

The Future of Plant Breeding

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ABSTRACT

A symposium was hosted 10 to 11 Mar. 2005 at Michigan State University to discuss the future of plant breeding education at public institutions. Plant breeding remains a vibrant, multidisciplinary science characterized by its ability to reinvent itself by absorbing and utilizing novel scientific findings and technical approaches. A contemporary breeding curriculum should include hands-on experience with the inheritance and selection of complex traits in actual plant populations, basic biology of plants (reproductive biology, Mendelian genetics), principles of quantitative genetics and selection theory, principles and practice of plant breeding and related sciences such as genomics, applied statistics, experimental design, and pest sciences. Plant breeding education should also comprise several professional skills, including knowledge of other languages, business management, and intellectual property rights. The private sector should play an increased role in the plant breeding. There is also a need for alternative types of training in plant breeding geared toward working breeders and farmers. Additional support for plant breeding education programs may come from the private sector and the federal government. With regard to specialty crops, increased support for research and education may result from a focus on the unique features of these crops. Finally, it is important to cultivate public awareness of the accomplishments of plant breeding.

THERE HAS BEEN INCREASING concern around the world about who will educate plant breeders in the future. To date, much of the M.S. and Ph.D. education in plant breeding has been provided by large public universities in the USA and other developed countries, yet the number of plant breeders at these institutions is steadily declining (Knight, 2003). Support has also declined dramatically for the International Agricultural Research Centers (IARCs) that have traditionally educated students from both developing and developed countries in plant breeding (Khush, 2006).

The loss of plant breeding programs is of great concern to both our domestic plant breeding industry and the international community. The bottom line is that we must sustain a critical mass of applied geneticists and plant breeders at public institutions if we are to maintain our education programs in plant breeding. A symposium, hosted 10 to 11 Mar. 2005 by the Plant Breeding and Genetics Group at Michigan State University, discussed this critical issue, along with the overall education of plant breeders (Hancock, 2006). Several segments of the entire plant breeding community were

represented, including private breeding programs, major commodity groups, international training centers, and university breeders.

This paper reviews the major themes discussed during this symposium including (i) defining plant breeding, (ii) describing plant breeding education and employment, (iii) designing a contemporary education in plant breeding, (iv) supporting plant breeding education programs, (v) addressing the critical needs of breeding specialty and subsistence crops, and (vi) promoting awareness of plant breeding.

Define Plant Breeding

Plant breeding is an applied, multidisciplinary science. It is the application of genetic principles and practices associated with the development of cultivars more suited to the needs of humans than the ability to survive in the wild; it uses knowledge from agronomy, botany, genetics, cytogenetics, molecular genetics, physiology, pathology, entomology, biochemistry, and statistics (Schlegel, 2003). Of particular importance is the ability to transfer, in addition to major genes, large suites of genes conditioning quantitative traits such as productivity and other traits of interest to humans. The ultimate outcome of plant breeding is mainly improved cultivars. Therefore, plant breeding is primarily an organismal science even though it is eminently suited to translate information at the molecular level (DNA sequences, protein products) into economically important phenotypes. The traditional definition of a plant breeder includes only those scientists who develop new cultivars and improved germplasm; however, many feel this definition should be expanded to include scientists who contribute to crop improvement through breeding research (Ransom et al., 2006).

As a science, plant breeding started soon after the rediscovery of Mendel's Laws at the beginning of the 20th century. Since then, plant breeding has evolved by absorbing approaches from different areas of science, allowing breeders to increase their efficiency and exploit genetic resources more thoroughly. Over the years, it has put to productive use progress in crop evolution, population and quantitative genetics, statistical genetics and biometry, molecular biology, and genomics. Thus, plant breeding has remained a vibrant science, with continued success in developing and deploying new cultivars on a worldwide basis. On average, around 50% of productivity increases can be attributed to genetic improvement (Fehr, 1984).

Plant Breeding Education and Employment

During the last decade, several surveys have assessed levels of education and employment in plant breeding (Frey, 1996; Traxler et al., 2005; Guner and Wehner, 2003). Important conclusions have come from these

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studies (Baenziger, 2006; Bliss, 2006): (i) A large majority of plant breeders now work in the private (65–75%) vs. public sector (25–35%) [The Frey (1996) survey indicated a general downward trend in public plant breeding employment with a loss in the 1990–1994 period of 2.5 scientist–year (SY) per year, whereas in the private sector there was an increase in the same period of 32 SY per year. Thus, plant breeding employment has increased overall, but has been accompanied by a shift from the public to the private sector.]. (ii) Plant breeders are predominantly occupied with agronomic (75%) vs. horticultural crops (25%). (iii) Plant breeding students are evenly divided between U.S. and foreign citizens. (iv) Developing countries are increasingly important in plant breeding education and research. (v) Private sector breeders are employed to a large extent (80%) in cultivar development, with the remainder distributed about equally between germplasm enhancement and plant breeding research. In the USDA, the proportions are 12, 48, and 40%, respectively, whereas in the state agricultural experiment stations they are 41, 29, and 30%, respectively.

