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ENHANCED EMERGENCE IN CORN BELT GERMPLASM FROM HOPI MAIZE

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ABSTRACT

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Hopi Maize is not represented in the background of elite Corn Belt germplasm. The drought resisting adaptations of Hopi Maize, particularly its capacity to emerge from deep planting, could be of benefit for some parts of the Corn Belt. Effectively incorporating exotic material into Corn Belt inbred line development programs can present difficulties.

Hopi Maize was crossed to an elite, but poor emerging, Corn Belt inbred to form a source population for inbred line development. S1 nursery rows were deep planted within a replicated emergence experiment. Early test crosses were made with plants selected for agronomic type. Material was advanced based on data analysis for emergence, selection for agronomic type, and combining ability. This system appeared effective for incorporating emergence and some other characters of Hopi Maize relatively quickly and with only minor modifications of standard commercial procedures using the Pedigree Selection Method.

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INTRODUCTION

Plant breeders recognize the importance of maintaining genetic diversity in crop breeding programs. Diversity is critical in providing basic variability for effective gain from selection for currently important plant traits and performance, and in providing for potentially valuable future selection. Crop plant germplasm represents a valuable resource, even when it confers no apparent immediate benefit to a breeding program.

Acquisition and preservation of new germplasm may be followed by integration into on-going breeding programs where new genes may confer a specific improvement or may enhance the genetic background of the breeding material. Vulnerability due to a narrow genetic base may decrease.

As a standard approach using the Pedigree Selection Method, adapted varieties or lines of corn are crossed to generate source populations for inbred line development. Crosses of adapted by exotic material with subsequent inbred line development could be effective as a method of enhancement breeding both for the direct development of new inbred lines from S1 populations and for the creation of new populations for recurrent selection. This approach has not been much used in commercial corn breeding mainly because of the additional time and difficulty involved. The commercial corn breeder is generally under a time pressure to quickly develop improved inbred lines for new higher yielding hybrid combinations. This is most efficiently achieved by working with crosses of elite adapted material. Despite the increasing degree of interrelationship among elite Corn Belt inbred lines, improvement and gain from selection for yield is still being made.

Public corn breeding programs have traditionally been more concerned with population improvement and germplasm enhancement. Unfortunately, many of the public corn breeding programs no longer have the funding to continue the type of long term conventional field breeding work involved in programs of population improvement and recurrent selection. A breeding approach is needed that can generate improved, and genetically enhanced, inbred lines or breeding material from exotic sources according to an acceptable commercial timetable.

This research was an effort to incorporate germplasm from Hopi Maize into a Corn Belt inbred line (an elite selection from an Oh 43 type). Specifically, the goal was to incorporate the superior emergence capacity of the Hopi Maize into the poor emerging, but high yielding, Oh 43. The breeding system employed was evaluated for effectiveness in developing enhanced breeding material. The basic procedure was a series of crosses of Hopi Maize and the Oh 43 type, followed by two generations of sib-mating. Inbred line development by the Pedigree Selection Method was then undertaken. Selecton was intense for agronomic plant type and emergence capacity in the S1 (F2) generation. The S1 nursery was planted as a replicated emergence experiment. The field research was at the Dekalb-Pfizer Genetics, Inc. maize breeding research station at Mason, Michigan. Field procedures were as close as possible to standard procedures at that station.

REVIEW OF LITERATURE

Brown,Anderson, and Tuchwena (1952) emphasized that germplasm of agricultural value may reside in some southwest Indian maize. Many varieties are extinct, but three fairly distinct varieties of Hopi Maize are still maintained. These are not represented in the background of any elite Corn Belt inbred lines.

Carter and Anderson (1945) classification southwest maize and it is relatively simple compared to that of some other areas. The southwest had been semi-isolated from other agricultural areas by geography and climate, and little cultural exchange occurred with other areas. Fields were few and often far apart in order to be near moisture. Well differentiated local varieties could develop.

Brown and Goodman (1977) and Mangelsdorf (1939) reported the development of southwest maize. There were at least three different sources, or recombinations of races. First there was the pre-historic Basketmaker race from Mexico. Modern varieties of this are called Pima-Papago. It has 10-16 kernel rows, floury endosperm, tillering, and purple coloration to the leaf sheaths. Chapalote and Reventador are related to it. Two later types were involved. One, the Mexican Complex, was a tapered ear dented kernel type from the Mexican Plateau. The other was the Eastern Complex with strong arching leaves, large basal portion of the ear and wide kernels in eight rows. The Eastern Complex is found in Guatemala and in the flints of the eastern United States. According to Carter and Anderson (1945), the Basketmaker race was modified toward the Mexican Complex with an increase in row number and denting of the kernels. Around 1200-1300 A.D. the Eastern Complex came into the southwest from the southeast and greatly modified southwest maize. Among present day southwest Indian maize, Hopi Maize shows the least Eastern Complex influence.

