48.2	69.4	4.7	9.5	60.9	67.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-71	26.7	5.8	50.9	48.3	69.7	4.8	9.1	61.9	67.3
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-35	27.8	5.8	52.4	48.3	69.5	4.4	9.6	60.3	66.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-56	27.3	5.7	50.4	48.4	69.9	4.6	9.2	61.4	67.1
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-33	26.1	5.7	51.9	47.8	69.5	4.8	9.0	60.9	66.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-94	25.5	5.6	52.9	48.1	69.5	4.7	9.2	61.3	66.4
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-52	28.1	5.6	52.1	48.3	69.6	4.6	9.6	61.3	67.5
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-101	27.1	5.6	51.6	47.9	69.3	4.4	9.5	61.1	66.3
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-81	27.4	5.5	52.2	47.9	69.5	4.6	9.1	60.6	67.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-6	27.6	5.5	51.4	48.1	69.8	4.3	9.3	60.9	67.9
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-104	24.8	5.5	50.6	48.7	69.9	4.6	9.6	60.5	66.7
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-85	25.5	5.3	51.8	48.1	69.6	4.6	9.4	60.7	66.6
TR3026xTR2040x[(GEM 22 x ND 2000) x ND 2000)-1]-106	33.0	4.9	48.5	47.7	68.7	4.8	9.5	60.2	68.5
DKC33-54 (83RM)	22.2	6.9	52.3	48.8	70.3	4.0	8.9	63.3	65.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	47.6	69.7	4.6	8.4	62.2	70.4
Pioneer 39D85 (87RM)	25.1	7.5	51.9	48.3	70.7	4.1	8.7	61.0	68.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	47.5	70.0	4.1	8.8	60.1	70.5
Experimental Mean	25.8	6.2	51.8	48.1	69.7	4.5	9.1	61.6	66.5
LSD(0.05)	2.9	1.4	1.9	1.0	0.8	0.2	0.6	0.9	1.7
CV%	9.1	18.1	3.0	1.8	0.9	4.3	5.1	1.2	1.8

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture .¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain. ‡‡ Days after planting to 50% plants with visible silk.

Table A2. Means† of test crosses with GEM4 BC_1:S_1 maize lines from trials across five North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-90	26.4	7.1	51.2	47.1	69.8	4.7	8.2	62.0	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-131	27.3	6.9	51.0	47.8	69.7	4.7	8.8	62.1	66.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-25	25.2	6.8	51.6	47.6	69.7	4.7	8.7	61.8	67.5
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-77	29.1	6.8	49.1	47.6	69.7	4.4	9.2	61.1	68.5
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-47	24.4	6.5	51.9	47.6	69.6	4.6	8.8	61.6	65.7
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-84	27.8	6.4	50.9	47.8	70.0	4.5	8.8	62.3	67.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-109	23.6	6.4	52.7	47.9	69.6	4.5	9.1	61.4	65.4
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-30	25.3	6.4	52.8	47.6	69.4	4.7	9.1	61.9	65.2
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-63	25.1	6.4	50.9	48.1	69.4	4.7	9.2	61.5	66.1
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-53	26.3	6.3	51.5	48.2	69.5	4.5	9.5	61.3	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-21	23.3	6.3	50.9	48.2	69.9	4.7	8.8	62.2	66.7
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-103	25.6	6.3	52.2	47.9	69.6	4.4	9.3	62.2	65.3
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-57	26.5	6.3	51.4	47.7	69.6	4.5	9.0	61.8	66.4
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-39	26.9	6.3	51.7	47.5	69.5	4.7	8.6	61.6	66.4
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-64	25.2	6.2	52.5	48.1	69.7	4.6	8.8	61.7	66.3
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-116	26.3	6.1	50.6	47.7	69.5	4.7	8.9	62.0	66.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-85	25.4	6.1	51.3	48.2	70.2	4.5	8.6	62.4	65.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-101	24.9	6.0	51.6	48.3	70.2	4.5	8.1	61.7	65.2
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-115	25.8	6.0	51.3	47.7	69.3	4.8	8.9	60.8	66.1
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-45	25.0	6.0	52.1	48.1	69.9	4.4	8.9	62.1	64.9
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-46	24.6	5.9	52.9	48.1	69.4	4.6	9.1	61.6	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-80	26.1	5.8	51.0	48.3	69.7	4.5	9.2	60.9	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-12	24.7	5.8	51.9	47.8	69.9	4.5	9.1	59.8	68.2
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-82	26.1	5.8	50.9	48.6	70.8	4.3	8.5	63.0	65.8
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-122	25.0	5.8	52.3	47.6	69.9	4.6	8.3	62.2	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-1	26.7	5.6	51.2	47.7	69.3	4.6	9.2	61.1	66.3
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-91	24.7	5.5	52.8	47.8	70.2	4.3	8.6	62.3	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-111	25.6	5.5	52.0	47.2	69.8	4.5	8.7	62.0	65.6
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-31	24.3	5.5	51.9	48.5	69.5	4.7	9.3	61.1	67.1
TR3026xTR2040x[(GEM 4 x ND 2000) x ND 2000)-1]-66	23.3	4.8	52.2	48.0	70.2	4.3	8.7	62.2	65.6
DKC33-54 (83RM)	22.2	6.9	52.3	48.8	70.3	4.0	8.9	63.3	65.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	47.6	69.7	4.6	8.4	62.2	70.4
Pioneer 39D85 (87RM)	25.1	7.5	51.9	48.3	70.7	4.1	8.7	61.0	68.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	47.5	70.0	4.1	8.8	60.1	70.5
Exp. Mean	25.8	6.2	51.8	48.1	69.7	4.5	9.1	61.6	66.5
Exp LSD(0.05)	2.9	1.4	1.9	1.0	0.8	0.2	0.6	0.9	1.7
CV%	9.1	18.1	3.0	1.8	0.9	4.3	5.1	1.2	1.8

