Pre-Breeding from the Perspective of the Private Plant Breeder

To see a world in a grain of sand and a heaven in a wild flower

William Blake, Auguries of Innocence

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ABSTRACT

Collection and preservation activities have greatly enriched the range of genetic diversity available to plant breeders. However, there has been limited use of exotic materials from collections or other sources by private plant breeders. Because of the emphasis on short term breeding goals, private breeders tend to use breeding materials with which they are familiar and which are reasonably adapted to the target environment, as against alien materials which require a lengthy and expensive program of pre-adaptation or pre-breeding. The genetic variability of sugarbeets in the United States has increased in the last two decades. And it does not appear that sugarbeet culture in the United States is particularly at risk because of genetic vulnerability. However, in the long run the broadening of genetic variation, both cytoplasmic and nuclear, may be of decisive importance in securing sugarbeets against epidemics as well as providing the base for continued breeding progress.

Additional Key Words: sugarbeet, exotic germplasm, genetic variation

It is almost axiomatic to state that a breeding program that is genetically broad based should provide the basis for steady gains under selection and the potential to respond readily to changing environments, diseases, and economic trends. In contrast, a program with a narrow genetic base would respond slowly to selection pressure and potentially increase the vulnerability of a crop to disease epidemics or infestations of insects. A lack of genetic variability across breeding programs could exacerbate these deficiencies regionally, nationally, or even internationally, conceivably threatening the usefulness of available varieties and, of longer term significance, the usefulness of breeding stocks (Smith and Duvick, 1989).

Plant breeders seek to provide cultivars of increased adaptation to agricultural environments. Genetic, cultural, and environmental changes have provided increased productivity by optimize the fit of cultivars to increasingly uniform and optimum cultural conditions. However, the result, as discussed by Simmonds (1962), Marshall (1977), and Timothy and Goodman (1979), is that there has been a simultaneous reduction in extant sources of adaptability available from diverse cultivated varieties, populations, and wild and weedy relatives. These potential liabilities can only be countered by first, the development of comprehensive, well documented, and accessible germplasm collections and secondly, by a plant breeding community that is willing to invest resources in long-term programs of germplasm diversification (Smith and Duvick, 1989).

Smith and Duvick (1989) point out that building a broader germplasm base *per se* is pointless as a practical goal, and that genetic diversity in a breeding program is practically worthless unless it encompasses genes that are useful, either in themselves, or in combination with other previously evaluated germplasm. This is of particular importance to private plant breeders who rely upon the sale of varieties in a competitive market.

A complete array of germplasm in a crop consists of (1) wild relatives, weed races, and landraces in the areas of diversity, (2) unimproved or purified cultivars used earlier in the major production areas or still used in minor areas, and (3) improved germplasm in commercial production and genetic testers from breeding programs and genetic studies. In addition the recent advances in biotechnology have extended the range of usable variation far beyond the related genera of a crop (Chang, 1991).

EXOTIC GERMPLASM USAGE IN MAIZE AND OTHER CROPS

For most crops vast stores of germplasm are available in numerous gene banks. However, it has generally been noted that only limited use of these materials has been made by private plant breeders.

The extent of the use of exotic germplasm and the derived benefits varies from crop to crop. However, according to Hawkes (1991) and Smith and Duvick (1989), the process of pre-breeding or germplasm enhancement has not progressed very far in most crops. Even so, some results using land races and wild relatives have been impressive, especially in wheat *(Triticum vulgare* Vill.), rice *(Oryza sativa* L.), tomato *(Lycopersicon esculentum),* sugarcane *(Saccharum officinarum* L.), and tobacco *(Nicotiana tabacum* L.) (Chang, 1985).

Accurate information regarding the degree of usage of exotic germplasm in current breeding programs or in commercially released varieties of cultivated crops is difficult to obtain. Such estimates must be based upon pedigree information which most likely is unavailable from private breeding programs. In addition there are differences of opinion with regard to what constitutes "exotic" germplasm. This also impairs any meaningful objective measurement of the contribution of exotic collections in variety development. Broadly defined, exotic germplasm could include all untried germplasm. A useful definition, however, is that of Hallauer and Miranda (1981), "all germplasm that does not have immediate usefulness without selection for adaptation to a given area." By this definition the term exotic could also apply to foreign elite germplasm as well as landraces, wild relatives, etc.

