NE-EDRsu1 and NE-EDRBtl1, Disease-resistant Sweet Corn Populations with sugary1 and brittle1 Endosperms

James L. Brewbaker1
Department of Tropical Plant and Soil Science, University of Hawaii, Honolulu, HI 96822

Brian T. Scully2
Everglades Research and Extension Center, Institute of Food and Agricultural Sciences, University of Florida, Belle Glade, FL 33430

Additional index words. Zea mays, recurrent mass selection, supersweet corn, shrunken2 gene, maize mosaic virus, Fusarium moniliforme, Puccinia sorghi, Puccinia polysora, earworms, thrips

The development of broadly based, open-pollinated populations as genetic resources for sweet corn improvement was proposed in 1976 under USDA–CSRS Regional Project NE66 (now NE124). The population NE-EDR (“Northeast, Exotic Disease Resistance”) was bred in Hawaii from crosses of temperate sweet corns with tropical populations chosen for high tolerance of diseases, insects, and stresses (Brewbaker et al., 1991; Kim et al., 1988a). Two counterpart populations, NE-HY-13A and -13B, were selected for high yield based on crosses with elite temperate field corns (Davis et al., 1988). The base population for NE-EDR was a yellow sweet corn with the sugary1 endosperm gene. Since 1989 this base was converted by backcrossing into sub-populations homozygous for the “supersweet” genes shrunken2 and brittle1, reflecting the shift of consumer interest from sugary1 to high-sucrose genotypes for enhanced postharvest quality. A germplasm release of the shrunken2 subpopulation, NE-EDRsh2, has been made by Scully et al. (2001). The high-sucrose mutant preferred in the tropics has been brittle1 (Zan and Brewbaker, 1999).

Origin

The NE-EDR populations were created as a genetic resource for breeders, comparable to CIMMYT’s populations and pools of field corn. They represent >60 cycles of recurrent mass and backcross selection. The primary intent was to expand the genetic base of sweet corn for disease tolerances, a base that largely involved three open-pollinated northeastern American cultivars (Tracy, 1994). Genetic background of NE-EDR is about one-half temperate and one-half tropical sweet corn, the latter derived from tropical field corns (Brewbaker, 1978). The tropical parents were chosen for their resistance to important diseases (Brewbaker, 1979). These include the seedling blight, and kernel rots caused by Fusarium moniliforme Sheld., and maize mosaic virus (MMV) and maize dwarf mosaic virus (MDMV). Tropical lines also incorporate racially nonspecific tolerance of common rust, southern rust, bacterial leaf blight, northern leaf blight, brown spot, and southern leaf blight. Causal agents are Puccinia sorghi Schw., Puccinia polysora Underw., Pseudonomas avenae Mains, Exserohilium turcicum (Pass.). Leonard & Suggs, Physoderma maydis Miyabe, and Bipolaris maydis (Nisik.) Schoen., respectively.

The NE-EDRSu1 base population and the derivative btl1 and sh2 sub-populations were bred largely at the Waimanalo Research Station of the Univ. of Hawaii on Oahu at sea level, 20°N lat. Breeding of the sh2 sub-population was initiated in Hawaii and completed by Scully (Scully et al., 2001) at the Everglades Research Station of the Univ. of Florida at sea level, 26°N lat. Breeding of the NE-EDR was started in 1976 using sugary1 lines with yellow endosperm. Conversions were begun in 1989 to supersweet genes shrunken2 and brittle1 in populations with both yellow and white endosperm.

Ten elite American sweet corn hybrids (sugary1 gene) that dominated the industry in 1975 were chosen as the base population of NE-EDR (Table 1). All were temperate except for Hawaii’s H68 or ‘TropIII’ (Brewbaker, 1968), a hybrid of Hawaii’s AAS (tropical) and Illinois’ ‘442 (temperate). All except H68 showed high susceptibility to maize mosaic virus, fusarium seedling rot, common and southern rust, and other diseases common in Hawaii (Brewbaker et al., 1998). While some of these problems were peculiar to the tropics, many were simply intensified by year-round corn production in Hawaii’s congenial climate.

