Plant Breeding Education

H. T. Stalker and D. A. Knauft

Introduction

Plant breeding is the science of applying genetic principles to create or manipulate important traits in plants for human use. Plant breeders increase the economic value of plants, whether through yield increases, quality improvements, introducing resistance genes, or other traits important for consumption or commercialization. This is important for both rural communities, where food is produced, and for urban settings where new and improved varieties of ornamentals, trees, and grasses are grown. Maintaining a sufficient food and fiber supply for the expanding human population is central to the well-being of society as well as for national security; plant breeders continue to play a critical role in achieving this goal. To maintain a healthy economy, plant breeders must be educated to play a central role in the continued growth of agriculture for our societal needs.

Plant selection, which first gave rise to domestication, has been conducted by humans since the beginning of agriculture through collection of useful plants for production near the village, saving seeds, and replanting the best ones. Before the advent of modern plant breeding, however, yield and quality of crops were highly variable. Historically, a large percentage of the population worked on farms to produce our food supplies, and this changed only after a combination of enhanced production technologies along with improved genetics produced increased productivity and yields. For example, the average yield of corn increased from less than 30 bushels per acre in the late 1920s to more than 150 bushels per acre today, with about ½ of the increase due to improved genetics through plant breeding.

Plant breeding emerged as a science during the early 1900s when genetic principles and statistical methods were incorporated into plant biology for plant improvement. Scientific plant breeding has accelerated the process of genetic improvement in plants many-fold over previous efforts based largely on trial and error. Until the mid-1900s, most plant breeding was carried out at public institutions where improved varieties were developed and distributed to user groups. Subsequently, opportunities to capture the economic benefit of improved varieties, either through biological means such as F_1 hybrid cultivars, or intellectual property protection from plant patents, utility patents and plant variety protection, provided an environment for commercial breeding companies to flourish and take over variety development of many crops. During this time, many university programs began to re-focus their research on germplasm enhancement and developing varieties of specialty crops, while continuing to educate future plant breeders. Plant breeding programs, whether in the private or public sector, require long-term investments and continuity because the time required from initial crossing to variety release may take a decade or more depending on the type of crop. This inter-dependent plant improvement system involving both public and private sectors has continued to satisfy the needs of U.S. society for more than 100 years.

Just as commercial use of F_1 hybrids and protection of intellectual property have allowed private companies to develop, protect and market proprietary varieties, the advent of biotechnology and genomic technologies has fostered a second major wave of privatization and consolidation in the seed industry. Beginning in the 1980s there have been accelerating capabilities to precisely identify and manipulate genes to create unique plant forms. Efficient hybrid breeding required breeders with better knowledge of and ability to apply advanced statistical methods to complement classical breeding. So too, molecular-based techniques require good laboratory facilities integrated with field labs and test sites to assure that plants identified by molecular methods or altered for specific traits also have the combinations of genes and traits acceptable for commercialization. Critically, the final proof of the worth of a newly developed plant population (variety) is in field performance in either multiple environments or for targeted environments to fill niches for high-value products. The modern plant breeder is at the center of crop improvement programs.

Problems faced today

Morris et al. (2006) refer to plant breeding as an industry under stress, pointing to continuing demand for breeders in both private and public sectors concurrent with diminishing resources for infrastructure, faculty, research funding and student support at universities and experiment stations where plant breeding education takes place. There is accumulating evidence to indicate that seed companies are having difficulty filling positions with plant breeders who are able to optimally utilize new scientific tools and information in concert with field-oriented activities required for new cultivar development. There are major concerns about how future demands can be satisfied both in the U.S. and globally because there are not sufficient numbers of plant breeders being educated to meet continuing demands for higher yields and quality in agricultural commodities.

Changes in workforce. Following World War II, many universities were expanding programs and a large number of plant breeders were hired, with programmatic support coming from state-appropriated resources and federal funds through the Hatch Act. By the 1980s, many of those faculty members at land grant universities were retiring. The 1980s also saw significant expansion of molecular technologies which have led to new areas of science in biotechnology, genomics, and bioinformatics. Administrators perceived a need to add new faculty in the emerging sciences, which was reinforced by large amounts of federal competitive grant funding for plant improvement being directed toward molecular genetics. Thus, many traditional agriculture programs, including ones in plant breeding, were redirected towards laboratory-based molecular biology research. Guner and Wehner (2003) reported that the numbers of plant breeding students in agronomy and horticulture departments had declined significantly partly because of reductions in the number of plant breeding faculty at land grant universities.