Galinat and Campbell (1967) disputed the southeast origin for the Eastern Complex, believing instead that an eight rowed maize race (Maiz de Ocho) spread from the southwest into the central plains and then to the northeast. They believe Maiz de Ocho entered the evolution of southwest maize around 700 A.D., and conferred better productivity and easier milling to southwest maize. They state that it is, in modified form through the Northern Flints, one of the components responsible for the heterosis in Corn Belt hybrids.

Brown, Anderson, and Tuchwena (1952) compiled data on three major Hopi Maize varieties: White Flour, Blue Flour, and Kokoma (purple). The White Flour variety showed stronger Eastern Complex and Mexican Complex influence than the Blue Flour. The Southwest Semident race (somewhat similar to the Northern Flints morphologically) is represented in most collections of Hopi White Flour since the Hopi do not separate the semident and flour forms of their white maize. Kokoma showed only a slight Eastern Complex influence. Kokoma is the most primitive, and closest relative of the pre-historic Basketmaker race.

Brown et al. (1952) described Hopi plant and ear types. The Blue Flour variety attains a height of about 4 feet and averages 10 or more tassel branches with a long central spike. The leaves appear long in relation to the height of the plant. The kernels are narrow and vary in row number from 10-20. Many ears show a distinct basal compression.

Kernel color is from a white endosperm, blue aleurone, and colorless pericarp. The intensity of the blue color is variable.

The White Flour variety is similar in maturity to Blue Flour. Plants are shorter and lighter green in color due to lack of anthocyanin. It tillers extensively and shows reduced internode lengths above the ear. Like Blue Flour, it has a many branched tassel with a long central spike but has generally wider kernels and wider shank. It does not show the distinct basal compression of Blue Flour. Kernel row number usually exceeds 14. Kernel color is from a white endosperm and a colorless pericarp and aleurone. Some kernels may show a light pink flush to the pericarp.

The Kokoma variety is the least grown of the three major varieties. The ears resemble the cigar shaped Basketmaker type. Kernel row number varies from 12-14. Kernel color is due to an intense cherry pericarp. There is a pronounced purplish color to the leaf sheaths and tassels. The purplish husks are used as a source of dye.

Anthocyanin in the aleurone layer of the endosperm gives the blue color to Blue Flour and is due to the dominant genes A1, A2, C, R, and Pr. The characteristic allele for Blue Flour is designated Ra in the R allele series. In most stocks of Blue Flour there are admixtures of 2 other alleles, Rnj and Rst, which give white seeds with a blue tip and speckled seed. In White Flour the kernels are mostly white due to an inhibitor gene. Variants may show a flush of purple or rose/pink. In Kokoma purple anthocyanin in the pericarp is due to a combination of the rch cherry allele of the R series and the P1 gene for plant color which gives much pigment to the sheaths, husks, tassels, cob, and pericarp.

The capacity of Hopi Maize to emerge well from deep planting was the primary reason for its use in this breeding program. One of the first to observe this characteristic was Collins (1915). He reported that an important factor in the drought resistance adaptation of Hopi Maize is its capacity to force the growing shoot of the seedling to the soil surface even when planted at a depth of 12 inches or more. When planted this deep, other varieties die before reaching the surface.

Benson and Reetz (1985) and Kiesselbach (1949) described emergence in maize. It is accomplished through a combination of coleoptile growth and mesocotyl (first internode) elongation. The mesocotyl is the structure between the scutellar and coleoptile nodes. The coleoptile node is the crown, or growing point, and is the site of nodal roots (permanent roots) formation. The coleoptile node is brought to about one inch below the soil surface by first internode elongation. If a kernel is planted one inch deep, emergence will be entirely by coleoptile growth. With deeper planting, the first internode elongates to bring the coleoptile close enough to the soil surface to make emergence possible. The first internode elongates rapidly by intercalary growth at its upper end. If planting is deeper than the first internode can elongate, or the coleoptile tip ruptures underground, emergence does not occur.

Collins (1915) reported that it was through first internode elongation that the Hopi Maize shoot was able to reach the soil surface from deep planting. He reported observations of Hopi first internodes over 36 centimeters in length. He found variation among maize varieties for first internode elongation, but relatively constant values within varieties. He observed Hopi Maize plants with no adventitious root formation. The seminal roots remained primary throughout the life of the plants rather than diminishing as occurs with most maize varieties. Collins speculated that this downward root system developed to reach moisture in a dry environment.

Inge and Loomis (1937) reported on growth of the first internode in maize. They planted seeds at varying depths in sand in a greenhouse and found first internode lengths varied with depth of planting and with varieties. Entries in their experiments included Hopi Maize and Corn Belt material. They observed the extreme development of the first internode in the Hopi Maize relative to the other varieties and stated that this explained its capacity to emerge when deeply planted. If seed was germinated in darkness, the first internode of the axis elongated rapidly and other shoot tissue developed slowly. When the coleoptile tip emerged, first internode development ceased, and plumule development accelerated. Formation of roots began at the coleoptile node. They reported that first internode elongation is due to cell division in the region just below the coleoptile node. In early development this division was dominant over cell division in the inhibited apical meristem. After emergence, when the first internode ceased development, the shift to plumule growth was irreversible.