The 10 temperate hybrids were crossed in a diallel with 12 subtropical sugary1 populations developed through 6 to 12 cycles of recurrent mass selection (RMS) in Hawaii (Table 1), using four ears of each population as females to each temperate hybrid as male. Most of the subtropical populations appear in the pedigree of 16 composites and synthetics (6 sugary1, 7 brittle1, 1 brittle2) released previously (Brewbaker, 1998). These populations included composites and synthetics, the latter based on inbreds from the cultivar Hawaiian Sugar, or from hybrids among Hawaiian inbreds and publicly available U.S. inbreds. The composites were derived from crosses of temperate sweet corns with tropical field corns chosen for their tender pericarp. Many tropical races and cultivars of field corn evolved as elote or green food corns, and customarily have thin pericarp and high consumer acceptability (Brewbaker et al., 1996). In contrast, Corn Belt Dents of the United States have pericarps much thicker than tropical corn races (Wang and Brewbaker, 2001).

Aliquots of the 480 hybrid ears were bulked to create NE-EDR, and were planted 1 Nov. 1976, as a population of 3300 plants from which 500 open-pollinated ears, comparable to an F1, were selected. Hardy–Weinberg estimates of gene frequencies in this population were made homozygous for the sh1 allele in cycle 6. Selection for agronomic quality and disease resistance was made insofar as possible prior to hand-pollination and at an intensity of >10% among >1000 plants per cycle. No insecticide, fungicide, or seed treatment is ever applied to corn at Waimanalo Research Station. During the 25 years of year-round breeding and evaluation of NE-EDR, 320 nurseries were planted that averaged 590 plots (5 m in length) per month. This maximized the frequency and severity of natural epidemics of diseases and insect pests. A temporal shuttle breeding strategy for the base population of NE-EDR was combined with selection, alternating from the warm, dry, long-day summers to the cool, wet, low-light winters (Jong et al., 1982). All epidemics were cyclical and more severe in winter. Five of the 13 cycles were conducted in winter months, under heavy selection pressure for diseases. Seven of the 13 cycles involved hand-sib pollination, with significant selection prior to silking, while six were conducted in isolation for open-pollination.

Table 1. Temperate sweet corn hybrids and tropical sweet corn populations that were crossed to form base population NE-EDR.

| Temperate hybrids | Tropical populations |
|-------------------|----------------------|
| Bonanza | Hawaiian Sugar* |
| Gold Winner | Hus SYN2 |
| Golden Cross Bantam | Hus SYN4* |
| Iobelle | Hus COMP 6* |
| Jubilee | Hus COMP 7 |
| Midway | Hus COMP 8 |
| NK 71036 | Hus COMP 9 |
| Silver Queen | Hus COMP 10* |
| Stylepak | Hus COMP 11 |
| Trop III (H68) | Hus 2SW COMP 12.3 |

*Described by Brewbaker (1998).
NE-EDR sub-populations

Two major sub-populations based on the "sweet" genes *brittle1* and *shrunken2* have been bred in addition to the base population NE-EDRsu1. NE-EDRbt1 originated in 1990 from crosses of NE-EDRsu1 Cycle 8 with *Hi* bt COMP 3 as the *bt1* donor (Brewbaker, 1998). The accelerated conversion involved 14 cycles of breeding that included five backcrosses followed by sibbing, selfing, and open-polliination in isolation. The fifth backcross involved a large population of the recurrent parent. Eight of the 14 cycles occurred in the winter, providing high selection pressure for viability of the high-succrose seeds and disease resistance. Although the double mutant, *sugary1 brittle1*, could be recovered from advanced cycles of selection, it was eliminated from the population due to its poor viability. NE-EDRsh2 also originated from crosses made in 1990 between NE-EDRsu1 Cycle 8 and temperate *shrunken2* hybrids, with five backcrosses and five sib cycles in Hawaii followed by backcrosses and sibs summarized by Scully et al. (2001).