† Means adjusted for lattice effects. ‡ Grain moisture at harvest. § Grain yield adjusted at 15.5% grain moisture. ¶ Test weight measured from test weight chamber in combine harvester. # Fermentable corn contents in grain. †† Extractable starch content in grain. ‡‡ Days after planting to 50% plants with visible silk.

Table A3. Means† of test crosses with GEM5 BC_1:S_1 maize lines from trials across five North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-212	25.3	7.2	49.2	48.5	69.7	4.6	9.4	61.8	66.6
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-9	21.8	7.2	52.2	48.0	70.0	4.5	8.7	62.5	64.8
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-57	27.5	7.1	52.3	48.2	69.9	4.4	9.1	61.7	67.8
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-142	26.8	7.0	50.9	48.1	69.6	4.7	9.0	62.0	68.0
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-97	25.3	7.0	51.7	48.0	69.7	4.6	8.8	62.3	66.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-219	24.1	7.0	52.7	48.0	69.8	4.5	8.8	62.3	65.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-183	25.3	6.9	51.3	48.1	69.7	4.5	9.3	61.9	66.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-204	26.5	6.9	51.1	48.0	69.5	4.8	9.3	61.1	65.3
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-149	26.8	6.8	51.3	48.0	69.1	4.7	9.5	60.4	66.6
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-54	24.2	6.8	51.0	48.5	69.7	4.5	9.3	61.9	66.9
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-33	23.2	6.8	52.0	48.2	69.7	4.5	9.1	61.7	66.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-24	21.8	6.8	52.3	48.2	69.3	4.7	9.2	62.1	65.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-186	25.2	6.7	51.3	48.2	69.8	4.5	9.2	61.6	66.3
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-84	25.4	6.6	50.5	48.8	70.1	4.4	9.2	62.0	66.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-18	26.5	6.6	51.1	47.7	69.2	4.8	9.2	62.1	66.6
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-19	23.7	6.5	53.4	48.5	69.9	4.5	9.2	61.4	65.1
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-181	24.8	6.4	51.4	48.5	69.5	4.4	9.4	61.0	67.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-184	24.0	6.4	53.1	48.0	69.6	4.6	9.1	61.9	65.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-72	24.3	6.4	52.3	48.3	70.0	4.5	9.1	61.2	66.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-215	23.3	6.4	52.7	48.0	69.9	4.5	8.7	62.1	65.3
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-141	24.3	6.3	52.6	48.4	69.2	4.7	9.6	61.1	66.1
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-178	25.0	6.2	52.5	47.8	69.6	4.5	8.8	62.1	66.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-122	26.2	6.2	52.3	47.7	69.5	4.4	9.3	61.7	65.9
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-80	24.9	6.2	52.3	48.7	70.0	4.6	9.1	61.4	65.8
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-15	23.6	6.1	51.2	47.8	69.4	4.7	9.1	62.3	66.6
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-25	25.8	6.1	51.3	48.9	70.2	4.4	9.1	61.0	67.2
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-13	25.1	6.0	51.5	47.8	69.5	4.5	9.2	61.7	65.4
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-138	25.5	6.0	52.3	47.7	69.7	4.4	9.0	62.3	66.5
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-162	25.2	6.0	52.4	48.1	69.6	4.7	9.0	62.0	65.8
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-190	24.3	6.0	53.2	48.0	69.8	4.5	9.0	61.4	65.0
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-32	24.8	5.9	51.9	48.4	70.1	4.3	9.0	62.3	67.7
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-132	22.9	5.9	53.8	48.4	70.0	4.3	9.2	62.1	65.0
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-148	27.6	5.7	49.5	48.2	69.7	4.8	8.7	62.6	68.3
TR3026xTR2040x[(GEM 5 x ND 2000) x ND 2000)-1]-128	24.8	5.4	52.0	48.2	69.6	4.7	9.0	61.7	66.7
DKC33-54 (83RM)	22.2	6.9	52.3	48.8	70.3	4.0	8.9	63.3	65.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	47.6	69.7	4.6	8.4	62.2	70.4
Pioneer 39D85 (87RM)	25.1	7.5	51.9	48.3	70.7	4.1	8.7	61.0	68.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	47.5	70.0	4.1	8.8	60.1	70.5
Experimental Mean	25.8	6.2	51.8	48.1	69.7	4.5	9.1	61.6	66.5
LSD(0.05)	2.9	1.4	1.9	1.0	0.8	0.2	0.6	0.9	1.7
CV%	9.1	18.1	3.0	1.8	0.9	4.3	5.1	1.2	1.8