Troyer (1964) observed maximim first internode lengths over 24 cm. for deep field planted Hopi Maize in Minnesota. He found a twin seedling showing a total of over 36 cm. of first internode development from an average amount of endosperm. He concluded that factors other than endosperm reserves limit maximum first internode elongation.

Troyer investigated the inheritance of the long first internode trait in Hopi Maize. He identified three chromosome arms (short arm of chromosome three, short arm of chromosome six, and short arm of chromosome nine) as regions bearing genes that affect first internode development. The genes conditioning the long first internode in Hopi Maize expressed some degree of dominance over their alellomorphs in crosses with the Corn Belt inbred line A188.

An early examination of Hopi Maize was conducted by the Arizona Agricultural Experiment Station (Clothier, 1913). Tests were conducted over three years, in different locations and soil types, with different maize varieties including two Arizona Indian varieties described as "Blue Aztec" and "White Aztec" (Hopi Blue Flour and White Flour). In the second year a deep planting of four to nine inches was undertaken, resulting in poor stands except for the Blue and White Aztec types which gave "medium" stands regardless of soil type. Clothier concluded that none of the varieties offered great promise for that area.

More recently, Day, Grove, and Thompson (1972) compared twenty maize varieties from the Arizona maize collection including Arizona Indian flour types and selections from the Mexican June Complex (white dent type introgressed with northwest Mexican flour maize). They found significant differences in height, leaf length and width, maturity, grain volume weight, and other characters. In particular, the Arizona Indian maize was earlier, had longer leaves, more stalks per plot (tillers), and higher grain volume weights than selections from the Mexican June Complex.

Day (1986) reported on the formation, and registration, of a maize population adapted to the arid, irrigated environment of the southwest United States, which included Hopi Maize germplasm in its background. Maize collections were made on Arizona Indian reservations from 1956-1968. Equal numbers of seeds of selections of flour and dent types and selections from the Mexican June Complex were planted at the Mesa Agricultural Centerin 1960. The Mexican June selections were detasseled and crossed with flour and dent pollen. Seed on the Mexican June was bulked to form the original population. This seed has been planted in isolation and open pollinated for 23 years in an irrigated area of southern Arizona. Seed of this "Arizona Arid Environment Maize Germplasm" was obtained from Day and planted at Mason, Michigan in 1986 for observation. Seed of Hopi Maize (P.I. #213734 USA-IA, Hopi Tribe) obtained from the Regional Plant Introduction Station at Ames, Iowa was planted for comparison. The Arizona germplasm was much later in maturity and very different in plant type from the Hopi material. Seed of Hopi Maize from the Iowa Plant Introduction Station was used in this breeding work and thesis research. No information on the specific background, composition, or first internode elongation of the Hopi Maize population was available.

Brown and Goodman (1977) and Wallace and Brown (1956) noted that most of the corn (Zea mays L.) germplasm in the United States today is derived from a mix of only two major antecedent races of corn (Northern Flint and Southern Dent). This represents only 2-5% of the total variation available. Additionally, many of the indigenous corn varieties of the United States were replaced by hybrids prior to organized germplasm preservation, and have been lost. Only a few of the original Corn Belt open pollinated varieties are represented in the background of present day Corn Belt material.

Considering this narrow genetic background, Hallauer and Sears (1972), Wellhausen (1965), and others have emphasized the great potential for the improvement of Corn Belt maize through the incorporation of unadapted, or exotic, germplasm into corn breeding programs. The increased diversity could enhance heterosis (Goodman, 1965) (Moll, Salhuana and Robinson,1962), and could provide a broadened genetic base for Corn Belt Dent race material.

In most cases exotic varieties can not be used directly in Corn Belt breeding programs. The problem is to determine the best procedures for integrating exotic material into breeding programs. Various methods of population improvement, including mass selection and recurrent selection, and backcross breeding have been used for adapting or integrating exotic material. Hallauer and Sears (1972) described an alternative approach involving crossing adapted and exotic maize. Their study involved two successful methods. One was a mass selection scheme (for early silk emergence and lower ear placement) for adapting a population of the exotic variety Eto Composite Maize. The other was a series of crosses of Eto Composite to adapted Corn Belt inbred lines. This resulted in considerable genetic variability in the F2 generation populations which could be effectively selected for desired traits. In both cases usable breeding populations were established.

MATERIALS AND METHODS

Fifty seeds of Hopi Maize were planted in 1982 at the Dekalb-Pfizer Genetics research station in Madison, Wisconsin. The most vigorous plants were crossed to an elite Oh 43 type inbred line. The Hopi Maize seed and plants appeared to be a population formed through the inter-varietal hybridization of various types of Hopi Maize. Characteristics of all three major Hopi varieties described by Brown et al. (1952) were present, including multiple kernel coloration and purplish leaf sheaths and tassels. The Oh 43 type inbred orginated from the second cycle of selection within the Lancaster Sure Crop open pollinated population. Lancaster Sure Crop was more of a flint type than Reids Yellow Dent, the other major open pollinated variety in the background of most Corn Belt inbred lines. The Oh 43 plants are medium height with short internodes, light green leaves, relatively tight husks, a thick white cob, and light yellow tassels and anthers. Relative maturity is approximately 104 days and U.S. heat units to flowering approximately 1600 when grown at Mason, Michigan. This inbred has relatively poor seedling emergence. It is a poor pollen shedder, especially under stress due to heat and lack of soil moisture.

