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Morphological Characterization and Classification of Open-pollinated Sweet Corn Cultivars

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Abstract. **Sweet corn is one of the most important vegetable crops in the United States, however the morphology and phylogeny of open-pollinated sweet corn cultivars has not been studied. Fifty eight open-pollinated sweet corn cultivars were characterized with thirty-four descriptors to provide information for breeders interested in broadening the genetic base of sweet corn. Principal component analysis and cluster analysis were performed to classify sweet corn cultivars based on morphology. Also, relationships among morphological variables in this set of cultivars were determined. The general ordination of cultivars followed an axis representing earliness, and plant, leaf, and tassel size, while ear and kernel attributes were less variable. The morphological variability among all of the widely used sweet corn cultivars, except 'Country Gentleman', was not greater than the variability found among the 'Golden Bantam' strains. Based on morphology, 52 of the cultivars could be considered as one race, which we propose be called 'Northeastern Sweets'. These may be a subset of the race 'Northern Flint'. Five of the remaining cultivars are from the north-central or southwestern United States and may represent races from those areas. The sixth cultivar is 'Country Gentleman', a commercially important sweet corn cultivar. Due to the importance of 'Country Gentleman' and the introgression of nonsweet germplasm into modern sweet corn, we believe that sweet corn should be defined based on its use as a vegetable and on the presence of one or more genes that increase sugar levels in the endosperm.**

While sweet corn is one of the most important vegetable crops in the United States, it is poorly represented in the USDA-ARS National Plant Germplasm System. Tapley et al. (1934) identified over 800 open-pollinated (OP) sweet corn cultivars, most of which originated in the northeastern United States. Today there are -25 sweet corn accessions comprising OP cultivars from the United States and Canada at the North Central Regional Plant Introduction Station (NCRPIS) at Ames, Iowa. Another source for OP cultivars is the Seed Savers Exchange (Adelman et al., 1993). The 1993 Seed Savers yearbook lists ≈3.5 cultivars, not including those obtained by seed savers from NCRPIS.

With the advent of hybrid sweet corn, development of OP cultivars ended and the OP cultivars served as source material for inbred development. However, inbred extraction concentrated, with a few notable exceptions, on three cultivars: 'Golden Bantam', 'Stowell's Evergreen', and 'Country Gentleman' (Huelson, 1954; Tracy, 1993; Gerdes and Tracy 1994).

Alleles useful for sweet corn improvement may be present in the few OP cultivars still in existence. However, if the germplasm is to be used it should be collected and characterized. Characterization of morphological variability will allow breeders to identify accessions with desirable characteristics such as earliness, disease resistance, or improved ear morphology. Characterization and grouping of germplasm will allow breeders to avoid duplication in sampling populations. Also, in the absence of pedigree records or information on combining ability it would be useful to organize the collection based on morphology. This may allow breeders to identify potential combining ability groups.

Numerical taxonomy and genetic relationships of maize races and cultivars has been the subject of many research programs over the past 50 years (Wellhausen et al., 1957; Bird and Goodman, 1977; Camussi, 1979,1980; Sanchez and Goodman, 1992: Llaurado and Moreno-Gonzalez, 1993). But, neither the relationships nor the diversity among sweet corn cultivars have been systematically investigated. Many tools are now available to study relationships among cultivars, including various types of molecular markers; however, morphological characterization is the first step in the description and classification of germplasm (Smith and Smith, 1989).

Our objective was to characterize and classify OP sweet corn cultivars, with primary emphasis on morphological traits.

Materials and Methods

Fifty-eight sweet corn cultivars were obtained from farmers, gardeners, and hobbyists associated with the Seed Savers Exchange (Adelman et al., 1992, 1993), NCRPIS, and the collection of the Univ. of Wisconsin-Madison (Table 1). Based on our examination of the NCRPIS records, Seed Savers Yearbooks (Adelman et al., 1993), and seed catalogs, this represents approximately 95% of the North American sweet corn OP cultivars available to the public. Seed of the cultivars were planted on 15 May and 18 June 1993 at the West Madison (Wis.) Agricultural Research Station in a Plano silt loam (fine-silty, mixed, mesic Typic Argiudolls). The first planting date resulted in good environmental conditions for sweet corn production while the second planting was exposed to two main stress factors that are typical in the upper Midwest: severe common rust *(Puccinia sorghi)* infestation and cool late season growing conditions. The experimental design was a randomized complete block with two replications per planting date. Two-row plots, 5.3 m long with 76 cm between rows, were overplanted with 30 seeds per row and thinned to an evenly spaced stand of 15 plants per row. Weeds were controlled with 2.3 $\text{liters}\cdot\text{ha}^{-1}$ cyanazine, 2.3 $\text{liters}\cdot\text{ha}^{-1}$ alachlor, and cultivation.

