

Development of Early Maturing GEM lines with Value Added Traits: Moving U.S. Corn Belt GEM Germplasm Northward

Marcelo J. Carena

Department of Plant Sciences, North Dakota State University (NDSU)

Introduction:

The NDSU corn breeding program has 78 years of existence focused on the development of early maturing (65-95RM) corn. It is currently the most northern public breeding program in North America what is unique and essential for the development of new and genetically diverse early maturing lines.

‘EarlyGEM’ is the continuous effort to incorporate GEM germplasm into the northern U.S. Corn Belt. The program started to move elite GEM tropical and temperate corn northward and westward as a source of new and diverse 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 planted more than 2.5 million acres of corn in both 2007 and 2008. This is a historical record that puts corn at the level of state wheat production. Since 1999, corn average has increased 460 % and breeding for early maturity, drought and cold tolerance, and grain quality are some of the reasons corn is becoming adapted to these once considered marginal areas. ND environmental challenges are mainly short period between killing frosts, limited heat supply, and limited rainfall. Therefore, grain quality, test weight, drought tolerance, cold tolerance, early seedling vigor, uniform emergence in cold soils, fast dry down, and early maturity are very important characteristics (as important as grain yield) essential to a hybrid in ND. However, industry hybrids are still late maturing, lack stress tolerance, and often end up with poor quality. Short-season corn must be harvested at moisture levels too high for safe storage and must be artificially dried for storage and transport. This is especially true in cooler years such as 2008.

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 '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 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. The inspiration of this long-term adaptation program was the backcross breeding program initiated by Dr. Pinnell at University of Minnesota (Rinke and Sentz, 1961) that yielded successful early maturing lines. However, the difference is that our program utilizes early maturing parents as recurrent ones and that only one backcross generation is produced without self-pollination. 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 [e.g. (GEMxND2000) x ND2000] elite early maturing lines with approximately 25% GEM germplasm (approximately 12.5% if we also consider industry germplasm used in original GEM crosses). These were selected for inbred line development including the early generation test presented in this report.

Inbred Line Development

The nine source populations consist of three Stiff Stalk (SSS) and six non Stiff Stalk (NSS) populations. Monies for 2007 funded mostly our breeding activities advancing over 3,000 adapted lines and test-crossing for first and second year early generation testing. 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 to the S3 generation. Only GEM 21 lines were crossed to industry testers for the data showed in this report (Table 1). GEM S1 selections were planted across three locations (Fargo, Prosper, and Casselton, ND) for early generation visual selection. These locations included breeding and disease nurseries which allowed us to select before flowering and to reduce the number of pollinations. S1 selections were advanced to S2 and crossed to LH and Iodent Bt industry testers. First year trials were conducted across six ND locations in 2007 and top S2 lines are being advanced to the S3 generation for both inbreeding and more extensive testing in winter nursery. In addition, winter nursery testing of inbreds and hybrids for drought tolerance were conducted. Field days were held to communicate the use of GEM genetic materials to broaden the germplasm base for the northern Corn Belt at across several ND locations.

Evaluation of 2007 and 2008 Experiments and Future Plans

Materials and Methods

Five hundred BC1:S1 lines derived from (AR16026:S17-66-1-B x ND2000) x ND2000 were advanced one generation of inbreeding and top ones (visually) were crossed to industry testers. A range of progeny BC1:S1s was used as male and two ranges of industry testers were used as females so that self-pollination could be done at the same time as cross-pollination. The seed produced on female ranges was bulked and used for yield trials. Experiments including 64 and 81 entries (depending on testers) were arranged in partially balanced lattice designs with two replications per location. Popular known commercial hybrids were included as checks which they were utilized as criteria for different traits and benchmark for advancing pedigrees. Data were collected for grain yield, grain moisture at harvest, root lodging, stalk lodging, test weight, and emergence percentage across ND environments (see 2007 annual and progress reports). A sub-sample of 500 g of kernels was collected from every plot in all environments and used to measure the grain quality of all genotypes. Grain quality screening was conducted in cooperation with Monsanto during Jan and Feb 2008. Additional BC1:S1 populations of six GEM lines and backcross populations of B73, Mo17, and Iowa Stiff Stalk Synthetic (BSSS) were selected for crossing to industry testers (Table 1). LH176, a tester representing a non-BSSS heterotic group (NSS), was crossed to GEM10, GEM3, BSSS, B73 representing the BSSS heterotic group (SSS). TR3026 x TR2040, a tester representing SSS was crossed with GEM26, GEM22, GEM4, GEM5 and Mo17 representing the NSS group. The cross between industry testers and 400 lines was conducted in the 2008 Fargo breeding nursery. One range of testers with opposite heterotic group was planted in between two ranges of incorporated BC1:S1 lines. The tester range was divided into two ranges by making a small isle at the middle of the tester range. The tester was crossed from the adjacent BC1:S1 lines. This allowed utilization of BC1:S1 lines as males and advancing one generation of selfing at the same time as crossing. The crossed seed produced in each of rows of female range will be bulked and tested in multi-location trials across ND environments. Trials will be conducted within heterotic groups arranged in partially balanced lattice designs with two replications in each location across five environments. Each plot will be 7 m long row and 0.76 m between rows. Each plot will be planted with 65 seeds which will be thinned to 45 plants per plot at knee height stage.