In a survey of private maize breeders, Goodman (1985) found that only about 4% of the total US maize acreage is being planted with hybrids containing any non-US germplasm and those hybrids generally have only 10 to 25% exotic germplasm. Thus, foreign exotic germplasm accounted for less than 1% of the US maize germplasm base, and tropical exotic germplasm was only a fraction of that. There appeared to be no evidence that the acreage of US maize hybrids containing exotic germplasm would increase significantly during the next 10 to 15 years. Goodman indicated that the use of exotic germplasm in maize seemed to be static, although Duvick (1981, 1984) had reported a gradual increase of the germplasm base of corn *(Zea mays* L.) in the US in the decade following the early 1970's.

Extensive use has been made of exotic sorghum *(Sorghum vulgare* Pers.) since the conversion and evaluation program at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, and at Texas A. & M. University (Smith and Duvick, 1989) began in the mid-1960's.

The soft red winter wheat breeding programs in the USA had an infusion of exotic germplasm during 1954-69. This followed a 35 year period during which a small number of closely related varieties formed the germplasm base (Cox et al., 1986).

Exotic germplasm from *Solanum* spp., in large part emanating from the International Potato Center (CIP) in Peru, has been used mainly as a source of pest and disease resistance in potatoes. In the US about 33 percent of released potato cultivars have exotic germplasm in their backgrounds. The comparable figure for European cultivars is greater than 50 percent (Peloquin cited in Smith and Duvick, 1989).

Tomato breeders have made extensive and critical use of exotic germplasm, thanks largely to the collection, evaluation, and breeding work of C.M. Rick (Rick, 1979). Additional examples of exotic use for these and other crops are given by Chang (1984, 1985) and by Hawkes (cited in Smith and Duvick, 1989).

GENETIC VARIATION AND USE OF EXOTIC GERMPLASM IN SUGARBEETS *(Beta vulgaris* L.)

Bosemark (1979, 1989) addressed the genetic variation and the genetic vulnerability of sugarbeets in Europe. He discussed the development of the sugarbeet from a limited range of fodder beet types less than 200 years ago, and suggested that although it is likely that spontaneous hybridizations with cultivated leaf-beet types and wild *B. maritima* have contributed additional genetic variation, the genetic base of sugarbeet is probably narrower than that of most other cross-fertilizing crop species. He argued that whereas rather intense selection for high sugar content prior to 1900 must have resulted in a gradual narrowing of the sugarbeet gene pool, the differentiation into E, N, Z, and ZZ types after about 1900 together with a growing number of beet breeding organizations served to conserve genetic variation. Further, he suggested that the breeding of first-generation synthetic varieties in the 1930's, and the introduction of autopolyploidy in the development of cultivars in the 1940's, also probably resulted in the conservation of genetic variation.

He also suggested that whereas present day hybrid cultivars are based upon more restricted germplasm than open-pollinated and synthetic cultivars, because many of them are top-cross diploid or triploid hybrids, they still have considerable genetic variation. It was his opinion that the nuclear genetic variability in these top-cross European hybrid varieties was sufficiently large that there need not be reason for concern even if some of these hybrids were grown over extensive areas. He expressed particular concern, however, for the almost complete cytoplasmic uniformity, irrespective of variety. He stated that even though in his opinion the sugarbeet gene pool in Europe was not dangerously narrow, a broadening of both cytoplasmic and nuclear variation, by breeders as well as on a farm-to-farm basis, may be of decisive importance in saving the crop against epidemics and in securing continued breeding progress.

Sugarbeet breeding programs were initiated in the US because of the threats from various diseases. From the mid-1930's to the present, the most widely grown cultivars had become characterized by resistance to specific diseases and areas of adaptation.

Lewellen (1992) divided the most important traditional American germplasm into three fairly definable types characterized by disease resistance, adaptation, and origin:

1). **Curly top resistant:** Germplasm developed by the USDA at Salt Lake City. This germplasm is resistant to curly top; US 1 and US 22 are the base for most subsequent developments. Improvements from these early curly top sources have been made by USDA and private breeders.

2). **Great Western (Colorado):** Germplasm developed primarily in Colorado by Great Western Sugar Co., American Crystal Sugar Co., Holly Sugar Co., and the USDA station at Fort Collins, CO. This germplasm is characterized by moderate resistance to Cercospora leaf spot and Fusarium yellows and segregation for root aphid resistance. The open pollinated cultivar GW359 is the most significant germplasm source.

3). **Eastern:** Germplasm primarily developed at USDA stations in East Lansing, MI; Beltsville, MD; and Waseca, MN. This germplasm combines resistance to Cercospora leaf spot and *Aphanomyces* and has adaptation to the upper Midwest. US 401, SP5822-0, and their derivatives are important germplasm sources.

