Development of Early Maturing GEM lines with Value Added Traits: Moving U.S. Corn Belt GEM Germplasm Northward
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I am the third breeder contributing to 80 years of NDSU corn breeding research. The breeding program is known for being the most northern public corn breeding program in North America and one of the few active U.S. corn breeding programs with strong stakeholders support. The program has the uniqueness to conduct research that integrates pre-breeding with cultivar development, which is unique for training. Most northern U.S. industry hybrids are not locally bred for North Dakota (ND) farms. The need for hybrids adapted to very short seasons, with drought and cold tolerance, fast dry down, and enhanced quality justifies the need for our program. We focus toward expanding corn north to cooler seasons and west to dry areas. The program acts as a genetic provider to foundation seed companies, retailer seed companies, processing industry, and public breeders nationally and internationally. During 1999-2010, NDSU was awarded 9 PVP corn certificates, released 12 corn products (4 populations and 8 inbred lines), and provided 7 experimental corn lines to foundation seed companies. I developed products not only for areas of heavy industry investment, but also for areas of low to zero industry investment, providing service to all ND farmers equally independent from their farm location and hybrid market. A new screening technique (AUDDC-area under the dry down curve) was proposed to identify faster drier corn products. This method has demonstrated to be accurate and reliable, industry is already utilizing it, and our program has been recognized for its development toward helping save billions of dollars to drying corn. Our population-hybrid concept has also been recognized as a profitable alternative of corn production. Stakeholders have recognized us with research awards and fellowships. Public and private institutions have either cooperated with the program on research of mutual interest or have utilized its products. State growers have put the NDSU corn breeding program in their top research priority. In kind cooperation from industry and western public centers has allowed us to increase our testing and breeding network to 24 locations (25,000 plots), and 20,000 winter and summer nursery rows annually. Winter nurseries have reduced in three times the timeframe for corn genetic improvement. Industry partnerships have allowed us to access expensive technology (extractable and fermentable starch screening, doubled-haploid production, SNP markers, drought-controlled environments, and NIR calibrations and equipment) and access to breeding rights, checks, testers, trait events, and research locations which has saved NDSU significant research monies, labor, and especially time annually.

The NDSU corn breeding program is the first research program to move elite tropical and temperate unique germplasm northward currently offering unique early maturing competitive products not available in the ND industry. This is the first research devoted to germplasm enhancement with tropical material in the northern U.S. Corn Belt based on a long-term program has been initiated to increase the genetic diversity of hybrids in the U.S. North Central Region. This obviously impacts the sustainability of ND corn production and profitability. Often commercial hybrids are late maturing, lack abiotic stress tolerance, and end up with poor grain quality. As a consequence corn, must be, harvested at moisture levels too high for safe storage, and needs to be artificially dried for storage and transport. The NDSU corn breeding project research generates more dependable diverse hybrids, earlier in maturity with higher test weight.
through its focus on the development of very early maturing inbred lines reducing the risks associated with late planting, early frost, and low grain quality. The program offers productive and diverse early maturing lines with high levels of starch under abiotic stresses. Released inbred lines and populations have served industry as sources for early maturity, fast dry down, high test weight, high drought and cold tolerance, high protein quality, genetic diversity, and specific adaptation to ND.

We have expanded USDA efforts to increase the genetic diversity of U.S. hybrids establishing a long-term program (NDSU EarlyGEM) to incorporate unique tropical and early-maturing alleles not present in the B73 genome. NDSU is the sole genetic provider of these products to industry. The NDSU ‘EarlyGEM’ project is a long-term program to incorporate GEM germplasm into the northern U.S. Corn Belt. The main purpose is to increase the genetic diversity of short-season corn. The program moves elite GEM tropical and temperate corn northward and westward as a source of new and unique elite products. The NDSU corn-breeding program is one of the few public programs that can still offer a strong emphasis on germplasm adaptation and improvement, inbred line development, and training of applied plant breeders. The NDSU corn breeding program has become a GEM cooperator in 1999 and since then a long-term program has been initiated to increase the genetic diversity of hybrids in the U.S. Northern Corn Belt.

Justification:
North Dakota (ND) producers continue to select corn 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 North Dakota commercial hybrids are mostly bred elsewhere (e.g. southern MN) making their adaptation to short-seasons challenging. Also, the lack of early-maturing industry testers limit the expansion of corn production to the northern U.S. Corn often needs to be harvested at moisture levels too high for safe storage and must be artificially dried for storage and transport.

The purpose of this research is to develop early maturing high quality GEM lines for utilization in the northern U.S. Corn Belt. Our hypothesis is that early maturing recovered versions of GEM lines can be obtained retaining grain yield and agronomic and quality traits with the advantage of maintaining useful genetic diversity.