The seed from these crosses was bulked and planted to form a sib-mating population of 250 plants in 1983. Ears were harvested from 25 vigorous and healthy plants. A chain sib-mating procedure was used. No plant was used as the pollen parent more than once. This seed was bulked and formed a 1984 sib-mating population of 350 plants. Thirty plants were selected and the seed bulked for a 1985 population of 500 plants. One hundred plants with good agronomic type were self pollinated. Forty of the best plants were harvested and 25 of these S1 ears were selected for good agronomic type with yellow kernel color and denting. Kernel color was of concern in this research since selection in the S0 (F1) and S1 generations for agronomic type included selection of plants and seed with mainly yellowish kernel color and "denting" kernel character. Coe and Neuffer (1977) reported that inheritance of the "dent" kernel form (which typifies field corn of the United States) is extremely complex and has been difficult to elaborate as a genetic mechanism. The initial Oh 43 x Hopi crosses were made with the Oh 43 as the female and most of the resulting seed was dent type.

The 25 selected ears were planted ear to row for 1986 S1 populations for inbred line development using the Pedigree Selection Method. They also served as 25 separate entries in a randomized complete block experiment with three replications designed to compare the relative emergence capacity of the Hopi x Oh 43 S1 lines with the Hopi and Oh 43 parents (making a total of 27 test entries).

Test crosses were made to selected plants in 11 of the 25 S1 families. These 11 families were selected for good agronomic type and for superior emergence capacity. Testers were the inbred lines A632HT, LH74, LH146, and B73HT. A yield trial was conducted in 1987.

Bulked S2 seed from the 11 selected families was used to form 11 entries in a 1987 emergence experiment, including again the Hopi and Oh 43 parent entries. The 1986 and 1987 research was conducted at the Mason, Michigan Dekalb-Pfizer research station.

The procedure was the same for both years' emergence experiments. Thirty kernels of each entry were planted four inches deep over a 15 foot row. This corresponds to a 30,000/acre planting population. Normal planting depth in the Corn Belt is one to two inches. It is not possible to plant seed four inches deep with conventional mechanical planters. Hand planting was done using a soil sample boring tool. A four inch core of soil was removed and one seed dropped into the hole. The hole was filled with finely worked adjacent topsoil and lightly tamped. Soil type was a Capac clay loam with about a nine inch surface layer. One replication was planted on each of three days, May 13, 14, and 15, in both years. After emergence, the number of plants per plot was counted. Families with the greater number of plants emerging were assumed to have higher frequencies of the alleles for expression of the trait.

The 1987 yield trial had 42 entries, 34 test crosses and eight commercial hybrids as checks. It was a randomized complete block design with two replications at one location. It was planted April 27 and harvested on October 1. It was unirrigated, and planted at normal depth, with 30 inch rows and plot size of 1/500 acre. Planting population was 30,000/acre with subsequent thinning to 24,000/acre. Plots were mechanically planted and harvested. Data were obtained for yield, percent grain moisture at harvest, early stand count, seedling vigor, final stand count, and resistance to ear droppage and stalk and root lodging. Early stand count gave a measure of emergence capacity. Seedling vigor was a rating from one to nine (highest). Lodging and ear droppage resistance were counts expressed as percent not lodged, or dropped, per plot. All data were then represented as a percent of mean for the test, or as percent of mean for the check hybrids. Selection indexes for Specific Combining Ability and General Combining Ability were calculated by assigning economic weights for yield, percent moisture, and resistance to lodging and ear droppage. Selection Indexes were expressed as percent of test mean for GCA and percent of check hybrid mean for SCA. An estimated relative maturity for each test cross was derived from regression analysis based on the observed test moisture and assigned relative maturity of the check hybrids.

The yield trial provided early testing information on combining ability based on the principles for early generation testing as described by Jenkins (1940), Sprague (1946), and Sprague and Miller (1952). Early testing here permits heavy discarding of families based on this first test. Future selection will be concentrated within and among families with good combining ability. Early testing research has shown that the combining ability of heterozygous material in the early stages of inbreeding does not differ significantly from the average combining ability of the lines eventually derived from it.

The 1987 S2 selection nursery was separate from the emergence experiment. One hundred plants were self pollinated. The 1987 yield trial and emergence data on a family basis through pedigree records can be used in selection for advancement to the 1988 S3 nursery. Some selected lines may also be formed into populations for future recurrent selection.

The analyses of variance for the two emergence experiments were done according to the procedure of Steel and Torrie (1980). Comparison of entry means was with the least significant difference, or LSD. For the yield trial, analyses of variance and tests of significance were performed with the procedures of Openshaw and Troyer at Dekalb-Pfizer Genetics.