Collins and Phillips (1991) reported that in 1980, there were a total number of 477 publically supported plant breeders working on all crops. By 1989 the number had decreased to 459 (-3.9%), with the majority being in a few states with the largest plant breeding programs, including Wisconsin, North Carolina, Texas, and Florida. Another survey by Frey (1996) reported that between 1990 and 1994 there was a decrease of 2.5% per year in faculty numbers. The same trend with number of plant breeding faculty at land grant universities occurred between 1994 and 2001 when the numbers fell from 528 to 424 (-19.6%) (Traxler et. al., 2005). However, this number also included 124 individuals whose primary activity is focused on discoveries in basic plant biology using molecular technologies. So in reality, only about 300 faculty are involved with breeding, germplasm enhancement and variety development (Bliss, 2007). This is in addition to the 20% decrease experienced during the previous decade. The decrease in university faculty numbers is actually greater than the figures indicate because full-time equivalent in plant breeding refers to that amount of effort devoted to the activity, and few university faculty have 100% research appointments because they also teach and perform extension activities. Perhaps a more realistic estimate of the impact of decreasing faculty numbers is revealed by the 9.3% decrease in number of programs in place by the end of the 1980s. At the same time, the numbers of plant breeders in the USDA fell from 177 to 161, while the numbers in commercial industry increased from 1497 to 1545.

Changes in plant breeding degrees awarded. Plant breeding degrees are generally conferred at the M.S. or Ph.D. level. Plant breeders have traditionally been educated at land grant institutions where between 1995 and 2000, 770 students earned plant breeding graduate degrees of which 360 were from the U.S. and 410 from the international community (Guner and Wehner, 2003). Of the 770 graduates, 359 earned M.S. and 411 earned Ph.D. degrees. While some year-to-year variation was observed, the number of degrees was generally stable throughout the period. Further, these numbers of graduates appeared to reasonably match the number of positions available. However, with significant increases in demand for trained plant breeders by commercial industry during the past few years, the number of graduates no longer fulfills the requirements of the job market.

Plant breeding is multi-disciplinary and degrees that either specialize in breeding or have significant breeding content may be conferred under different titles. There is only one plant breeding department in the U.S. (Cornell University), and relatively few universities offer a graduate degree in plant breeding. Most institutions with significant research and training efforts in plant breeding confer degrees in the name of the major department, usually agronomy, crop science, horticulture, or plant science. This makes it difficult to track precisely the number of graduating plant breeders and leads to the misperception by those outside the discipline that very few plant breeders are being educated and entering the profession. Today, there are an estimated 47 universities that offer plant breeding programs, but approximately 50% of graduates come from seven institutions (Guner and Wehner, 2003). All of these universities offer degrees in departments working with field crops, but only three also offer degrees in horticulture. Importantly, it is questionable whether there is sufficient critical mass of educators at many land grant institutions to provide a relevant, high quality plant breeding curriculum.

Facilities and location of faculty. Modern breeding programs that include an optimal balance between applied molecular studies and the necessary experience gained from field-based programs require field space for genetic analyses and population selection and testing as well as laboratory facilities supporting molecular- and whole-plant biology. Competition for limited space and other resources at many universities, has caused many plant breeding faculty to be located at off-campus sites where field plots may be available, but without access to other facilities, and apart from professional colleagues. Separation of plant breeding faculty from the central academic communities has added an element of difficulty for attracting and advising students as well as participating in general educational activities. As a result, the numbers of plant breeding faculty effectively teaching in the classroom and/or advising graduate students is only a fraction of the total number employed at universities. In addition to supplying adequate funding for more graduate students many on-campus plant breeding faculty will need improved facilities in order for their programs to meet increasing demands.

Funding for plant breeding. There are major concerns within the university and private business sectors about whether future demands for plant breeders can be met because of insufficient funding for educating new plant breeders. Funding issues include number of faculty and competitive compensation; support for student stipends, tuition, and fees; and research and teaching operations. Public support for agricultural research and education in general has been declining and faculty must seek multiple sources of additional funding such as with national competitive grants, foundations and industry support. Most competitive grants of significant magnitude are for short periods of specialized research heavily weighted towards discoveries in molecular mechanisms underlying plant growth and development. As a result, many plant breeding programs may complete poorly because they are must include field evaluation research and population selection in addition to increasing efforts toward applied molecular genetics. Even with competitive grant funds, resources are not available to conduct the large field studies needed for viable plant breeding programs. Importantly, 'ownership' in plant breeding programs needs to be addressed because this research seems to be either too applied or not applied enough to satisfy federal funding agencies, and industry historically has resisted supporting basic plant breeding research.

