Successful Use of Resistance to Control Diseases of Sweet Corn

Jerald K. Pataky, Professor, Department of Crop Sciences, University of Illinois, Urbana 61801, and **Patrick R. Mosely,** Director of Sweet Corn Research, Illinois Foundation Seeds, Inc., P.O. Box 722, Champaign 61824

The ultimate goal of cooperative efforts of commercial and public sweet corn breeders and plant pathologists is to develop highly resistant hybrids adapted for various uses and geographic areas. This can be done by diligently following an organized program of plant health (6), which includes identifying important diseases, monitoring pathogen populations, developing efficient inoculation methods and rating systems, identifying resistant germ plasm, incorporating resistances into adapted germ plasm, integrating other control methods with resistance, and studying the epidemiology of diseases and inheritance of resistances. In addition to adhering to a program of plant health, plant pathologists also must consider the constraints that commercial production of sweet corn place on breeding for resistance. To consider these constraints, plant pathologists must be extremely familar with the various uses and markets for which sweet corn is developed, and the advantages and limitations of various methods of plant breeding.

Sweet Corn and Resistance

Sweet corn (*Zea mays* L.) is a major vegetable crop in the United States, where over 325,000 ha (800,000 acres) are grown commercially each year (1). About 70% of the hectarage is processed (frozen or canned) and 30% is sold fresh. On-farm value of processed and fresh sweet corn is about $250 to $275 million each. Sweet corn ranks second among canned and frozen vegetables; 454 million kg (one billion pounds) of cut corn and corn-on-the-cob are frozen and 60 million cases are canned annually. Per capita annual consumption of fresh and canned sweet corn is about 3 and 5 kg (6.5 and 11 pounds), respectively, which reflects a decrease of about 10% in the past decade.

Nearly 65% of processed sweet corn is grown in Wisconsin, Minnesota, and Illinois, and about 20% is grown in Washington, Oregon, and Idaho. Fresh sweet corn is produced throughout the United States in the summer, with about 25,000, 14,000, 10,000, and 6,000 ha (60,000, 35,000, 25,000, and 15,000 acres) grown in the East, Midwest, West, and South, respectively. From October to May, fresh sweet corn production is concentrated in Florida, where about 20,000 ha (50,000 acres) are grown. In the past decade, mean yields of processed and fresh crops were about 2,250 kg/ha (6.3 tons/A) and about 420 crates/ha (170 crates/A), respectively; and prices averaged about $0.071/kg ($65/ton) and $7.5/crate). The average on-farm value of processed and fresh sweet corn has been about $988 and $3,212 per hectare ($400 and $1,300 per acre), respectively.

In the past 20 years, two types of high-sugar sweet corn, shrunken-2 and sugary enhancer, replaced traditional sugary types in most fresh sweet corn markets. The change to high sugar types (sometimes called supersweet) continues, as several food processing companies plant more acreage with these improved hybrids. Of nearly 500 sweet corn hybrids available commercially, about 50% are shrunken-2, 30% are sugary enhancer, and 20% are traditional sugary.

Diseases that reduce yield differ among and within the major geographical areas where sweet corn is grown. Stewart's wilt (*Erwinia stewartii*) is a major problem in southern portions of the Midwest, the Ohio River valley, and portions of eastern and mid-Atlantic states. Common rust (*Puccinia sorghi*), which is not a problem on early-planted crops in the Midwest, is the major disease of mid- and late-season crops. Northern leaf blight (*Exserohilum turcicum*) and common rust are the primary diseases in Florida. Common smut (*Ustilago maydis*), maize dwarf mosaic (MDMV), and anthracnose leaf blight (*Colletotrichum graminicola*) are problems in certain areas and years. Germination and seedling vigor of many shrunken-2 hybrids are adversely affected by seed- and soil-borne fungi, particularly *Penicillium oxalicum*, *Fusarium moniliforme*, and *Pythium* spp.

Foliar fungicides are applied routinely in Florida and occasionally in other areas, primarily to control northern leaf blight and common rust. Chlorothalonil, mancozeb, maneb, and propiconazole are registered for use on sweet corn. Seed treatment fungicides are used routinely, and biological seed treatments are being tested.