RESULTS

Emergence experiment data is presented in Table 1. Table 2 shows analysis of variance for 1986. Highly significant entry differences were found (F(26/52) = 12.9, p<.01). Comparison of paired entry means for significant differences was with LSD(.01). Emergence of the Hopi parent was significantly better than the Oh 43 parent. None of the S1 entries showed significantly better emergence than the Hopi parent or significantly lower emergence than the Oh 43 parent. The mean for the test was significantly better than the Oh 43 parent. The 11 S1 entries selected for retesting were also selected for S2 advancement and yield testing. Selection was based on agronomic type and on emergence significantly better than the Oh 43 parent and not significantly lower than the Hopi parent.

The 1987 emergence experiment (Table 3) also showed highly significant entry differences (F(12/24) = 21.56, p<.01). The Hopi parent and all S2 families were significantly better emerging than the Oh 43 parent (Table 4). Two families (11 and 16) were not significantly lower than the Hopi parent. The ranked order of entries and comparisons of means are shown.

The 1987 yield trial data for the check hybrids and the six best test crosses are presented in Table 5. Based on an economically weighted selection index, six of the S2 lines performed well in specific hybrid crosses, outyielding and standing better than some of the commercial check hybrids. Column headings in Table 5 are selection index, yield, percent moisture at harvest, yield to moisture ratio, seedling vigor,early stand, final stand, not drop ears, not stalk lodge,

Table 1. Emergence Experiment Entry Means.

	Number Plants Emerged		
Family	1986 (S1)	Selected	1987 (S2)
Hopi x Oh 43-1	20 +*	x	11 +
Hopi x Oh 43-2	17 +		
Hopi x Oh 43-3	9		
Hopi x Oh 43-4	25 +*	x	14 +
Hopi x Oh 43-5	19 +*	x	17 +
Hopi x Oh 43-6	14		
Hopi x Oh 43-7	22 +*		
Hopi x Oh 43-8	22 +*		
Hopi x Oh 43-9	17 +		
Hopi x Oh 43-10	21 +*		
Hopi x Oh 43-11	21 +*	x	18 +*
Hopi x Oh 43-12	18 +*		
Hopi x Oh 43-13	22 +*	x	15 +
Hopi x Oh 43-14	16 +		
Hopi x Oh 43-15	18 +*		
Hopi x Oh 43-16	21 +*	x	20 +*
Hopi x Oh 43-17	20 +*	x	9 +
Hopi x Oh 43-18	20 +*		
Hopi x Oh 43-19	8		
Hopi x Oh 43-20	17 +		
Hopi x Oh 43-21	21 +*	x	12 +
Hopi x Oh 43-22	13		
Hopi x Oh 43-23	20 +*	x	12 +
Hopi x Oh 43-24	22 +*	x	14 +
Hopi x Oh 43-25	20 +*	x	12 +
Oh 43 parent	9		5
Hopi parent	23		22
Test Mean	18		14
Std. Dev.	2.08		1.69

(+) Designates significantly better than Oh 43. (*) Designates not significantly lower than Hopi. Selection and 1987 retesting based on agronomic type and emergence.

Table 2. ANOVA: 1986 Emergence Data.

SOURCE	DF	SS	MS	F
replications	2	21.51	10.76	2.48
entries	26	1459.8	56.15	12.9** p<.01
error	52	225.83	4.34	
total	80	1707.4		

LSD(.01)=4.544

Eleven entries selected for 1987 retesting were significantly better than Oh 43, and not significantly lower than Hopi.

Table 3. ANOVA: 1987 Emergence Data.

SOURCE	DF	SS	MS	F
replications	2	1.44	.72	.25
entries	12	739.9	61.66	21.56** p<.01
error	24	68.6	2.86	
total	38	809.9		

Table 4. 1987 Emergence Experiment Means Comparisons and Ranking.

1) Hopi	a
2) Hopi x Oh 43-16	a b
3) Hopi x Oh 43-11	a b c
4) Hopi x Oh 43-5	b c d
5) Hopi x Oh 43-13	c d e
6) Hopi x Oh 43-4	d e f
7) Hopi x Oh 43-24	d e f g
8) Hopi x Oh 43-21	e f g h
9) Hopi x Oh 43-23	e f g h i
10) Hopi x Oh 43-25	f g h i j
11) Hopi x Oh 43-1	f g h i j k
12) Hopi x Oh 43-17	h i j k
13) Oh 43	l

All possible pairwise comparisons of means with LSD (.01)=3.88. Any two means followed by the same letter are not significantly different.

Table 5. Yield Trial Data for Specific Hybrids (SCA).