Description

**Horticultural traits.** The NE-EDR populations emerged silks between 48 and 60 d in Hawaii, and were harvested as fresh corn in ∼10 weeks. They ranged widely in maturity during the year, and would be considered "spring season" relative to commercial U.S. hybrids. For comparison, the hybrid Jubilee silks in 46 to 50 d in Hawaii. The NE-EDRs are segregating for daylength sensitivity, and some plants would be delayed 1 week or more to silk by 16-h days. Field emergence rates of NE-EDR populations appear to follow those reported by Zarn and Brewbaker (1999) for near-isogenic lines, with *su1* 85%, *bt1* 74%, and *sh2* 52%.

The NE-EDRs appear similar to field corns, with rare tillers and flag leaves, strong brace roots, and high tolerance of lodging tolerance and stalk breakage. Leaf-area indices are higher (9 to 13) than in temperate hybrids. Husks extend well over the slightly tapered ear, providing high tolerance to earworms. NE-EDR populations at low frequency. The base population NE-EDRbt1 cycle 14 segregated 18% white kernels (wy/wy) and 35% pale yellow kernels, believed to be based on allele *y8*. A detailed description of horticultural properties in Florida of sister composite NE-EDRsh2 has been published by Scully et al. (2001).

**Disease tolerances.** The NE-EDR populations were grown for breeding or evaluation in ∼120 of the ∼320 Waimanalo corn nurseries since 1976, of which there were 22 breeding nurseries for *su1*, 25 for *bt1*, and 19 for *sh2*. Disease and insect epibiotics varied greatly within and among these years (Brewbaker, 1974; Moon et al., 1999), and selection often dramatically improved resistance within populations for diseases, e.g., MMV, fusarium kernel rot, southern rust, or physoderma brown spot. Assessments of disease tolerances (Table 2) were based largely on empirical observations on a 1–9 scale of these 120 trials. In many trials commercial U.S. hybrids were also grown as susceptible checks, with scalar averages of 7 to 9 (Kim et al., 1988a). High resistance characterized most Univ. of Hawaii field corns in these trials, which are grown commercially in Hawaii without pesticides. MMV resistance (Brewbaker, 1998) did not occur in any American sweet corn in 1975. Thus, NE-EDR breeding focused initially on selection for resistance, shown by Ming et al. (1997) to involve chromosome 3 locus *Mv*. In Nov. 2000 the gene frequency of resistant allele *Mv* was 62.4% among 500 plants of the two NE-EDRs, while >90% of temperate checks were virus-infected. Resistance to aphid-Bremmutter MDMV occurs among the tropical parents of NE-EDR, but aphid predation prevents spread of MMV in Waimanalo nurseries. Virus resistance of any type is uncommon in temperate corns (Brewbaker et al., 1991), and other resistance genes expected to occur in NE-EDR include those to the corn stilt complex of Mesoamerica.

The NE-EDRs express high tolerance of fusarium kernel, ear, and seedling rots, since seeds are never fungicide-treated and *Fusarium moniliforme* Sheld. is epidemic in fields dedicated to corn at Waimanalo. Under the wet winter conditions of 1992, untreated seed of *sh2/sh2* and *se/se* hybrids germinated 7%, while NE-EDR germination exceeded 60%. Ears harvested in May 2001 for National Seed Storage Laboratory showed kernel rot in 6% of NE-EDRsu1 and 27% of NE-EDRbt1, generally confirming experience in Hawaii with these endosperm genes. Occasional viiary seeds occurred in 1% of *su1* ears and in 9% of *bt1* ears. Ears of a Jubilee Supersweet check revealed 85% kernel rot and 12% viiary. NE-EDR and other Hawaii-bred populations uniquely show little or no damage to thrips (Frankliniella sp.), which are abundant and a serious problem on temperate germplasm in Hawaii’s seed industry. Thrips are a similar problem in Queensland, Australia, where Hawaii’s hybrids show high tolerance (I. Martin, personal commun.). Actual injury to corn by thrips is believed to be minimal, but they are suggested to provide an avenue for entry by fusarium. Thus the selection for fusarium resistance may have conferred some thrip tolerance on Hawaii-bred populations.