Table 1: GEM maize populations and their pedigrees used for incorporation.

SSS Populations	Pedigree
GEM 10	DKB844:S1601-507-1-B-B
GEM 3	CUBA 117:S1520-388-1-B
B73	BSSS(HT)C5
BSSS	16 SS lines
NSS Populations	
GEM 5	BR52051-N04-70-1
GEM 4	SCR01:N1310-265-1-B-B
GEM 26	FS8B(T): N1802-35-1-B-B
Mo17	
GEM 22	CHO5015:N12-123-1-B-B

Statistical Analyses

Analyses of variance were performed for all traits within and among environments. Homogeneity of variances was evaluated for each location. Genotypes were considered as fixed effects while environments and replications within each environment were considered as random effects. Analyses of variance for each location were performed using the PROC LATTICE procedure from SAS. Means adjusted by incomplete blocks were used when the relative efficiency of lattices was higher than 105 % compared with a randomized complete block design (RCBD); otherwise, unadjusted means were used for the combined analyses. In the same way, the effective error (average of the variance) instead of RCBD error mean square was used as a denominator in the *F*-test when relative efficiency of lattice designs was greater than 105 % compared with RCBD. Adjusted or unadjusted means (depending on efficiencies) from each location were used to perform a combined analysis of variance using the PROC GLM procedure from SAS. The data set was analyzed as a RCBD where locations were considered as the replications. The pooled error mean square was calculated as the average of the sum of squares of the residual variances from each location divided by the total degrees of freedom and the number of replications within each location. Components of variance and broad-sense heritability were calculated in order to determine the proportion of variation due to genetic effects. Estimates were obtained based on the expected mean squares for this design. Fisher protected least significant differences (FLSD) were used to compare among genotype means at $P \leq 0.05$.

Results

Improvement in seed genetics through early maturing corn-breeding programs focused on more starch per acre has the potential to make impact in grain quality genetic improvement. Corn hybrids vary in extractable and fermentable corn starch percentages. This variation, however, is not only due to the genetic potential of hybrids but also due to the environment. Table 2 shows data generated from the top performing hybrids between GEM-derived genetic materials and several industry testers. At least 37 and 14 NDSU experimental lines with 12.5 % GEM exotic germplasm showed, in hybrid combinations with industry testers, over 101 % of top check mean extractable and fermentable starch, respectively. Moreover, when considering the mean of the checks, 39 NDSU experimental lines had more fermentable starch in GEM-derived hybrid combinations. In addition, most experimental hybrids performed better than commercial hybrids in grain protein and grain oil contents.

Table 2. Means combined over 11 ND environments of five grain quality traits for selected entries sorted by extractable starch for GEM-derived maize hybrids.