Within each of the regional germplasm types, one or a few open-pollinated cultivars, populations, or synthetics were pivotal. In each case, these base populations were derived from selecting, hybridizing, and resynthesizing within open-pollinated European commercial cultivars and other stocks obtained in breeder-to-breeder exchanges. To this day, highly selected versions of the original populations are still undergoing population improvement for disease resistance and combining ability (Lewellen, 1992).

It was stated in the National Academy of Sciences report entitled "Genetic Vulnerability of Major Crops" (1972) that two public sugarbeet hybrids, USH9 and USH20 (developed by USDA breeders), and similar related private hybrids together accounted for about approximately 40 percent of the US acreage. In the two decades since that report was issued, the genetic base of sugarbeets in the US has broadened significantly. This is due to the activities of several international seed companies beginning in the early 1970's. This infusion of diversity has come in the form of commercial cultivars, parental material, and breeding lines and populations developed in Europe and Japan (Lewellen, 1992). This foreign germplasm has been utilized directly, and also in combination with parental lines developed from the traditional American germplasm types.

Although the overall genetic variation in the US remains narrower than in Europe, it does not appear to be dangerously narrow. This is particularly the case in those areas requiring little or no disease resistance where foreign germplasm contributes significantly to the extant genetic variability. However, in those areas requiring higher disease resistance the situation has been slower to change, and the genetic variation tends to remain narrower. This would appear to be the case in areas of the west, particularly those areas that require high curly top resistance. The active presence of several sugarbeet seed companies has served to broaden the genetic variability of the sugarbeet crop in the US. Recent mergers and acquisitions may in the long run act to again narrow the genetic variation in the US.

The rapid development of new sugarbeet varieties may, to a limited extent, serve to partially offset the potential liabilities of a somewhat narrow gene base within a region in a given year, as was suggested by Duvick (1977) for maize.

Lewellen (1992) noted that very little if any of the important germplasm used in commercial cultivars in the US can be traced through the formal plant introduction stations or the national or international germplasm systems. He stated that the only exception might be the use of advanced breeding lines and open-pollinated cultivars that had been received from China through the Plant Introduction Office. This material was apparently directly usable as parental lines in the production of cultivars with good Cercospora leaf spot resistance and high sucrose content.

D.L. Doney (personal communication cited by Lewellen, 1992), chair of the Sugarbeet Crop Advisory Committee (CAC), stated that in the past the NC-7 collection of *Beta* at Ames, IA, had been little used. This inattention was in part due to the method of seed multiplication and high degree of interpollination among accessions. In addition the entries were not well described and had no useful database. Doney (personal communication) reported a significant increase in requests for seed from the Ames collection by private breeders, particularly breeders in Europe, in the years since the CAC began its activities.

Although it has been known for many years that breeders might draw on the hybridization of sugarbeets with wild species of *Beta,* especially *B. maritima* and other members of the section Vulgares, to improve the cultivated form, few serious attempts have been made to pursue integration of this germplasm. A notable exception is Munerati's work with Cercospora leaf spot resistance found in *B. maritima* biotypes from estuaries of the Po River and along the Adriatic Coast of Italy. He repeatedly crossed and backcrossed these strains with sugarbeets to obtain non-bolting leaf spot resistant hybrids. Today most leaf spot resistant varieties in Europe as well as in the US are considered to have been derived from Munerati's selections (Bosemark, 1979; Coons, 1975).

Bosemark (1989) has suggested that the use of recurrent selection procedures offers the best possibility of adapting and incorporating exotic germplasm into breeding populations. Because the average performance of these populations must be very close to that of commercial hybrids, the 'wild' gene pool must be kept separate until adapted and upgraded. His suggested scheme for pre-breeding utilizes the a_1 gene for Mendelian male sterility and the S^f gene for self-fertility in both the 'wild' gene pool and an elite population to facilitate the evaluation as half-sib families and/or S_1 families. This makes it possible to assess the value of the exotic germplasm before it is incorporated into the elite population.

PRE-BREEDING - GENERAL

For the last few decades consistent increases in genetic yield potential in many crops have resulted primarily from the utilization of elite germplasm, for example in maize (Duvick, 1977; Smith and Duvick, 1989; Castleberry et al., 1984), sorghum (Miller and Kebede, 1984), soybean *(Glycine max* (L.) Merr.)(Specht and Williams, 1984), cotton *(Gossypium barbadense* L.) (Meredith and Bridge, 1984) and wheat (Schmidt, 1984).

However successful plant breeders have been with a nearly total reliance upon elite germplasm, it would be both short-sighted and dangerous to rely upon this past success. Plant breeders are working with biological systems where new pests or diseases can quickly reveal the risks of complacency. It is for this reason that most plant breeders include an increase in genetic diversity as an important breeding objective.