HYBRID	SEL INDEX	YLD	%MST	Y/M	SDL VIG	ERL STD	FNL STD	NOT DRP	NOT STL	NOT RTL	EST RM
A632HT X #25	117	129+	91	141	99	96	102	100	114	100	97
A632HT x #16	115	105	80-	132	99	108	103	100	130+	100	93
LH 146 x #17	106	114	93	123	99	100	103	100	111	100	97
LH 74 x #16	103	104	91	114	99	93	98	100	117	100	97
LH 74 x #4	107	103	94	109	117	105	103	100	129+	100	97
B73HT x #23	108	117	128+	92	117	94	100	100	140+	100	107
Dekalb 524	116	130+	103	126	135	93	96	100	120	100	100
Dekalb 464	99	107	89-	121	117	100	102	100	103	100	96
Pioneer 3475	126	133+	112+	119	126	97	100	100	144+	100	103
Dekalb 547	110	114	109	105	81	104	103	99-	135+	100	102
Dekalb T1100	107	138+	140+	98	108	95	101	100	123	100	111
Dekalb T1000	80	77-	106	73	63-	90-	95	100	116	100	101
Dekalb 572	90	104	125+	83	45-	88-	93-	99-	121	100	106
Dekalb 484	78	80	101	79	81	107	103	99-	107	100	99
Test mean	89	61bu	20%	100	5.6	49	47	100	65%	100	99
Check mean	100	65bu.	21%	101	5.1	48	46	100	79%	100	101

Hybrid data is expressed in percent of test mean. Selection index is based on check mean. Estimated relative maturity and test and check means are in units of measurement. Economic weights are 1.00 for yield, -2.00 for moisture, and .80 each for stalk and root lodging and ear droppage resistance. Plus or minus indicates significantly different from test mean with LSD (.10).

not root lodge, and estimated relative maturity. Analysis of variance for yield showed significant entry differences (F 41/35=1.85, p<.05). The coefficient of variation was 17.860%. A broad sense heritability of 0.459 was calculated for yield. ANOVA for other traits showed highly significant differences for percent moisture (F 41/36=5.15, p<.01); highly significant differences for early stand (F 41/41=2.59, p<.01); and significant differences for resistance to stalk lodging (F 41/41 =1.77,p<.05). Coefficient of variation for early stand was 7.136%, and a broad sense heritability of 0.613 was calculated. Early stand is of interest because of its relationship to emergence capacity. The yield test was not deep planted, but the capacity to produce long mesocotyls may correlate positively with seedling emergence force and produce better stands at normal planting depths (Troyer, 1964). However, significantly better emergence was not shown for any test crosses.

From yield trial data and two years' results of emergence testing, further selection on a family basis is possible. Family 16, for example, was not statistically different from the Hopi parent in both years' emergence experiments, was of good agronomic plant type, and its selection index was fourth best when crossed with A632HT. It showed good early stand data and statistically significant better resistance to stalk lodging. Family 25 was the highest yielding of the test crosses (with A632HT), and had the second highest selection index overall for a specific hybrid combination. Families (lines) #4, #17, and #23 also merited further selection.

Selection indexes for General Combining Ablity for all the test lines are presented in Table 6. General Combining Abilities for lines

#16, #25, and #17 were the highest. Lines with good GCA are expected to do well in specific hybrid combinations. The 1987 S2 plant selections from these families will be advanced to S3 development in 1988. Populations for recurrent selection may be formed with these selected S2 families. Crosses of some S2 lines with other Corn Belt inbred lines were made to form source populations for future breeding.

Table 6. Inbred Line Evauation Index (GCA).

LINE	SELECTION INDEX
Hopi x Oh 43-1	100
Hopi x Oh 43-4	97
Hopi x Oh 43-5	101
Hopi x Oh 43-11	106
Hopi x Oh 43-13	80
Hopi x Oh 43-16	109
Hopi x Oh 43-17	123
Hopi x Oh 43-21	95
Hopi x Oh 43-23	97
Hopi x Oh 43-24	84
Hopi x Oh 43-25	123

GCA selection indexes are the average of the selection indexes for each inbred in each of its hybrid combinations based on the test means rather than the check means (as with SCA). Economic weights used were the same as those for SCA.

DISCUSSION

Various approaches may prove useful to integrate exotic material into Corn Belt breeding programs. The method presented here had the advantage of concentrating selection for adaptation and potentially improved agronomic value in one operation that produced encouraging results quickly and efficiently.

Yield testing of S4 lines at more locations will be possible with adequate seed amounts available at that stage. Deep planted yield trials should be conducted.

Hybrids emerging well from deep planting (3-3.5 inch depths), would provide several beneficial options to the farmer. With a dry seedbed at planting time, these hybrids would allow the farmer to adjust planting depth downward to reach available soil moisture. They might prove useful for no-till on coarse textured soils with low water-holding capacity or with some minimum tillage planting practices and conditions. Chisel plowing leaves plant residues on the soil surface that can interfere with good seed placement. Stands are often reduced because some of the seed is placed in these residues rather than in the soil. Deeper planting would put the seed through the plant residues into the soil with more available moisture to ensure better stands. Long mesocotyl hybrids should be evaluated in no-till, minimum tillage, and conventional tillage yield trials.