High general resistance occurs in NE-EDR (Table 2) to the mixture of races of common rust that are epidemic in the long months at Waimanalo. In 1988, an NE-EDR population in cycle 7 averaged 3.2 on a 1–9 rust scale vs. an average of 6.3 for 98 temperate sweet corn hybrids (Kim et al., 1988b). In 2000, 100 temperate hybrids averaged 7.2 on this scale (Pataky et al., 2001) and produced no marketable ears. A nearby population of NE-EDRsu1 ranged widely but averaged 3.6 on this scale. All specific resistance genes except *rp1-677A* (Kim and Brewbaker, 1987) are ineffective in Hawaii. The resistance allele *Rp1-d* is present in NE-EDR but is now widely ineffective (Pataky et al., 2001). Southern rust can be very severe at Waimanalo in dry cool winters, and major QTLs for resistance have been identified in tropical field corns at this location (Moon et al., 1999). Mature-plant resistance is rare in temperate sweet corns but common to all Hawaii-bred sweet corns (Table 2).

Northern leaf blight is occasionally severe at Waimanalo, where monogenes for specific resistance such as *Hl* and *Hr* are ineffective. Tropical parents of the NE-EDRs had high general resistance (Brewbaker, 1998), and temperate parents were susceptible or carried *Hl*. In Florida, the NE-EDR populations averaged 1.6 on the 0 to 9 scale of Scully et al. (2001), vs. 3.3 for ‘Florida Staysweed’ and 0.9 for ‘Waimanalo Supersweet’. Southern blight is uncommon in Hawaii, but tolerance has been observed (Table 2). Brown spot is common throughout the year at Waimanalo, and the NE-EDRs appear to be highly tolerant (Table 2). Tolerance of bacterial leaf blight, caused by *Pseudomonas avenae* Manns, is also high (Table 2), with fewer than 4% infected plants in a 2001 spring nursery showing >90% infection of susceptible inbreds.

Tolerance for several diseases should segregate in the NE-EDR populations, but have not been assessed. Common smut, caused by *Ustilago maydis* (DC) Cda, is an example, for which NE-EDR may segregate susceptible plants at rather high frequencies, since suscepti-

Table 2. Empirical scores for nine diseases (1 highly resistant to 9 highly susceptible) averaged over two decades of observations in Hawaii of populations NE-EDRsu1 and NE-EDRbt1 sweet corn.

| Disease | common name | Disease | causal organism | Score |
|---------|-------------|---------|----------------|-------|
| MMV | Maize mosaic virus | Ear and kernel rot | Fusarium moniliforme | 2 |
| Common rust | Puccinia sorghi | Southern rust | Puccinia polysora | 4 |
| Northern leaf blight | Erysiphe turcicum | Southern leaf blight | Bipolaris maydis | 6 |
| Brown spot | Physoderma maydis | Bacterial leaf blight | Pseudomonas avenae | 3 |

HortScience, Vol. 37(3), June 2002

601
Cultivar & Germplasm Releases

Susceptibility is common among tropical lines. Also among the tropical parents of the NE-EDRs are composites or varieties that had tolerance of Stewarts’ bacterial wilt (Ming et al., 1999), head smut, caused by Sphacelotheca reiliana (Kuhn) Clint, downy mildew diseases, and other stalk and kernel rots.

Availability

All seeds are open-pedigree and available at cost from Hawaii Foundation Seed Facility, Dept. Tropical Plant and Soil Science, College of Tropical Agriculture and Human Resources, Univ. of Hawaii, 3190 Maile Way, Honolulu, HI 96822. The two NE-EDR populations are stored at the U.S. National Seed Storage Laboratory, Ft. Collins, Colo., and are registered (NE-EDRsu1 = PI 619435, NE-EDRbt1 = PI 619436), and the sh2 population is registered as PI 614830 (Scully et al., 2001). Recipients are requested to acknowledge the use of these materials in research, patenting, or germplasm development.