Duvick (1984) surveyed 67 public and 34 private US plant breeding programs, including cotton, soybean, wheat, sorghum, and maize. The majority of respondents for each crop reported that elite materials were generally more useful than landraces or related species as sources of pest resistance and stress tolerance. Therefore, in spite of the contributions made by exotic germplasm, there is no evidence that exotic germplasm is now, or will be in the near future, the major germplasm source of elite varieties of the major US field crops.

The reasons for the low use of exotic germplasm by private plant breeders has been discussed by several authors (Brown, 1983; Chang, 1985; Goodman, 1985; and Smith and Duvick, 1989). Brown states that although the reasons for the limited use are somewhat more complicated, in general there appear to be two primary reasons. First, although a vast amount of material is available, there is not much known about the major characteristics and potential usefulness of the individual accessions making up that store of materials. In other words, only a small amount of the material residing in the germplasm banks has been adequately evaluated.

The second reason is that unimproved varieties, landraces, weed races, and wild relatives contain many undesirable traits. To eliminate such traits while retaining the few desirable genes that may be present is a formidable breeding task requiring much time and patience. It is not an activity from which rapid progress can be expected. These preparatory procedures are known as conversion or germplasm enhancement or pre-breeding.

Smith and Duvick suggested that the major hindrances to the use of exotic germplasm by private plant breeders are the uncertainties and difficulties of progress in a reasonable time frame. And additionally, needed selections of exotic germplasm frequently cannot be effectively identified since, for most crops, much of the available exotic germplasm in collections (or *in situ)* is poorly documented. And further, in many cases when germplasm enhancement or pre-breeding has been attempted, breeding strategies may have been used which though successful with adapted germplasm, may be inappropriate with unadapted germplasm, exacerbating the many agronomic problems which may be encountered with exotic germplasm.

Pre-breeding to allow the recombination and evaluation of characters under complex genetic control is a time-consuming and difficult task. It is often necessary to break tight linkages between desirable and undesirable genes, and furthermore, several cycles of recombination and mild selection may be required to develop gene pools that are sufficiently adapted to allow further progress (Chang, 1985; Hawkes cited in Smith and Duvick, 1989; Smith and Duvick, 1989). For maize Lonnquist (1974) recommended the incorporation of exotic accessions into gene pools by mild selection for a minimum of five generations. In all cases, longer periods are required with exotic germplasm than the well-adapted elite germplasm (Chang, 1985). The transfer of even simply inherited traits may require pre-breeding because they may be masked by other genetic effects such as maturity response.

Smith and Duvick (1989) discussed the need for fundamental research in taxonomy and also appropriate breeding strategies. Questions that need to be addressed are: which exotic sources should be used; what degree of recombination is necessary; how much exotic germplasm should be incorporated into elite germplasm; and which specific by exotic combinations show good results?

Given the time frame for such fundamental studies and the process of pre-breeding the primary responsibilities for this work should be the responsibility of public breeders and researchers. However, private/public cooperation can be particularly fruitful, and private breeders have a significant and necessary role in the process. They have the obligation to communicate with public breeders, to provide funds if possible, and to lobby support for pre-breeding and associated fundamental research. They can assist in the maintenance and evaluation of public collections. In addition they can themselves contribute basic broad based breeding populations and inbred lines upon which they no longer rely to the base germplasm collections and thus enlarge the reservoir of variability.

SUMMARY

The genetic variability of sugarbeets in the United States has increased in the last two decades. And it does not appear that sugarbeet culture in the United States is particularly at risk because of genetic vulnerability. However, in the long run the broadening of genetic variation, both cytoplasmic and nuclear, may be of decisive importance in securing sugarbeets against epidemics as well as providing the base for continued breeding progress.

Most plant breeders, and especially private plant breeders who operate under the pressure of short term goals, tend to use materials that are already adapted to the target environments. Since the advent of modern plant breeding, steady progress has been made in numerous crops using almost exclusively adapted germplasm. Despite this success most breeders are generally in agreement regarding the need to expand the genetic base of the crops with which they work with exotic germplasm. Because of the uncertainties and difficulties of progress in a reasonable time frame they will use exotic germplasm only if pre-breeding is performed first.

The broadening of the genetic base of crops requires a system of well maintained and appropriately described collections. Classification, characterization, and pre-breeding of materials in collections will greatly stimulate their use by private plant breeders. In the absence of these activities private breeders will, in general, continue to ignore the collections.

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