Many authors have suggested sets of characters appropriate for classification or taxonomy in maize (Goodman and Paterniani, 1969; Sanchez et al., 1993). Since the main goal of this research was a practical characterization of sweet corn germplasm for

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Table 5. Effect of infestation level on ear damage by European corn borer on resistant sweet corn breeding lines[z].

Entries across levels of infestation

1989		1990	
Lines	Acceptable ears (%)[y]	Lines	Acceptable ears (%)
96	77a	2667	94a
98	75a	620	88ab
169	63ab	618	86ab
132	54 b	621	80 b
Jubilee 1	9 c	2670	55 c
Jubilee 2	2 c	Jubilee	10 d
$LSD_{0.01}$	20		13

Levels of infestation across entries (lines and controls)

Level	Acceptable ears (%)	
(no. of larvae)	1989	1990
50	57a	79a
100	42ab	70ab
150	32 b	64 b
200	39 b	62 b
$LSD_{0.01}$	15	10

[z] Means within column followed by the same letter do not differ ($P = 0.01$).

[y] Ears scoring 3 or lower on the 1 to 9 visual rating scale (Table 2) for ear damage were classed as acceptable for commercial processing.

larvae might leave an ear with a high population.

Jarvis and Guthrie (1987) applied one, two, four, and eight egg masses per ear (≈30 eggs/mass) to compare kernel damage in popcorn, dent corn, and sweet corn. Damage was determined by counting the number of kernels damaged, and the egg masses were not placed at the ear tip. ‘Silver Queen’ and ‘Tahitian Hi-Sugar’, the two sweet corn hybrids used, were considered susceptible, with damage ranging from 7.9 and 19.5 kernels per ear, respectively, at one egg mass, to 17.6 and 64.8 at eight egg masses. Location of damage was not considered and actual hatch of eggs per mass was not reported. In our research, ears arbitrarily were classed as acceptable if receiving up to 1% kernel damage, with damage occurring only at the ear tip. On an average hybrid ear, 1% kernel damage would equal about five kernels. Ears having one or more kernels damaged by larval penetration into the. side or base of the ear, however, were not considered acceptable.

In conclusion, moderate ear-feeding resistance was confirmed for the several breeding lines, and most lines transmitted a significant level of resistance in testcross combination. Resistance generally was maintained when the ear silk channel was shortened, or when larval numbers were increased. While resistance levels comparable to those of the breeding lines used in this research have been shown by Bolin et al. (1993) and Hutchison et al. (1992) to have potential in reducing insecticide needs, even higher levels undoubtedly will be desirable in ECB resistance management by the sweet corn industry. The industry has long had as its goal a zero tolerance for product contamination by the ECB, and the processing sector also continues to have a strong interest in eliminating need for costly hand-trimming of ears.

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breeding purposes, we chose 34 descriptors among those proposed by IBPGR (1991) (Table 2). Data were taken on ten randomly chosen plants per plot.

The following descriptors wererecorded (Table 2): days to 50% silking, days to 50% tasseling, anther color, silk color, foliage size, tassel type, kernel shape, leaf orientation, prolificacy, common rust *(Puccinia sorghi)* and smut *(Ustilago maydis)* susceptibility, leaf length, leaf width, number of leaves above the uppermost ear including the ear leaf, tiller number, plant height, ear height, tassel length, number of primary branches on tassel, number of secondary branches on tassel, number of tertiary branches on tassel, kernel type, kernel color, 1000 kernel weight, cob color, ear shape, kernel row arrangement, kernel row number, ear length, ear diameter, kernel length, kernel thickness, tip damage, and number of kernels per row.

Individual analyses of variance were performed for each of the 34 descriptors combined over planting dates. Cultivar effects were considered fixed while all other effects were random. To classify the sweet corn cultivars, principal component analysis (PCA) and cluster analysis (CA) (Sneath and Sokal, 1973) were computed, with the data combined across and within planting dates. PCA plot was drawn to show the ordination of the cultivars. The seven principal components with an eigenvalue larger than 1 were standardized to produce the Mahalanobis' generalized distances (Goodman, 1968) and a cluster was made with the unweighted pair-group method by using arithmetic averages (UPGMA) (Sneath and Sokal, 1973). Finally, the relationships among the traits were studied by means of a cluster analysis (procedure VARCLUS of SAS). All the analyses were conducted with the SAS system (SAS, 1989).