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture .¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain.†† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Table A4. Means† of test crosses for GEM26 BC$_1$:S$_1$ maize lines from trials across five North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-32	26.9	7.2	52.1	48.3	69.4	4.6	9.3	61.9	66.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-132	26.9	6.9	52.3	47.8	69.7	4.5	9.0	61.5	65.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-84	27.4	6.8	51.2	47.9	69.6	4.5	9.1	61.2	67.1
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-79	27.0	6.7	51.6	47.4	69.7	4.5	9.0	62.5	66.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-44	22.0	6.6	53.0	48.4	69.6	4.5	9.6	61.4	65.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-54	26.8	6.6	52.0	48.0	69.5	4.5	9.1	61.6	65.5
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-56	26.1	6.5	50.9	48.4	69.7	4.6	9.4	60.8	65.9
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-108	24.6	6.5	52.0	48.8	70.3	4.4	9.0	62.4	65.3
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-74	25.2	6.5	53.0	47.8	70.0	4.2	9.2	62.1	65.6
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-118	26.6	6.5	52.7	48.6	69.6	4.5	9.6	61.6	66.6
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-35	25.0	6.5	53.3	48.7	69.9	4.5	9.4	61.9	65.6
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-93	27.2	6.4	51.1	48.1	69.5	4.7	9.0	62.4	67.4
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-104	25.0	6.3	51.7	47.5	70.1	4.6	8.7	62.8	66.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-18	25.7	6.2	53.2	47.5	69.8	4.4	8.9	62.4	65.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-126	28.2	6.2	51.5	47.9	69.5	4.6	9.2	61.0	66.1
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-26	27.1	6.1	51.6	47.5	70.1	4.4	8.5	62.5	67.4
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-89	26.9	6.0	51.3	48.2	69.7	4.6	9.1	61.6	67.1
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-43	25.6	6.0	51.8	48.4	70.6	4.4	8.5	62.1	66.9
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-20	25.9	6.0	53.2	48.2	70.0	4.5	9.0	61.8	66.1
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-17	27.7	6.0	51.4	48.0	69.7	4.5	9.3	62.0	66.4
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-100	28.2	5.9	51.9	47.9	70.4	4.4	8.5	62.1	66.8
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-112	25.6	5.7	51.8	47.9	69.8	4.5	8.8	62.4	66.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-73	29.3	5.6	49.6	47.5	69.1	4.8	9.3	61.4	66.4
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-27	25.2	5.6	52.2	47.8	69.7	4.5	9.1	62.1	66.7
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-110	29.9	5.5	51.4	47.8	69.8	4.6	8.8	61.6	67.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-33	24.2	5.4	53.0	48.5	69.9	4.2	9.2	61.7	67.3
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-121	28.8	5.3	51.9	47.8	69.6	4.5	8.8	61.7	66.4
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-62	25.4	5.2	52.7	48.0	69.8	4.4	9.3	61.7	65.2
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-59	24.9	5.1	51.2	47.9	69.7	4.5	8.9	62.4	66.0
TR3026xTR2040x[(GEM26 x ND2000)xND2000)-1]-36	25.9	4.5	51.6	48.2	70.1	4.5	9.1	62.0	66.9
DKC33-54 (83RM)	22.24	6.9	52.3	48.8	70.2	4.04	8.9	63.3	65.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	47.6	69.7	4.6	8.4	62.2	70.4
Pioneer 39D85 (87RM)	25.1	7.5	51.9	48.3	70.7	4.1	8.7	61.0	68.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	47.5	70.0	4.1	8.8	60.1	70.5
Experimental Mean	25.8	6.2	51.8	48.1	69.7	4.5	9.1	61.6	66.5
LSD(0.05)	2.9	1.4	1.9	1.0	0.8	0.2	0.6	0.9	1.7
CV%	9.1	18.1	3.0	1.8	0.9	4.3	5.1	1.2	1.8

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Table A5. Means† of test crosses with Mo17 BC$_1$:S$_1$ maize lines from trials across five North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-65	26.1	6.9	51.6	48.6	70.2	4.5	8.9	61.3	66.9
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-103	25.4	6.8	52.3	48.6	69.5	4.5	9.6	61.1	65.6
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-94	25.9	6.8	51.7	48.3	69.9	4.6	9.1	61.9	64.9
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-45	27.4	6.5	51.0	48.7	70.3	4.4	9.0	61.3	67.7
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-68	28.5	6.3	51.4	47.9	69.4	4.5	9.2	61.3	66.7
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-41	27.9	6.1	51.6	48.6	70.6	4.5	8.5	61.8	68.7
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-71	26.7	6.0	50.8	47.7	70.0	4.4	8.7	61.1	67.5
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-34	26.2	6.0	53.2	48.1	69.5	4.6	9.2	60.9	66.0
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-67	25.6	5.9	52.1	47.9	69.8	4.5	8.9	61.7	67.0
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-43	24.4	5.8	54.1	47.7	70.1	4.4	8.7	62.2	65.7
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-85	24.9	5.8	52.8	48.3	69.8	4.8	8.7	61.9	65.0
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-74	26.1	5.8	52.4	48.3	69.8	4.4	9.2	61.1	66.5
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-51	27.1	5.6	51.5	48.1	69.6	4.6	9.2	61.5	66.6
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-73	26.5	5.4	51.9	47.4	69.8	4.5	8.9	61.6	67.8
TR3026xTR2040x[(MO 17 x ND 2000) x ND 2000)-1]-39	27.8	5.3	51.5	48.0	69.3	4.5	9.4	60.2	66.2
DKC33-54 (83RM)	22.2	6.9	52.3	48.8	70.3	4.0	8.9	63.3	65.8
NP2623CBLL x TR3030 (90RM)	27.3	7.9	48.9	47.6	69.7	4.6	8.4	62.2	70.4
Pioneer 39D85 (87RM)	25.1	7.5	51.9	48.3	70.7	4.1	8.7	61.0	68.4
TR3127GT x TR3621CBLLRW (92RM)	30.7	6.7	49.6	47.5	70.0	4.1	8.8	60.1	70.5
Entry Mean	25.8	6.2	51.8	48.1	69.7	4.5	9.1	61.6	66.5
LSD(0.05)	2.9	1.4	1.9	1.0	0.8	0.2	0.6	0.9	1.7
CV%	9.1	18.1	3.0	1.8	0.9	4.3	5.1	1.2	1.8