Resistance to each of the major diseases has been incorporated into sweet corn germ plasm through traditional plant breeding. Nevertheless, in order to effectively control these diseases, resistances must be incorporated into inbreds, and subsequently hybrids, which meet the extremely demanding quality standards of various sweet corn markets. Hybrids with superior resistance will not be grown commercially if they are inferior for traits such as emergence, seedling vigor, husk protection, tip fill, ear size, kernel style, pericarp thickness, sweetness, or canning characteristics. Since important qualities differ among the various markets for sweet corn, resistant hybrids with acceptable quality for one market may be unacceptable for another.

Inbred lines with superior combining ability for several important traits are used in many hybrid combinations and are referred to as elite testers. While it is extremely difficult to develop a superior inbred tester, it can be exceedingly easy to lose that superiority when attempting to improve an elite breeding line for a specific trait such as disease resistance. Thus, superior inbreds usually are improved for resistances that are relatively highly heritable through some form of backcross breeding. Highly resistant inbreds also can be developed from improved populations, but inbred line development through population improvement can be laborious, extremely time-consuming, and more likely than backcross breeding to result in materials with inferior quality.

Commercial breeders develop hybrids that are competitive for a market-specific set of quality factors rather than for resistance to diseases that may not be important commercially in certain years or areas. Before breeding for disease resistance, commercial seedsmen must consider consumer (i.e., grower) demand. It is not profitable to improve resistance at the expense of superior quality, if resistance is relatively unimportant to growers. How-

Corresponding author: Jerald K. Pataky
E-mail: snook@vmd.cso.uiuc.edu

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ever, when a disease occurs frequently and severely enough to concern growers in a specific market, resistance becomes one of the factors required of hybrids for that market. In that case, resistant hybrids will increase seed sales compared to susceptible hybrids of equal quality, and the time and resources used to incorporate resistance is justified.

Public researchers have greater flexibility to expend resources on longer term projects that produce resistant germ plasm that may be used as source material for the development of elite lines. Ultimately, this germ plasm must meet minimal quality standards if it is to be accepted for commercial use.

Common Rust

Breeding for resistance to common rust illustrates many of the important aspects of developing and using resistance to control diseases of sweet corn, including areas of research that are best suited for public and commercial researchers.

Common rust has been severe on sweet corn grown in the Midwest in the past 20 years because of cool, wet weather; cultural practices in field corn that have accelerated the arrival of and increased the amount of primary inoculum; and the susceptibility of superior sweet corn hybrids. Yields are reduced about 0.6% for each 1% rust severity at harvest (10). In several years of trials in central Illinois, rust severity ranged from 15 to 40% and from 25 to 80% on moderately susceptible and susceptible hybrids, respectively (12).

Susceptibility of superior inbreds. A group of superior shrunken-2 inbreds, which were derived from conversions of the sugary inbred Ia 2132, are parents of many popular supersweet hybrids. Unfortunately, these elite inbreds and their sugary ancestor are extremely susceptible to common rust. The 2132-hybrids are grown extensively for fresh sweet corn because of superior performance. Improved versions of these hybrids also are gaining popularity with processors. In order to maintain market share, commercial breeders must incorporate rust resistance into new lines developed from these and other susceptible elite inbreds without losing their superior combining ability.

***Rp* resistance.** Many single-gene resistances to common rust (*Rp* genes) that have not been widely used in field corn are effective in North America (4), even though they are not effective in many other parts of the world. Most of these resistance genes were identified in the 1950s and 1960s from central American, African, or eastern European sources (5). New sources from Mexico have been identified recently (W. F. Tracy, *personal communication*). To the best of our knowledge, *Rp1d* is the only gene presently used in sweet corn hybrids, although several breeders are working with *Rp1e, Rp1f, Rp1g, Rp1k*, and *Rp3c*. Possibly, some of these effective genes are really complexes or "compound" genes at *Rp1* (7). At least one hybrid with *Rp3c* resistance has been tested recently.