Frequently, funding for many plant breeding programs comes from commodity organizations. For large-acreage crops such as wheat, soybean and cotton, state and national commodity organizations have sufficient resources for significant funding of related programs; but for smaller-acreage crops and some large acreage crops such as maize and hay and pasture crops, funding is generally much less and insufficient to support research and graduate students. Furthermore, most commodity organizations have a yearly funding cycle that does not assure graduate student stipends for the 2-4 years required for program completion. Commercial investment in plant breeding education is inadequate (Morris et al., 2006), and most university breeding programs historically have educated student with other funding sources.

National problem and the opportunity

What can be done if plant breeding graduate training programs are funded at a level to impact the problem? Graduate student education and professional training is the critical educational issue required to sustain and energize the discipline of plant breeding. The 'next generation' plant breeder will require traditional and new technical skills (e.g., bio informatics and informational technologies), and also the ability to work in multi-disciplinary teams consisting of individuals located at multiple locations. These disciplines extend well beyond the traditional plant pathology, plant physiology, and agronomy fields and now include computer scientists, electrical engineers, mathematical modelers, economists, lawyers, and others. Thus, the next generation plant breeder also needs many experiences in communicating with non-expert scientists and non-science professionals.

Much of the shortage of trained personnel could be resolved with additional funding for assistantships and fellowships in revitalizing public plant breeding programs. It is also critical for the future of the discipline that outstanding undergraduate students be attracted into plant breeding graduate programs. Funding for undergraduate internships, both at academic institutions and private companies, would result in more students being attracted to breeding and jobs that utilize breeding knowledge. This is critical for providing plant breeders for private industry positions and to replace faculty retiring at universities, and to house the plant breeding faculty on campuses rather than at branch stations.

Students must receive educational experiences sufficiently broad to allow them to solve complex problems inherent of crop improvement. A curriculum mix appropriate for graduate students in breeding should include field-based research expertise, statistical acumen, plant biology, molecular genetics, transmission genetics, quantitative genetics, population genetics, plant pathology and a range of other courses and scientific experiences. To gain sufficient expertise, especially for students enrolled at institutions without a broad complement of plant breeding faculty able to offer a complete series of plant breeding courses, funding could be used to establish interuniversity collaborative teaching programs. For example, distance education centers could be established so that the needed courses for a M.S. or Ph.D. candidate are taught online by recognized experts wherever they are located. If those courses were considered part of the graduate education program at the home institution, students from across the country could enroll, and receive a much broader and more in-depth education.

Breeding infrastructure support should also address the need for broadening of national plant breeding efforts to include not only major crop species but also forest trees, ornamental plants, shrubs, perennials and annuals, vegetables, fruits, and newly introduced or developing crops which initially have narrow markets. Because commercial companies often do not breed new varieties of many specialty (but highly important) crops grown in the U.S. (or internationally), public programs have traditionally taken responsibility for these species. Public funding combined with industry support for endowed faculty positions at universities to conduct an educational and research program in specific minor crops would contribute substantially to plant breeding education while providing new cultivars to meet national need for food, fiber, and biofuels.

Finally, funding should be concentrated at locations fully committed to building a diverse faculty team capable of teaching different facets of plant breeding including both classical and cutting-edge methodologies. To do otherwise will be detrimental for not only the seed industry which depends on improved varieties for commercialization but also our humankind world wide that depends on agriculture for their wellbeing.

The resources needed to sustain plant breeding efforts. Many of the decisions contributing to the current situation were made 20 or more years ago. Because many faculty are reaching retirement age, significant levels of new funding to hire new faculty as well as support graduate education is need at many universities. Maintaining sufficient numbers of outstanding individuals on campuses will require commitment and support from administrators to insure that faculty salaries and support are competitive with comparable positions in the commercial sector to preserve programs from being 'raided' by other institutions or companies. Opportunities to partner with commercial plant breeders may help to assure continued viability in the public sector.

It is important that plant breeders are located on or near the central campus to facilitate teaching courses and advising graduate students as well as interacting with the general faculty. A person stationed away from a central campus at a satellite station might be involved in graduate student courses and perhaps even in distance education courses, but would not be able to teach classes on campus with much regularity Distance education will present a valuable alternative for specific courses, but the comprehensiveness of a balanced graduate education in statistical and genetic analyses as well as the significant training obtained through apprenticeship with practicing breeding programs can best be gained through active participation and personal interaction. Although urbanization around campuses has increased pressures for universities to sell land, and there must be a conscious effort to preserve some experiment station facilities for both training and research in close proximity to teaching campuses.