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain.†† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Appendix B

Table B1. Means† of test crosses with B73 BC$_1$:S$_1$ maize lines from trials across six North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
LH176 x[(B73 x ND2000)xND2000-1]-45	24.6	7.1	50.6	48.2	70.2	4.3	9.2	62.6	67.2
LH176 x[(B73 x ND2000)xND2000-1]-68	25.1	7.0	49.5	47.9	69.5	4.6	9.7	62.3	67.3
LH176 x[(B73 x ND2000)xND2000-1]-12	24.2	7.0	50.5	47.9	69.8	4.3	9.6	62.2	68.9
LH176 x[(B73 x ND2000)xND2000-1]-70	23.4	6.8	51.4	48.1	70.3	4.4	9.4	63.1	66.1
LH176 x[(B73 x ND2000)xND2000-1]-67	24.8	6.7	49.0	48.2	70.1	4.3	9.6	62.1	67.7
LH176 x[(B73 x ND2000)xND2000-1]-35	25.4	6.7	49.8	47.6	69.6	4.4	9.5	62.0	67.6
LH176 x[(B73 x ND2000)xND2000-1]-75	22.6	6.5	49.8	47.8	70.0	4.6	9.5	62.6	67.5
LH176 x[(B73 x ND2000)xND2000-1]-27	26.3	6.5	49.3	47.7	69.8	4.3	9.5	62.6	68.4
LH176 x[(B73 x ND2000)xND2000-1]-8	26.0	6.4	49.0	47.5	69.9	4.5	9.3	62.3	68.4
LH176 x[(B73 x ND2000)xND2000-1]-20	23.1	6.4	50.5	48.1	69.5	4.4	9.6	61.5	67.3
LH176 x[(B73 x ND2000)xND2000-1]-41	23.6	6.0	50.0	48.3	70.5	4.3	9.3	62.7	66.1
LH176 x[(B73 x ND2000)xND2000-1]-11	25.8	5.8	50.6	47.9	70.1	4.5	9.5	61.6	68.4
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	47.8	69.9	4.4	8.5	62.5	71.4
Pioneer 39D85 (87RM)	22.4	7.5	51.5	48.3	70.8	4.1	9.1	61.8	67.8
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	46.4	69.3	4.2	9.3	61.0	70.2
DKC33-54 (83RM)	19.4	7.1	53.3	47.9	69.8	4.0	9.1	63.9	66.0
Entry Mean	24.3	6.4	49.8	47.7	69.9	4.3	9.6	62.3	68.3
LSD (0.05)	2.3	1.8	2.0	0.9	0.9	0.3	0.6	1.2	1.9
CV%	6.9	17.6	9.2	0.9	5.2	3.7	1.0	5.6	2.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Table B2. Means† of test crosses with BSSS BC$_1$:S$_1$ maize lines from trials across six North Dakota environments.