Another apparent drought (and temperature) resisting adaptation of Hopi Maize is profuse pollen shedding under extremely hot and dry conditions at time of flowering. This plant characteristic was not a subject of investigation in this research, but it was apparent from observations of the material in the field. The profuse pollen shedding was seen in several of the Hopi x Oh 43 families in 1987. The Oh 43 type parent is a poor pollen shedder. It did not pollinate effectively in the Mason, Michigan Dekalb nursery. The 1987 growing season was unusually hot and dry both at planting and flowering.

The 1986 season was almost the reverse. Moisture was over-abundant at planting, and again at harvest, with no moisture stress during the growing season. These two extremes may account for some of the variation in the two emergence tests. Only two families showed emergence not significantly lower than the Hopi parent in 1987, while all 11 selected families were not significantly lower than Hopi in 1986. The S2 lines in the 1987 emergence experiment had been inbred a second generation. There may have been more segregation for poorer emergence, and some loss of vigor associated with emergence. The numbers of plants emerged in 1987 were substantially less for almost all entries except the Hopi parent. All 11 families were still significantly better emerging than Oh 43.

The four inch planting depth appears to have served as sufficient selection pressure to identify some families with enhanced emergence capacity. Plants were dug from the 1987 emergence experiment to observe first internode growth. Plants that emerged appeared to do so mainly because their first internode elongated sufficiently. Most of the plants that did not emerge had insufficient first internode growth to bring the coleoptile node close enough to the soil surface. Figure 1 shows a Hopi plant in the emergence experiment. The first internode has elongated about 4 inches (10 cm.) with emergence by the coleoptile.

Actual planting depth for the experiment was closer to 5 inches. A four inch hole was dug, but when covering the seed, an additional inch of topsoil was placed over the hole. This is seen in Figure 1 where the coleoptile node is 4 inches from the seed, and the coleoptile shows about one inch of additional underground growth. Figure 2 shows a plant from Hopi x Oh 43-16 S2 line. This plant also emerged with 10 cm. of first internode growth and about 1 inch (2.54 cm.) of coleoptile growth. Figure 3 shows seedlings of the Oh 43 parent in the experiment with first internode lengths and/or seedling emergence force insufficient for emergence.

When selecting offspring from an exotic by adapted cross there is a tendency toward recovering the adapted parent type. In this research an effort was made to select for good agronomic types as well as Oh 43 types. Oh 43 types with improved emergence (and improved pollen shed) made up about half of the plants selected in 1986. Another recurring good plant type was taller than Oh 43 with a longer and thinner ear with thinner and deeper kernels. A third selected type was similar to Oh 43 but larger with an intense cherry/purple tassel that shed pollen profusely. This plant type had red cobs with dark orange colored kernels. It was the predominant plant type in one of the best families selected for advancement (family #16). Plant maturities fell into three major classes: an early group which included mostly good Oh 43 types, a middle group with more variations in plant type, and a late group which included many Oh 43 types. Approximate relative maturities ranged from 95-110 days. Progeny of selected plants maintained good agronomic characteristics. There was no apparent negative linkage of improved

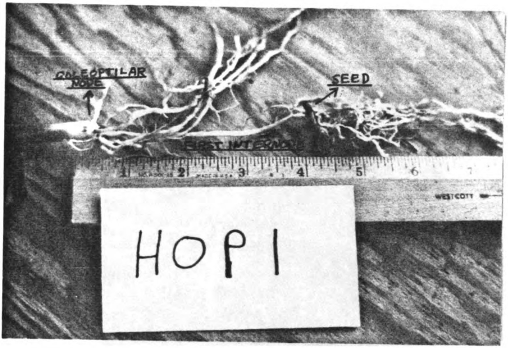

Figure 1. First Internode Elongation of Hopi Parent.

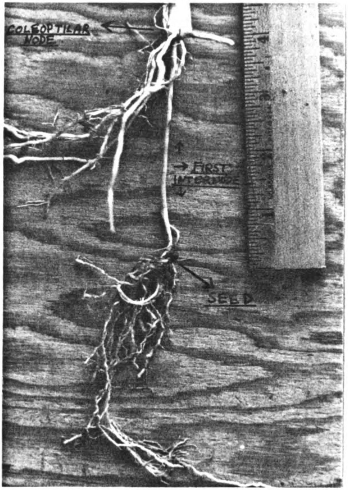

Figure 2. First Internode Development of Hopi x Oh 43-16 Line.

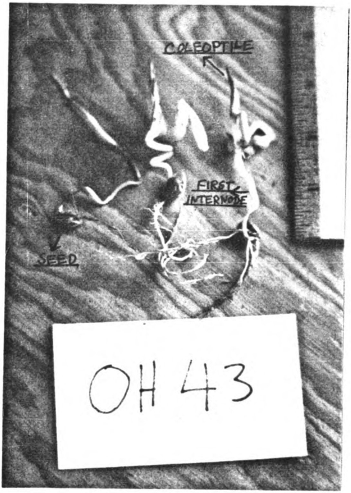

Figure 3. Failure of Emergence for Oh 43 Parent Seedlings.

emergence with agronomic traits.