Literature Cited

Brewbaker, J.L. 1968. H38 and H68, Hawaiian sweet corn hybrids. Hawaii Agr. Expt. Sta. Circ. 66:11.
Brewbaker, J.L. 1974. Continuous genetic conver-
sions and breeding of corn in a neutral environ-
ment. Proc. Amer. Seed Trade Assn. Corn and Sorghum Res. Conf. 29:118–133.
Brewbaker, J.L. 1977. Hawaiian Super-sweet #9 Corn. HortScience 12:355–356.
Brewbaker, J.L. 1998. Disease-resistant tropical sweet corn populations. HortScience 33:1262–1264.
Brewbaker, J.L., S.K. Kim, and M.L. Logroño. 1991. Resistance of tropical maize inbreds to major virus and virus-like diseases. Maydica 36:257–265.
Brewbaker, J.L., L.B. Larish, and G.H. Zan. 1996. Pericarp thickness of the indigenous American races of maize. Maydica 41:105–111.
Brewbaker, J.L., K. Kaukis, D.W. Davis, J.L. Brewbaker, and L.B. Larish. 1988. Registration of NE-HY-13A and NE-HY-13B, complementary populations of sugary maize germplasm. Crop Sci. 28:381.
Brewbaker, J.L., S.K. Kim, and M.D. McMullen. 1999. Identification of RFLP markers linked to a major gene, sw1, conferring resistance to Stewart’s wilt in maize. Maydica 44:319–323.
Davis, D.W., J.L. Brewbaker, and K. Kaukis. 1988. Registration of NE-HY-13A and NE-HY-13B, complementary populations of sugary maize germplasm. Crop Sci. 28:381.
Jong, S.K., J.L. Brewbaker, and C.H. Lee. 1982. Effects of solar radiation on the performance of maize in 41 successive monthly plantings in Hawaii. Crop Sci. 21:13–18.
Kim, S.K. and J.L. Brewbaker. 1987. Inheritance of resistance of sweet corn inbred IL677a to Puccinia sorghi Schw. HortScience 22:1319–1320.
Kim, S.K., J.L. Brewbaker, and A.R. Hallauer. 1988a. Insect and disease resistance from tropical maize for use in temperate zone hybrids. Proc. Corn and Sorghum Research Conf. 43:194–226.
Kim, S.K., J.L. Brewbaker, M.L. Logroño, and G. Srinivasan. 1988b. Susceptibility of U.S. sweet corn hybrids to Puccinia sorghi Schw. in Hawaii. Crop Protection 7:249–252.
Ming, R., J.L. Brewbaker, H.G. Moon, T.A. Musket, R.N. Holley, J.K. Pataky, and M.D. McMullen. 1999. Identification of RFLP markers linked to a major gene, sw1, conferring resistance to Stewart’s wilt in maize. Maydica 44:319–323.
Ming, R., J.L. Brewbaker, R.C. Pratt, T.A. Musket, and M.D. McMullen. 1997. Molecular mapping of a major gene conferring resistance to maize mosaic virus. Theor. Appl. Genet. 95:271–275.
Moon, H.G., J.L. Brewbaker, and X.W. Lu. 1999. Major QTLs for disease resistance and other traits identified in recombinant inbred lines from tropical maize hybrids. Maydica 44:301–311.
Pataky, J.K., M. Gonzalez, J.L. Brewbaker, and F.J. Klopppers. 2001. Reactions of Rp-resistant, processing sweet corn hybrids to populations of Puccinia sorghi virulent on crop with the Rp1-d gene. HortScience 36:324–327.
Scully, B.T., J.L. Brewbaker, J.K. Pataky, W.F. Tracy, and M.E. Smith. 2001. NE-EDR sh2: A yellow shrunken-2 sweet corn population with disease resistance from exotic sources. HortScience 36:1149–1151.
Tracy, W.F. 1994. Sweet corn. In: A. Hallauer (ed.). Specialty corns. CRC Press, Boca Raton, Fla.
Wang, B. and J.L. Brewbaker. 2001 Quantitative trait loci affecting pericarp thickness of corn kernels. Maydica 46:159–165.
Zan, G.H. and J.L. Brewbaker. 1999. Seed quality of isogenic endosperm mutants in sweet corn. Maydica 44:271–277.