Pedigree	Moist‡	Yield§	TWT¶	HFC#	Starch	Oil	Protein	ES††	DS‡‡
	(%)	(t/ha)	(lb/bu)	(%)	(%)	(%)	(%)	(%)	(days)
LH176 x[(BSSS x ND2000)xND2000-1]-24	22.8	6.7	50.6	47.4	69.6	4.4	9.5	63.0	67.3
LH176 x[(BSSS x ND2000)xND2000-1]-40	22.7	6.7	50.0	47.7	70.6	4.1	9.5	62.7	69.1
LH176 x[(BSSS x ND2000)xND2000-1]-48	25.9	6.4	46.6	47.3	69.4	4.5	9.6	60.8	68.3
LH176 x[(BSSS x ND2000)xND2000-1]-50	26.2	6.3	48.8	47.4	69.6	4.6	9.6	61.6	69.4
LH176 x[(BSSS x ND2000)xND2000-1]-19	25.2	6.3	49.3	47.7	69.7	4.4	9.6	61.6	68.6
LH176 x[(BSSS x ND2000)xND2000-1]-7	24.3	6.3	50.0	47.5	69.7	4.3	9.7	62.5	68.3
LH176 x[(BSSS x ND2000)xND2000-1]-91	23.2	6.2	50.2	47.4	69.9	4.3	9.4	62.1	69.3
LH176 x[(BSSS x ND2000)xND2000-1]-74	25.3	6.1	49.1	47.9	70.0	4.4	9.8	61.8	69.1
LH176 x[(BSSS x ND2000)xND2000-1]-31	22.1	6.0	51.6	48.0	70.1	4.1	9.5	62.9	66.5
LH176 x[(BSSS x ND2000)xND2000-1]-115	25.4	6.0	49.9	47.3	69.8	4.5	9.5	62.1	68.3
LH176 x[(BSSS x ND2000)xND2000-1]-10	23.5	6.0	50.5	47.3	68.8	4.8	9.7	61.7	67.6
LH176 x[(BSSS x ND2000)xND2000-1]-94	23.2	5.9	48.5	47.3	70.2	4.2	9.0	62.7	68.6
LH176 x[(BSSS x ND2000)xND2000-1]-105	22.6	5.8	50.8	47.8	70.5	4.0	9.3	63.2	67.8
LH176 x[(BSSS x ND2000)xND2000-1]-68	24.0	5.8	49.7	47.5	69.4	4.2	10.0	61.4	69.0
LH176 x[(BSSS x ND2000)xND2000-1]-101	23.6	5.8	51.8	47.9	69.1	4.4	10.4	61.4	67.9
LH176 x[(BSSS x ND2000)xND2000-1]-63	23.9	5.7	49.6	47.8	70.2	4.1	9.3	63.0	69.1
LH176 x[(BSSS x ND2000)xND2000-1]-70	23.5	5.7	50.2	48.0	70.2	4.1	9.7	62.7	68.8
LH176 x[(BSSS x ND2000)xND2000-1]-54	24.4	5.7	49.3	47.3	69.9	4.2	9.5	62.3	69.3
LH176 x[(BSSS x ND2000)xND2000-1]-117	23.0	5.3	48.9	48.2	70.0	4.4	9.8	61.7	68.2
LH176 x[(BSSS x ND2000)xND2000-1]-16	21.4	5.3	51.7	47.3	69.2	4.2	10.1	62.5	66.9
LH176 x[(BSSS x ND2000)xND2000-1]-49	24.7	5.2	48.9	48.0	70.8	4.2	9.1	62.4	69.4
LH176 x[(BSSS x ND2000)xND2000-1]-51	22.3	5.2	51.9	48.0	70.3	4.1	9.7	62.9	68.6
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	47.8	69.9	4.4	8.5	62.5	71.4
Pioneer 39D85 (87RM)	22.4	7.5	51.5	48.3	70.8	4.1	9.1	61.8	67.8
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	46.4	69.3	4.2	9.3	61.0	70.2
DKC33-54 (83RM)	19.4	7.1	53.3	47.9	69.8	4.0	9.1	63.9	66.0
Experimental Mean	24.3	6.4	49.8	47.7	69.9	4.3	9.6	62.3	68.3
LSD (0.05)	2.3	1.8	2.0	0.9	0.9	0.3	0.6	1.2	1.9
CV%	6.9	17.6	9.2	0.9	5.2	3.7	1.0	5.6	2.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain. ‡‡ Days after planting to 50% plants with visible silk.

Table B3. Means† of test crosses with GEM10 derived BC_1:S_1 maize lines from trials across six North Dakota environments.