Hybrid	Fermentable Starch %	Starch Content %	Oil Content %	Protein Content %	Extractable Starch %
TR4615xND07-224	16.47	70.30	3.01	9.32	67.83
TR4615xND07-207	16.47	69.97	3.46	9.00	67.63
TR4615xND07-212	16.48	69.93	3.21	9.43	67.10
TR4615xND07-255	16.62	69.68	3.11	9.97	66.93
TR4615xND07-249	16.55	69.87	3.15	9.72	66.48
TR4615xND07-228	16.38	69.88	3.28	9.45	66.28
NP2123BtXND07-255	16.42	69.37	3.62	9.70	66.10
NP2123BtXND07-260	16.42	69.42	3.77	9.32	65.53
NP2123BtXND07-212	16.42	69.13	4.00	9.17	65.50
TR4615xND07-209	16.60	69.20	3.45	10.08	65.48
LH176 X ND07-59	15.93	69.53	3.32	8.73	65.40
NP2123BtXND07-224	16.27	69.07	3.72	9.73	65.27
NP2123BtXND07-208	16.50	69.12	3.71	9.87	65.20
LH176 X ND07-4	16.05	69.95	3.10	8.92	65.13
TR3621BT X ND01-28	16.23	69.58	3.13	9.10	65.02
TR4615xND07-256	16.53	69.20	3.43	10.12	64.92
LH176XND07-217	16.33	70.08	3.25	9.35	64.90
NP2123BtXND07-214	16.35	68.80	4.02	9.80	64.82
LH176 X ND07-71	16.15	70.33	3.23	9.08	64.78
NP2123BtXND07-213	16.37	69.42	3.75	9.58	64.78
NP2123BtXND07-217	16.28	69.13	3.56	10.25	64.52
LH176 X ND07-43	16.08	69.80	3.25	8.97	64.47
LH176 X ND07-72	16.02	70.08	3.23	9.05	64.30
TR4615xND07-85	16.47	69.05	3.17	10.08	64.25
Pioneer 39K19	16.42	69.27	3.23	9.35	64.17
Pioneer 39D85	16.12	69.43	3.45	8.43	64.02
NP2123BtXND07-209	16.32	68.30	3.98	10.37	63.95
LH176XND07-260	16.38	69.28	3.47	10.17	63.73
LH176 X ND07-91	16.00	69.85	3.37	8.70	63.65

NP2123BtXND07-220	16.38	68.40	4.20	9.88	63.60
LH176XND07-253	16.23	69.12	3.58	10.17	63.52
LH176XND07-207	16.18	68.67	3.82	10.27	63.52
TR3621Bt X ND97-6W	16.40	68.33	4.11	9.80	63.35
LH176XND07-249	16.35	68.82	3.60	10.45	63.33
NP2123BtXND07-225	16.38	68.90	3.63	10.17	63.18
ND07-220XLH176	16.15	68.48	4.09	9.73	62.90
TR4615xND07-155	15.93	68.62	4.27	8.82	62.63
Mean	16.26	69.15	3.61	9.64	64.33
CV (%)	1.07	0.88	5.74	7.48	1.77
LSD (0.05)	0.19	0.69	0.24	0.82	1.30
Checks	16.27	69.35	3.34	8.89	64.09

Summary of Accomplishments

Earlier maturing versions of GEM-derived S₃ lines (12-20 days earlier) were produced. Recovered BC₁:S₁ lines from one pedigree could retain yield at ND relative maturity in new hybrid combinations. Preliminary data show several experimental GEM-derived (12.5 % originally exotic) have, among other traits, not only better grain yield performance than popular industry hybrids at similar grain moisture at harvest but also highly significant better performance in grain quality traits. GEM-derived lines showed over 101% of check mean yield in at least seven cases (second-year data) that will be advanced to third year testing confirming non-Corn Belt germplasm good combining abilities (Griffing and Lindstrom, 1956). Also, exotic populations carry more genetic diversity (Goodman, 1965).

Extensive testing for agronomic traits and nutritional evaluation and analyses of hybrids will continue. We will extend this type of work to the other eight GEM-derived populations that are in need of extensive testing. Benchmarks will increase to 105 % of check mean yield and release decisions will follow. We also plan to develop new early-maturing GEM populations including top lines to increase our efforts to identify alternative heterotic patterns for the northern U.S. Corn Belt.

This is the first research devoted to <90RM germplasm enhancement with incorporation of tropical and late-temperate genetic materials for unique inbred line development. Winter nurseries with three generations per year are providing new lines in four years. Comprehensive planned long-term research programs should be developed independent from the granting systems, indirect cost needs, and promotion and tenure concerns. As a consequence of long-term efforts we currently have early maturing GEM materials adapted to the northern U.S. Corn Belt which are competitive products for industry use.