Even if no elite lines are derived directly from this adapted by exotic cross, the best lines for combining ability might prove useful when intercrossed to form populations for future recurrent selection while maintaining the deep planting selection pressure. Lines could be extracted after each cycle and evaluated in hybrid combinations. While promising, it is too early to predict if this program will result in derivation of elite breeding lines. This breeding program has taken a modest step toward increasing germplasm diversification with incorporation of maize from native southwest Americans into a Corn Belt breeding program.

SUMMARY

Hopi Maize emerges from planting depths over ten inches by its inherent capacity to produce long first internodes. To improve the emergence of an elite Oh 43 type inbred line crosses were made with Hopi Maize. Bulked seed was planted to form a population of 250 plants. After two generations of sib-mating, 100 plants with good agronomic type were self pollinated. Twenty five selected ears were shelled and planted ear to row for 1986 S1 populations for inbred line development using the Pedigree Selection Method. At the same time, together with the Hopi and Oh 43 parents they served as 27 entries in a randomized complete block design experiment to compare emergence capacities. Eleven of the 25 S1 families were selected for agronomic type and emergence significantly better than the Oh 43 and not significantly lower than the Hopi parent. The best plants within those families were selected for advancement. Test crosses were made to plants in the 11 families for a 1987 yield trial. Bulked S2 seed of the 11 families and the parents formed 13 entries in a 1987 emergence experiment.

Based on yield trial data and two years' emergence data, further selection on a family basis was possible. Six families showed merit warranting further selection. The 1987 S2 plant selections from these families will be advanced to an S3 selection nursery. Some of these S2 families may be intercrossed to form populations for recurrent selection.

The breeding method used appeared effective for concentrating selection for adaptation and improved agronomic value in one operation. All research was conducted at a commercial maize breeding station. Only minor modifications of standard procedures were necessary.

LIST OF REFERENCES

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Benson, G.O. and Reetz, H.F. Corn plant growth from seed to seedling. National Corn Handbook-3, 1985.

Brown, W.L., Anderson, E.G., and Tuchwena, R. Observations on three varieties of Hopi Maize. American Journal of Botany 39:597-607, 1952.

Brown, W. L. and Goodman, M.M. Races of Corn. In G.F. Sprague (Ed.), Corn and Corn Improvement, American Society of Agronomy, 1977.

Carter, G.F. and Anderson, E. A Preliminary survey of maize in the southwestern U.S. Missouri Botanical Garden Annals 32:297-322, 1945.

Clothier, R.W. The dry farm crops for the Sulfur Springs Valley. Arizona Ag. Exp. Station Bulletin 70, 1913.

Coe, E.H. and Neuffer, M.G. The Genetics of Corn. In G.F. Sprague (Ed.), Corn and Corn Improvement, American Society of Agronomy, 1977.

Collins, G.N. A drought resisting adaptation in seedlings of Hopi Maize. Journal of Ag. Research 1:293-303, 1914.

Day, A.D. Registration of Arizona Arid Environment Maize Germplasm. Crop Science 26:390, 1986.

Day, A.D., Grove, D.R., and Thompson, R.K. Arizona Indian corn. Ariz. Acad. of Science 7(1): 8-11, 1972.

Galinat,W.C. and Campbell, R.G. The diffusion of 8 rowed maize from the southwest to the central plains. Mass. Ag. Exp. Station, 1967.

Goodman, M.M. Estimates of genetic variance in adapted and exotic populations of maize. Crop Science 5:87-90, 1965.

Hallauer, A.R. and Sears, J.H. Integrating exotic germplasm into Corn Belt maize breeding programs. Crop Science, vol. 12, 1972.

Inge, F.D. and Loomis, W.E. Growth of the first internode in maize seedlings. American Journal of Botany 24:542-547, 1937.

Jenkins, M.T. The segregation of genes affecting yield of grain in maize. Journal of American Society of Agronomy 32:55-63, 1940.

Kiesselbach, T.A. The structure and reproduction of corn. Research Bulletin 161, Lincoln, Nebraska, 1949.

Mangelsdorf, P.C. and Reeves, R.G. The origin of Indian corn and its relatives. Texas Agric. Exp. Stn. Bulletin 574:1-315, 1939.

Moll, R.H., Salhuana, W.S., and Robinson, H.F. Heterosis and genetic diversity in variety crosses of maize. Crop Science 2:197-198, 1962.

Sprague, G.F. Early testing of inbred lines of corn. Agron. Journal 38:108-117, 1946.

Sprague, G.F. and Miller, P.A. Influence of visual selection during inbreeding on combining ability in corn. Agronomy Journal 44: 258-262, 1952.

Steel, R.G. and Torrie, J.H. Principles and Procedures of Statistics. McGraw-Hill, 1980.

Troyer, A.F. The inheritance of long first internode in corn. Ph.D. Thesis. U. of Minnesota, 1964.

Wallace, H.A. and Brown, W.L. Corn and its Early Fathers. Michigan State University, 1956.

Wellhausen, E.J. Exotic germplasm for improvement of Corn Belt maize. Annual Hybrid Corn Industry Res. Conf. Proc. 20:31-45, 1965.