Pedigree	Moist‡ (%)	Yield§ (t/ha)	TWT¶ (lb/bu)	HFC# (%)	Starch (%)	Oil (%)	Protein (%)	ES†† (%)	DS‡‡ (days)
LH176 x[(GEM 10xND2000)xND2000-1]-42	22.6	7.8	51.6	48.2	70.1	4.1	9.8	62.6	67.0
LH176 x[(GEM 10xND2000)xND2000-1]-31	22.5	7.2	50.4	47.8	70.4	4.2	9.2	63.2	67.8
LH176 x[(GEM 10xND2000)xND2000-1]-33	24.6	7.1	49.0	48.1	70.3	4.1	9.5	62.7	68.5
LH176 x[(GEM 10xND2000)xND2000-1]-17	23.5	7.1	50.8	48.1	69.9	4.4	9.7	62.8	67.5
LH176 x[(GEM 10xND2000)xND2000-1]-9	23.9	6.9	50.6	47.6	70.0	4.3	9.2	62.3	69.3
LH176 x[(GEM 10xND2000)xND2000-1]-22	22.6	6.9	51.1	47.8	69.7	4.3	9.7	62.4	68.3
LH176 x[(GEM 10xND2000)xND2000-1]-23	22.0	6.8	49.0	47.4	69.4	4.4	9.6	62.0	68.5
LH176 x[(GEM 10xND2000)xND2000-1]-47	24.8	6.8	50.1	47.5	70.0	4.3	9.1	62.6	68.6
LH176 x[(GEM 10xND2000)xND2000-1]-39	24.2	6.7	49.5	47.7	69.9	4.2	9.7	61.9	69.2
LH176 x[(GEM 10xND2000)xND2000-1]-40	25.2	6.7	50.2	47.5	69.9	4.3	9.7	62.8	68.4
LH176 x[(GEM 10xND2000)xND2000-1]-1	24.3	6.7	51.5	48.3	70.6	4.3	9.3	62.6	68.5
LH176 x[(GEM 10xND2000)xND2000-1]-18	25.1	6.7	49.8	47.7	70.3	4.1	9.4	63.3	68.6
LH176 x[(GEM 10xND2000)xND2000-1]-36	24.3	6.6	49.7	48.2	70.0	4.3	9.3	62.5	68.6
LH176 x[(GEM 10xND2000)xND2000-1]-4	25.0	6.6	49.8	47.8	70.1	4.3	9.4	61.8	68.6
LH176 x[(GEM 10xND2000)xND2000-1]-34	22.9	6.5	50.7	47.7	69.9	4.3	9.5	62.3	68.4
LH176 x[(GEM 10xND2000)xND2000-1]-12	25.0	6.5	48.5	47.9	70.5	4.1	9.4	62.5	69.2
LH176 x[(GEM 10xND2000)xND2000-1]-32	24.0	6.4	49.3	48.5	70.4	4.2	9.5	62.8	68.4
LH176 x[(GEM 10xND2000)xND2000-1]-27	22.2	6.3	49.6	47.8	69.7	4.4	9.6	61.8	67.7
LH176 x[(GEM 10xND2000)xND2000-1]-43	22.7	6.3	50.6	48.0	69.8	4.4	9.4	62.8	68.4
LH176 x[(GEM 10xND2000)xND2000-1]-49	22.3	6.3	51.6	48.0	70.3	4.1	9.2	64.3	69.2
LH176 x[(GEM 10xND2000)xND2000-1]-5	23.6	6.3	50.8	47.8	70.4	4.1	9.4	63.1	67.0
LH176 x[(GEM 10xND2000)xND2000-1]-7	24.6	6.2	49.0	47.8	70.1	4.3	9.5	62.4	68.9
LH176 x[(GEM 10xND2000)xND2000-1]-44	22.4	6.2	51.6	48.2	70.1	4.4	9.4	63.0	66.6
LH176 x[(GEM 10xND2000)xND2000-1]-21	24.4	6.0	49.8	47.7	70.6	4.2	9.1	63.1	69.1
LH176 x[(GEM 10xND2000)xND2000-1]-19	23.4	5.8	51.0	47.9	70.3	4.4	9.3	62.9	68.7
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	47.8	69.9	4.4	8.5	62.5	71.4
Pioneer 39D85 (87RM)	22.4	7.5	51.5	48.3	70.8	4.1	9.1	61.8	67.8
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	46.4	69.3	4.2	9.3	61.0	70.2
DKC33-54 (83RM)	19.4	7.1	53.3	47.9	69.8	4.0	9.1	63.9	66.0
Experimental Mean	24.3	6.4	49.8	47.7	69.9	4.3	9.6	62.3	68.3
LSD (0.05)	2.3	1.8	2.0	0.9	0.9	0.3	0.6	1.2	1.9
CV%	6.9	17.6	9.2	0.9	5.2	3.7	1.0	5.6	2.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain. †† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Table B4. Means† of test crosses with GEM3 derived BC_1:S_1 maize lines from trials across six North Dakota environments.