Sweet corn breeders recognize that widespread use of *Rp* resistance will select for virulence in populations of *P. sorghi*, so inbreds with durable forms of resistance are being developed while *Rp* resistance is used to solve immediate problems. Each source of *Rp* resistance probably will be used in North America until virulence is widespread. Possibly, the frequency of virulent phenotypes will vary annually and regionally depending on selection pressures placed on overwintering populations of *P. sorghi* and on patterns of dispersal of primary inoculum from overwintering locations. Some of the less frequently used *Rp* resistances or various complexes of *Rp* genes, which could be combined relatively easily in hybrids, may be effective longer than widely used resistance (e.g., *Rp1d*), thus delaying the need for highly effective, durable resistance. Using the *Rp* genes in multilines or mixtures is not realistic at present, largely because of uniformity needed at harvest.

Partial resistance. Moderate levels of partial rust resistance occur in several sweet corn inbreds developed from various backgrounds, although none are as highly resistant as some tropical and field corn germ plasms. Transferring rust resistance from these unadapted sources into adapted sweet corn is a long-term project. Some public programs are using recurrent selection to incorporate relatively high levels of partial rust resistance into adapted populations (2,14). Most commercial breeders use some form of pedigree line breeding to incorporate partial resistance from materials that are already relatively well adapted, even though few of these sources have high levels of resistance. For example, moderate levels of partial rust resistance have been obtained in lines developed from IL677a, the inbred in which the sugary enhancer trait was first described. Commercial breeders are more likely to use this type of material in pedigree selection programs because resistance is in adapted material and it appears to be highly heritable (8). Partial rust resistance in sweet corn has been associated with sporulation-related components of the infection cycle (9) and, recently, with latent period (3). Accumulation of resistance genes expressed through different components may result in higher levels of partial resistance, although this also is a long-term project well suited for public researchers.

Use of rust-resistant hybrids. Proprietary hybrids developed by food processing companies were among the first widely grown *Rp*-resistant sweet corn. In the mid-1980s, seed companies introduced a few *Rp*-resistant hybrids such as aRRestor, Excellency, Prevailer, and Terminator. *Rp*-hybrids with acceptable quality were enthusiastically welcomed by food processors in the Midwest, because susceptible hybrids grown during severe rust epidemics required the use of EBDC fungicides, which were under special review by the Environmental Protection Agency. Currently, most food processors in the Midwest require *Rp*- or partial rust resistance in hybrids being considered for planting after mid-May. Most seed companies have incorporated the gene *Rp1d* into at least one elite inbred, and several *Rp*-hybrids are available. Of 380 hybrids evaluated in 1993 in a disease nursery at the University of Illinois, 56 were *Rp* resistant, but only seven non-*Rp* hybrids had less than 15% rust severity (13). Better levels of partial rust resistance are needed in a greater number of hybrids. In addition to providing partial control of rust, moderate levels of resistance can enhance the level of control achieved by fungicides (11).

Resistance to several diseases. There are no areas of sweet corn production where rust is the only disease problem. In the past 2 years, some *Rp*-resistant sugary hybrids grown under unusually wet conditions in the Midwest needed several applications of fungicides to prevent substantial yield reductions due to northern leaf blight. Similarly, rust resistance is of limited benefit in Florida without adequate resistance to northern leaf blight, and vice versa.

Resistance to multiple diseases has become an important criterion in many areas. Many food processors in the Midwest give extra consideration to hybrids with multiple resistances, such as ACX92CN15RR, ACX92CN16RR, ACX93CN108RR, ACX-93CN109RR, Eliminator, Esteem, GH 2628, More, ProSweet 415R, Sch 51041, Sch 51044, Sch 51091, Shimmer, Sunex 2577, and Terminator.

Grower demand for resistance, competition among seed companies, and incorporation of resistance into adapted materials by commercial and public researchers should result in a greater number of commercially acceptable, disease-resistant sweet corn hybrids. Hybrids with high levels of partial resistance to multiple diseases are the key component of an efficient and sustainable program of disease management in sweet corn.

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