The data set is a mixture of continuous and discontinuous variables. Romesburg (1984) suggests several methods to analyze such data sets. But, methods based on making continuous variables discontinuous can also result in the loss of information (Romesburg, 1984). Dropping discontinuous variables from the analysis will also result in the loss of information. And all the variables included are considered important descriptors by IBPGR (IBPGR, 1991). On the other hand, Romesburg (1984) suggests that in some cases such variables may be combined in one analysis and result in accurate and useful information. In maize, discontinuous and continuous morphological variables have been used in combined analysis and resulted in useful classifications that were later supported by other measurements such as molecular markers (Smith and Smith, 1989). We felt that the loss of useful information

Table 2. Traits recorded[z] in the 58 cultivars.

Code	Trait	Unit	Description
DAS	Days to silking	Days	Days to 50% silking
DAT	Days to tasseling	Days	Days to 50% tasseling
ANC	Anther color	1–4	1 = yellow, 2 = mostly yellow with some purple, 3 = mostly purple with some yellow, 4 = purple
SIC	Silk color	1–4	1 = yellow, 2 = mostly yellow with some purple, 3 = mostly purple with some yellow, 4 = purple
FOL	Foliage	1–7	3 = small to 7 = large
TAT	Tassel type	1–3	1 = primary branches only, 2 = secondary branches, 3 = tertiary branches
KSA	Kernel shape	1–4	1 = shrunken to 4 = rounded
LEO	Leaf orientation	1–2	1 = erect, 2 = pendant
PRO	Prolificacy	Number	Ears/plant, plot average
RUS	Rust sensitivity	1–9	1 = very low to 9 = very high
SMU	Smut sensitivity	1–9	1 = very low to 9 = very high
LEL	Leaf length	cm	Ear leaf length
LEW	Leaf width	cm	Ear leaf maximum width
LEN	Leaf number	Number	Number of leaves above the uppermost ear including the ear leaf
TIN	Tiller number	Number	Tillers/plant
PLH	Plant height	cm	Stalk base to tassel base
EAH	Ear height	cm	Stalk base to ear base
TAL	Tassel length	cm	First branch to top
TBP	Tassel primary branches	Number	
TBS	T. secondary branches	Number	
TBT	Tassel tertiary branches	Number	
KTY	Kernel type	6 or 8	6 = flint, 8 = sweet
KEC	Kernel color	1,2,3,9,10	1 = white, 2 = yellow, 3 = purple, 9 = red, 10 = mixed
KEW	Thousand kernel weight	g	
COC	Cob color	1 or 10	1 = white, 10 = mixed white and red
EAS	Ear shape	1 or 2	1 = cylindrical, 2 = cylindrical–conical
KRA	Kernel row arrangement	1–2	1 = regular, 2 = irregular
RON	Row number	Number	Kernel rows/ear
EAL	Ear length	cm	Ear base to top
EAD	Ear diameter	cm	Central ear diameter
KEL	Kernel length	cm	1/2 ear minus cob diameter
KTH	Kernel thickness	cm	Length of an ear segment/number of kernels
TID[y]	Tip damage	Number	Tip damaged ears out of 10
NKR	Number of kernels/row	Number	Number of kernels along ear

[z] According to the definition of IBPGR (1991). + 10 is the value for mixed colors, this value has been added to the CIMMYT values, in the list of descriptors.

[y] This trait has been added to the IBPGR list of traits.

Table 1. The 58 sweet corn cultivars included in this study and the source of seed.