Pedigree	**Moist‡**	**Yield§**	**TWT¶**	**HFC#**	**Starch**	**Oil**	**Protein**	**ES††**	**DS‡‡**
	(%)	**(t/ha)**	**(lb/bu)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(days)**
LH176 x[(GEM 3xND2000)xND2000-1]-81	24.6	7.1	49.5	47.7	70.0	4.2	9.9	61.9	68.8
LH176 x[(GEM 3xND2000)xND2000-1]-54	24.4	7.0	50.0	48.0	69.5	4.4	9.8	61.7	68.5
LH176 x[(GEM 3xND2000)xND2000-1]-35	29.6	6.8	48.6	47.7	69.5	4.6	9.8	61.3	70.7
LH176 x[(GEM 3xND2000)xND2000-1]-30	23.6	6.8	50.1	47.6	69.9	4.3	9.4	62.4	68.2
LH176 x[(GEM 3xND2000)xND2000-1]-97	23.4	6.7	49.9	47.0	69.0	4.6	9.6	61.3	68.9
LH176 x[(GEM 3xND2000)xND2000-1]-77	23.8	6.7	50.5	47.9	69.4	4.4	9.9	62.5	66.8
LH176 x[(GEM 3xND2000)xND2000-1]-73	24.3	6.7	49.8	48.2	70.1	4.3	10.2	62.2	68.3
LH176 x[(GEM 3xND2000)xND2000-1]-94	24.0	6.6	51.6	48.0	69.4	4.3	10.2	61.9	68.0
LH176 x[(GEM 3xND2000)xND2000-1]-116	23.8	6.6	51.2	47.6	69.4	4.6	9.5	62.6	67.8
LH176 x[(GEM 3xND2000)xND2000-1]-91	25.0	6.6	49.6	47.4	69.3	4.2	9.7	62.3	68.3
LH176 x[(GEM 3xND2000)xND2000-1]-22	25.2	6.6	49.4	47.9	70.3	4.2	9.5	62.8	68.6
LH176 x[(GEM 3xND2000)xND2000-1]-67	24.0	6.6	50.0	47.7	69.6	4.4	9.8	62.0	68.6
LH176 x[(GEM 3xND2000)xND2000-1]-2	23.8	6.5	50.2	47.5	70.0	4.3	9.6	62.4	68.5
LH176 x[(GEM 3xND2000)xND2000-1]-103	24.5	6.5	49.9	47.8	70.0	4.2	9.8	62.4	69.4
LH176 x[(GEM 3xND2000)xND2000-1]-50	24.1	6.5	49.7	47.7	69.7	4.3	10.0	61.2	69.3
LH176 x[(GEM 3xND2000)xND2000-1]-27	22.9	6.4	49.6	47.7	69.2	4.5	10.2	61.7	66.9
LH176 x[(GEM 3xND2000)xND2000-1]-100	25.4	6.4	48.3	47.5	69.9	4.2	9.7	62.2	68.9
LH176 x[(GEM 3xND2000)xND2000-1]-47	24.4	6.4	49.1	47.9	69.9	4.5	9.6	62.2	69.7
LH176 x[(GEM 3xND2000)xND2000-1]-56	24.3	6.3	49.6	47.6	69.8	4.4	9.2	62.7	67.8
LH176 x[(GEM 3xND2000)xND2000-1]-74	24.6	6.3	49.1	47.9	69.5	4.4	9.9	61.7	69.8
LH176 x[(GEM 3xND2000)xND2000-1]-13	24.2	6.3	50.1	47.4	70.0	4.2	9.7	61.7	68.6
LH176 x[(GEM 3xND2000)xND2000-1]-84	24.9	6.2	49.4	47.9	69.7	4.4	9.7	62.6	68.9
LH176 x[(GEM 3xND2000)xND2000-1]-69	24.5	6.2	49.1	47.4	69.5	4.4	9.8	62.0	67.2
LH176 x[(GEM 3xND2000)xND2000-1]-92	27.3	6.2	48.9	47.5	69.7	4.4	9.6	62.4	69.0
LH176 x[(GEM 3xND2000)xND2000-1]-96	26.5	6.2	47.9	47.6	69.6	4.5	9.6	62.0	68.0
LH176 x[(GEM 3xND2000)xND2000-1]-21	24.2	6.1	49.2	47.9	69.8	4.4	9.7	61.9	67.4
LH176 x[(GEM 3xND2000)xND2000-1]-3	30.2	6.1	48.3	48.2	70.2	4.3	9.8	62.6	68.4
LH176 x[(GEM 3xND2000)xND2000-1]-45	23.8	6.0	48.1	48.1	70.2	4.2	9.8	61.7	67.7
LH176 x[(GEM 3xND2000)xND2000-1]-105	25.8	6.0	49.3	47.4	69.9	4.3	9.3	62.1	68.6
LH176 x[(GEM 3xND2000)xND2000-1]-98	26.2	5.9	49.2	47.4	69.1	4.7	9.9	62.0	67.5
LH176 x[(GEM 3xND2000)xND2000-1]-24	25.2	5.9	48.4	47.5	69.9	4.3	9.5	63.0	68.5
LH176 x[(GEM 3xND2000)xND2000-1]-37	28.4	5.9	48.1	47.5	69.9	4.2	9.6	62.4	69.3
LH176 x[(GEM 3xND2000)xND2000-1]-28	26.1	5.9	49.4	47.7	69.9	4.5	9.8	62.0	69.8
LH176 x[(GEM 3xND2000)xND2000-1]-82	23.5	5.9	49.2	47.5	69.1	4.5	9.9	61.3	68.8
LH176 x[(GEM 3xND2000)xND2000-1]-25	24.8	5.9	50.5	47.2	69.9	4.3	9.4	62.2	68.1
LH176 x[(GEM 3xND2000)xND2000-1]-31	24.7	5.8	49.2	47.7	69.7	4.6	9.4	62.0	67.0
LH176 x[(GEM 3xND2000)xND2000-1]-12	24.4	5.8	49.4	47.0	69.9	4.1	9.4	63.4	67.7
NP2623CBLL x TR3030 (90RM)	25.8	8.5	47.9	47.8	69.9	4.4	8.5	62.5	71.4
Pioneer 39D85 (87RM)	22.4	7.5	51.5	48.3	70.8	4.1	9.1	61.8	67.8
TR3127GT x TR3621CBLLRW (92RM)	29.0	8.2	48.9	46.4	69.3	4.2	9.3	61.0	70.2
DKC33-54 (83RM)	19.4	7.1	53.3	47.9	69.8	4.0	9.1	63.9	66.0
Experimental Mean	24.3	6.4	49.8	47.7	69.9	4.3	9.6	62.3	68.3
LSD (0.05)	2.3	1.8	2.0	0.9	0.9	0.3	0.6	1.2	1.9
CV%	6.9	17.6	9.2	0.9	5.2	3.7	1.0	5.6	2.0

† Means adjusted for lattice effects.‡ Grain moisture at harvest.§ Grain yield adjusted at 15.5% grain moisture.¶ Test weight measured from test weight chamber in combine harvester.# Fermentable corn contents in grain.†† Extractable starch content in grain.‡‡ Days after planting to 50% plants with visible silk.

Appendix C

Table C1. Spearman's coefficient of rank correlation for experiment I (non stiff stalk group of testcrosses and checks) means across North Dakota environments with significant genotype x environment interaction (P > 0.05).