Universities have become much more entrepreneurial during recent years as operational dollars from state and federal sources have disappeared. This has resulted in greater emphasis on obtaining grants to support program operations, graduate education and in some cases salary supplements. As a result, most publicly funded plant breeders are significantly underfunded. Traditional plant breeding research has had very limited access to competitive funding at the national level unless grants were heavily lab oriented with molecular components. Several options to ameliorate this situation are needed, including policy changes to encourage plant breeding projects to compete for federal grant funding along with increased private industry support for plant breeding fellowships. A national awareness must be established to show that plant breeding is critical for the long-term vitality of our agricultural-product dependent industries.

Support for operation of regional centers of excellence should be considered to facilitate cooperation among universities for plant breeding education. These regional centers for translational research were originally proposed as part of the Senate version of the farm bill, but have subsequently been removed. Barriers imposed by the university- and state-level administrations can be broken down to allow easier cooperation between faculty at different institutions. Enhancing cooperation between universities would greatly improve the over-all education of future plant breeders and increase the number of students being trained in the science. But to do so will require resources to sustain centers, with the educational components being central to fulfilling their mission.

Partnering among universities will be increasingly important to assure a large number of highly qualified individuals enter the workforce. Plant breeding students at universities are usually schooled in the principles of genetics, plant breeding, statistics, as well as related subjects related to their dissertation problem. This prepares students with the ability to analyze data or and make decisions required to make maximum progress in crop improvement. Methodologies vary among species, but the underlying principles are the same, and a well-educated plant breeder can work on any species after learning the peculiarities of a particular crop species. More than 50% of all plant breeding efforts in the U.S. were devoted to only eight crops during the 1990's, including maize, soybean, cotton, wheat, tomato, alfalfa, sorghum, and potato (Frey, 1996). The survey was updated in 2001 by Traxler et al. (2005), and the same trends were observed with very few crops representing a large percentage of the plant breeding efforts. Thus, a large percentage of the graduates will end up working with a species other than the one used for graduate work and a broad education is required to fulfill the job requirements. Furthermore, it is likely that about two-thirds of new graduates will be working for private companies in the seed and food sectors.

Many of the plant breeders working outside the U.S. are trained in this country. Plant breeding infrastructure in many countries globally is woefully lacking, especially in developing countries (Guimaraes et al., 2006). Traditionally, many breeders for those countries have been educated in the U.S. and they will continue to look to us for education. Unfortunately, plant breeding in the international community varies from non-existent in many countries to very good in a few (e.g., India, China, South Africa, Brazil, Argentina, Mexico, and Chile) (Morris et al., 2006). The seven countries listed are not equipped to graduate sufficient numbers to fulfill the global needs. The Consultative Group on International Agricultural Research (CGIAR) represents the international centers with the largest number of plant breeders who develop germplasm and varieties around the globe. They cooperate with universities to advise dissertation projects, but they do not have a mandate for education and do not offer formal coursework (Kush, 2006). For the foreseeable, education of plant breeders in the U.S. will include a large number of international students.

What are the matrices of success?

The critical component for plant breeding is the need and opportunity to educate scientists for the future development of new, genetically-improved varieties. Education is best performed at universities and colleges where students can integrate classroom experiences with and mentor-supervised apprenticeships in dynamic breeding programs. Faculty members have multiple responsibilities to teach, publish scientific findings, create new varieties, and interact with the general public. The multiple components of successful training of the next generation of plant breeders require the support of faculty positions with requirements to create new varieties, train the next generation of breeders, and provide sufficient funding to sustain their programs. Many disciplines depend upon post-graduate research experience to supplement graduate school experiences, and for plant breeders, this could occur at universities or in the commercial sector with companies that have the capacity to train individuals in specific techniques.

Sustaining a viable plant breeding effort in the U.S. will require significantly increased funding for new faculty positions with a mandate to teach as well as to improve crop species that are not being covered by private industry. Salaries for plant breeding faculty must be competitive to permit universities to address retention issues for productive individuals. Faculty need to work at institutions with sufficient numbers of plant breeders to assure a comprehensive curriculum and to give students an option in dissertation topics and crop species. A prerequisite for that to occur is the recognition by granting agencies that plant breeding is a critical, impact science. Lastly, programs such as internships or work-study experiences are needed at the undergraduate level to attract bright students into the discipline.

The missed opportunity if graduate education in plant breeding is not funded

Education is the foundation of the American culture. Failure to educate plant breeders sufficiently to meet national needs will result in lower agricultural productivity, erosion of food, feed, fiber and energy sustainability, higher costs for essential products and a lower standard of living. Plant breeding programs are investments for the future where continual generation of new genetic diversity coupled with selection of the best new plants is required for a full pipeline of new varieties. When a decade or more is required to produce a new variety, program continuity is essential. By the time a crisis unfolds and is recognized it may be too late to protect or revive a critical industry.

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