Code	Cultivar name	Provider	Former origin
alg	ALTA GOLD	PI 219870[z]	
ana	ANASAZI	SS NM FL T[y]	
atk	ATKINSON	PI 198641	
aum	AUNT MARY'S	SS CA FI D	SS MO PE R 1992
bao	BABY ORCHARD	PI 219872	
bae	BANTAM EVERGREEN	SS MN EK M	SS WI HA M 1989
bay	BAXTER'S YELLOW	PI 255982	
bla	BLACK AZTEC	SS OR TH C	
blm	BLACK MEXICAN	PI 162573	
cam	CAMPBELL	SS IA DR G	
clb	CLEM BENNETT	SS OH DE J	SS WV NO S 1984
cog	COUNTRY GENTLEMAN	Univ. Wisconsin[x]	
dog	DORINNY	SS IA DR G	
dou	DORINNY	PI 220866	
eae	EARLY EVERGREEN	PI 231297	
eaj	EARLY JUNE	PI 219876	
eap	EARLY PEARL	PI 228183	
gbb	GOLDEN BANTAM BURNELL	PI 255981	
gbm	GOLDEN BANTAM (MASS.)	PI 255977	
gbd	GOLDEN BANTAM (ND)	PI 219879	
gby	GOLDEN BANTAM (NY)	PI 255976	
gbw	GOLDEN BANTAM (WI)	Univ. Wisconsin	
gem	GOLDEN EARLY MARKET	SS IA DR G	
goe	GOLDEN GEM	PI 219880	
goi	GOLDEN GIANT	PI 231302	
gos	GOLDEN SUNSHINE	SS IA DR G	
haw	HAYES WHITE	SS MN TJ J	SS MI KE R
hid	HIDASTA	SS IA HA B[w]	
hsi	HOOKER'S SWEET INDIAN	SS OR TH C	
how	HOPI WHITE	SS NM HO D	SS NM SA L 1983
hmu	HOWLING MOB	PI 231298	
hmg	HOWLING MOB	SS IA DR G	USDA 1982
kwm	KENNEDY'S WHITE MIDGET	SS OR TH C	SS IA DR G
lmb	LINDSEY MEYER BLUE	Univ. Wisconsin	
luh	LUTHER HILL	SS NY CH M	SS ONT PI G
mal	MALCOMBS	SS IA DR G	SS OH KN T 1984
mar	MANDAN RED	SS WI NE K	SS IA DR G 1991
mib	MIDNIGHT BLUE	SS KS CR T	SS WI EA T 1988
mis	MIDNIGHT SNACK	SS IA DR G	
non	NO NAME	SS MN BE D	
nue	NUETTA	PI 219886	
nut	NUETTA	PI 213796	
orb	ORCHARD BABY	SS CA AS S	SS IA DR G
ore	OREGON EVERGREEN	PI 231299	
pac	PAIUTE CROSS	SS UT WO D	
pec	PEASE CROSBY	PI 255983	
qua	QUEEN ANNE	SS IA DR G	SSOH KN T 1984
rhi	RHODE ISLAND	PI 245130	
seu	STOWELL'S EVERGREEN	PI 219893	
sew	STOWELL'S EVERGREEN	Univ. Wisconsin	
sun	SUNSHINE	PI 219894	
sbb	SWEET BABY BLUE	SS NY HE C	
tus	TUSCARORA	SS MN KE O	Burr, 1865
wbw	WEST BROOKFIELD WHITE	PI 255975	
whw	WHIPPLE'S WHITE	PI 231300	
wyu	WHIPPLE'S YELLOW	PI 231301	
wyg	WHIPPLE'S YELLOW	SS IA DR G	PI 231301
yuc	YUKON CHIEF	SS AK VA J	Alaska Agr. Expt. Sta.

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[z] Seed with PI numbers was obtained from the North Central Plant Introduction Center, Ames, Iowa.

[y] The letters following SS are the codes from Seed Savers 1993 Yearbook (Adelman et al., 1993).

[x] Univ. Wisconsin is the sweet corn breeding program, Dept. of Agronomy, Univ. of Wisconsin-Madison.

[w] Seed Savers 1992 Yearbook (Adelman et al., 1992).

Table 5. Groups of variables found in the 58 sweet corn cultivars

Group	Subgroup	Variables (traits^z)
1	1	DAT DAS FOL TAT SMU LEL LEW LEN PLH EAH TAL TBP TBS
	2	RUS TBT RON EAD KEL
	3	KEW NKR EAL
	4	LEO TIN
	5	EAS
	6	KRA
2	1	KTY KSA COC KTH
	2	KEC PRO TID
	3	ANC SIC

^{z}See Table 2 for name and description of the traits.

man' type rowing. (Galinat, 1971; Tapley et al, 1934). Our data confirm its uniqueness.

These results are supported by an isozyme study on the same germplasm (Revilla and Tracy, 1995). In that study three of the six independent cultivars, 'Hidasta', 'Anasazi', and 'Hopi White' clustered with Mexican/Southwestern USA corns. Based on isozymes 'Country Gentleman' did not cluster with any other sweet corn (Revilla and Tracy, 1995).

Based on morphology, clusters 1 through 5 could be considered as one race which we propose be called "Northeastern Sweets". Given the history of these sweet corn cultivars it is likely that Northeastern Sweets are a subset of the race Northern Flint (Goodman and Brown, 1988). This grouping as well as the relationship with Northern Flint is supported by a phylogeny based on isozymes (Revilla and Tracy, 1995). However, rather than use a racial classification based on morphology, we believe that it is preferable to continue to define cultivars as sweet corn based on their use as a vegetable and on the presence of one or more genes that increase sugar levels in the endosperm. This is due to the introgression of nonsweet germplasm into modern sweet corn inbreds (Haber, 1945; Tracy, 1994) and the importance of Country Gentleman germplasm both per se (Tracy, 1994) and as a contributor to modem inbreds (Gerdes and Tracy, 1994, Gerdes et al., 1993).

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