Days of Anthesis

Environments	10 Prosper	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	0.47	0.47	0.42
10‡Casselton		1.00	0.49	0.46
09† Prosper			1.00	0.43
09 Casselton				1.00

Days of Silking

Environments	10 Prosper	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	0.32	0.49	0.27
10 Casselton		1.00	0.48	0.38
09 Prosper			1.00	0.59
09 Casselton				1.00

Grain Extractable Starch (%)

Environments	10 Prosper	10 Larimore	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	0.48	0.45	0.49	0.39
10 Larimore		1.00	0.27	0.22	0.22
10 Casselton			1.00	0.41	0.45
09 Prosper				1.00	0.64
09 Casselton					1.00

High Fermentable Corn (%)

Environments	10 Prosper	10 Larimore	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	-0.01	0.23	-0.11	0.02
10 Larimore		1.00	0.04	0.05	0.01
10 Casselton			1.00	0.06	0.00
09 Prosper				1.00	0.15
09 Casselton					1.00

Grain Oil (%)

Environments	10 Prosper	10 Larimore	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	0.46	0.37	0.27	0.35
10 Larimore		1.00	0.35	0.19	0.30
10 Casselton			1.00	0.15	0.29
09 Prosper				1.00	0.47
09 Casselton					1.00

Table C1. (Continued)

Grain Protein (%)

Environments	10 Prosper	10 Larimore	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	0.30	0.41	0.54	0.42
10 Larimore		1.00	0.10	0.30	0.22
10 Casselton			1.00	0.33	0.34
09 Prosper				1.00	0.39
09 Casselton					1.00

Grain Starch (%)

Environments	10 Prosper	10 Larimore	10 Casselton	09 Prosper	09 Casselton
10 Prosper	1.00	-0.03	0.25	0.14	0.15
10 Larimore		1.00	0.13	0.14	0.04
10 Casselton			1.00	0.22	0.21
09 Prosper				1.00	0.48
09 Casselton					1.00

† Year 2009.‡ Year 2010.

Table C2. Spearman's coefficient of rank correlation for experiment II (stiff stalk synthetic group of testcrosses and checks) means across North Dakota environments with significant genotype x environment interaction (P > 0.05).

Days of Anthesis

Environments	09Casselton	10Casselton	10Prosper	09Prosper
09†Casselton	1.00	0.26	0.35	0.30
10‡Casselton		1.00	0.29	0.30
10Prosper			1.00	0.48
09Prosper				1.00

Extractable Starch (%)

Environments	09Casselton	09Prosper	10Casselton	10Larimore	10Prosper
09Casselton	1.00	0.57	0.40	0.20	0.32
09Prosper		1.00	0.34	-0.02	0.19
10Casselton			1.00	0.33	0.55
10Larimore				1.00	0.48
10Prosper					1.00

Grain moisture at harvest (%)

Environments	09Barney	09Prosper	10Casselton	10Larimore	10Prosper	09Casselton
09Barney	1.00	0.26	0.42	0.40	0.37	0.49
09Prosper		1.00	0.41	0.30	0.40	0.46
10Casselton			1.00	0.59	0.40	0.63
10Larimore				1.00	0.51	0.55
10Prosper					1.00	0.55
09Casselton						1.00

Table C2. (Continued)

			Grain Oil (%)		
Environments	09Casselton	09Prosper	10Casselton	10Larimore	10Prosper
09Casselton	1.00	0.46	0.33	0.29	0.54
09Prosper		1.00	0.34	0.24	0.40
10Casselton			1.00	0.25	0.47
10Larimore				1.00	0.40
10Prosper					1.00

			Grain Protein (%)		
Environments	09Casselton	09Prosper	10Casselton	10Larimore	10Prosper
09Casselton	1.00	0.30	0.36	0.18	0.36
09Prosper		1.00	0.35	0.00	0.30
10Casselton			1.00	0.07	0.46
10Larimore				1.00	0.20
10Prosper					1.00

			Grain Starch (%)		
Environments	09Casselton	09Prosper	10Casselton	10Larimore	10Prosper
09Casselton	1.00	0.33	0.37	0.21	0.31
09Prosper		1.00	0.30	0.24	0.24
10Casselton			1.00	0.31	0.32
10Larimore				1.00	0.26
10Prosper					1.00

			Test weight (lb/bu)			
Environments	09Barney††	09Casselton	10Casselton	09Prosper	10Larimore	10Prosper
09Barney	1.00	0.42	0.41	0.43	0.45	0.42
09Casselton		1.00	0.46	0.42	0.52	0.48
10Casselton			1.00	0.25	0.35	0.36
09Prosper				1.00	0.38	0.30
10Larimore					1.00	0.46
10Prosper						1.00

			Grain yield (t/ha)			
Environments	10Casselton	10Larimore	10Prosper	09Casselton	09Prosper	09Barney
10Casselton	1.00	0.01	-0.02	0.16	0.16	0.16
10Larimore		1.00	0.19	0.24	-0.08	-0.05
10Prosper			1.00	0.08	0.01	-0.02
09Casselton				1.00	0.09	0.09
09Prosper					1.00	0.07
09Barney						1.00

† Year 2009. ‡ Year 2010.