General Objective:
The long-term goal of the ‘NDSU EarlyGEM’ program is to increase the genetic diversity of early maturing hybrids through the incorporation of exotic useful germplasm. The purpose of this research is to develop early maturing (90RM) high quality GEM-derived lines for utilization in the northern U.S. Corn Belt.

Specific Objectives:
1) Incorporate GEM germplasm as donor for high quality and genetic diversity.
2) Adapt GEM germplasm to short-season environments.
3) Develop new early maturing NDSU EarlyGEM unique lines competitive for industry use.

Germplasm Development
A backcross breeding program was initiated including GEM and ND elite lines to move U.S. Corn Belt GEM germplasm northward and westward. In 2001 we observed 152 GEM S3 lines
from released GEM sets A, B, and C, for fifteen adaptation traits. The most adapted (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 lines. As expected, only 28 early maturing GEM lines were used to develop new populations from late by early crosses (less than 20% of the original GEM lines had potential to be utilized under ND conditions). Early maturing lines were planted at three different planting times in order to have successful seed production. F1 generations were backcrossed to early-maturing lines only once. Later flowering plants were discarded. Also, later maturing F1 generations and others were discarded based on agronomic deficiencies (poor stands, low seedling vigor under cold stress, drought stress, lodging, insect and disease susceptibility, height, and relative maturity). A second round of screening was conducted in BC1:S0 generations. Rows were screened for seedling vigor and checked for uniformity. Plants with below average agronomic characteristics were discarded. Only nine populations were kept to produce BC1:S1 elite early maturing lines.

**Inbred Line Development**

The NDSU Early GEM program started with nine source populations that consist of three Stiff Stalk (SSS) and six non Stiff Stalk (NSS) populations. Stiff Stalk donors (CUBA117:S1520-388-1-B, CHIS775:S1911b-B-B, and AR16026:S17-66-1-B) and non-Stiff Stalk ones (BR52051:N04-70-1, SCR01:N1310-265-1-B-B, FS8B(T):N1802-35-1-B-B, UR13085:N215-11-1-B-B, CH05015:N15-184-1-B-B, and CH05015:N12-123-1-B-B) were advanced through modified pedigree selection with early and late generation hybrid testing across industry testers. NDSU EarlyGEM efforts slowly increased through the years at a point they now represent 35% of NDSU inbred line development (Fig. 1).

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**Figure 1.** Germplasm pre-breeding sources for NDSU maize inbred line development (adapted from Carena et al., 2009).
2010 Progress

34 experiments were evaluated in 2010 and NDSU EarlyGEM programs have been used as checks in all experiments across locations.

a) Late generation trials between NDSU EarlyGEM AR16026:S17-66-1-B x ND2000) x ND2000 derived lines and industry testers have identified two short-season lines for release to Foundation Seed Companies. Lines have been increased in 2010 Fargo summer nursery.

b) Early generation trials of hybrids between industry testers and 400 SS and nSS BC1:S1 NDSU EarlyGEM lines have identified 12 new short-season lines for late generation testing with advanced industry testers. Experiments were arranged in partially balanced lattice designs and were tested not only for agronomic traits but also for grain quality traits. Breeding crosses, this time, were much more diverse and included accessions DKB844 (NDSU EarlyGEM10), CUBA117 (NDSU EarlyGEM3), BR52051 (NDSU EarlyGEM5), SCR01 (NDSU EarlyGEM4), FS8B(T) (NDSU EarlyGEM26), and CH05015 (NDSU EarlyGEM22). See graphs below for top grain quality entries.

Lines are in winter nursery for additional testcrossing with several industry testers of the opposite heterotic group. In addition, NDSU EarlyGEM S3 testcrosses were produced in the summer for evaluation across locations in 2011.

c) Early generation trials of full-sib NDSU EarlyGEM progenies (over 200) were evaluated across locations in 2009 for recurrent selection and germplasm improvement. Sixteen full-sib families were identified based on a heritability index for recombination in the 2010 Fargo-breeding nurseries and selfing for inbred line development.

d) 23 new breeding crosses were backcrossed in 2010 summer nursery. Both early maturing lines and hybrids have been used as recurrent parents. Selfing of backcrosses is schedule for 2011.

e) Thousands of NDSU EarlyGEM early generation lines were advanced in the 2010 summer nurseries (a duplication of nurseries was made to assess early seedling vigor and emergence percentage across locations and at different planting dates, the more advanced ones with at least three rows per line). They were checked for uniformity and inbred characteristics. Top lines were sent to winter nursery for additional crossing and testing.

Results:
- Better grain yield, grain oil, grain protein, and extractable starch at similar level of harvest moisture in hybrid combinations as compared to checks
- Early maturing (<90RM) germplasm with unique alleles for value-added traits and disease resistance (the photo below is from NDSU EarlyGEM line in 2009 with heavy pressure of ear rots.)