The number of individuals obtaining degrees in plant breeding is relatively stable in recent years. Guner and Wehner (2003) found that 770 plant breeding degrees were awarded in the USA in the period from 1995 to 2000, with no detectable downward trend. This is an annual average of 154 plant breeding graduates, distributed about equally between domestic and international students. Bliss (2006) estimated that the USA requires 45 to 110 graduates each year, assuming turnover rates of 2 to 5% in the current pool of 2200 plant breeders. Hence, the job market for plant breeders remains quite strong with salaries comparing favorably with other occupations in the agricultural sciences. No full scale surveys of plant breeding exist for the rest of the world, although the demand for new breeders appears to be low in developing countries (Guimarães and Kueneman, 2006).

While the number of plant breeding graduates is currently adequate to meet U.S. and perhaps world needs, the university education programs that will produce the breeders of the future are themselves at risk. The number of plant breeders employed by agricultural experiment stations dropped by 21% just from 1994 to 2001, leaving only 420 plant breeders associated with universities (Traxler et al., 2005). Guner and Wehner (2003) and Ransom et al. (2006) posit that there are now only a handful of institutions in the USA with the critical mass of faculty necessary to offer a complete plant breeding curriculum. The loss of even a few of these programs will mean insufficient breeders for future generations. Thus, we are in a paradox of a strong demand for plant breeding graduates to fill well-paying, scientific jobs, yet public funding and education in this area are declining and will ultimately result in shortages of plant breeders.

Several negative factors weaken the strength of plant breeding programs at public institutions (Baenziger, 2006; Guner and Wehner, 2003). As plant breeders retire, they are replaced by scientists involved in more basic genetic studies. This shift is fueled by the percep-

tion that private sector breeding efforts are adequate to meet cultivar needs. Cuts in University resources have also led to reduced support of field programs. This has pushed the current crop of public plant breeders to shift their activities toward fundamental/basic studies that can be supported by federal grants and the private sector. These negative factors have reduced the number of plant breeding faculty available in the future to teach the range of courses needed to support a plant breeding curriculum.

Other Trends Affecting Plant Breeding

Plant breeding is affected by increasing globalization in two major ways: (i) an increasing commercialization of agricultural products with its additional export opportunities, but also (ii) increased competition from other regions with lower production costs (Morris et al., 2006). Furthermore, new trade rules and the award (or elimination) of subsidies can rapidly alter the competitive climate among countries. Such changes can dramatically alter the value of individual commodities at the international level, increasing or decreasing the importance of plant breeding programs over short time periods (Morris et al., 2006).

The concept of ownership of biodiversity has changed radically during the last 25 yr. Whereas until 1980, genetic diversity was considered the common heritage of humankind, it is increasingly being subjected to laws and treaties that allow institutions and companies employing plant breeders to claim ownership on cultivars (Gepts, 2004). The full effect of this change on plant breeding innovation, germplasm accessibility, and exchange remains to be determined, but it is limiting the exchange of plant materials among breeding programs because of the increase in ownership claims such as patents, plant variety protection certificates, and material transfer agreements.

Overall, public research and development (R&D) investment has decreased but private R&D investment has increased (Morris et al., 2006), which mirrors the employment trends mentioned earlier. Public research programs have also qualitatively changed their focus, as funding has shifted from applied field experiments to genomics and molecular biology. A direct offshoot of these more basic approaches, genetic engineering is presented erroneously as a speedier, more precise plant breeding alternative, whereas genetic engineering is simply another way of generating genetic diversity at the onset of a plant breeding cycle (Gepts, 2002). In short, improved cultivars are still generated through conventional approaches. That is why most agricultural biotechnology companies have purchased breeding companies.

Pursuing genetic engineering as an alternative rather than as a complement to plant breeding has large consequences on choices about R&D investment, education, and employment. This is increasingly apparent in many developing countries, where plant breeders are replaced by biotechnologists (Morris et al., 2006; Guimarães and Kueneman, 2006). These allocation changes will not enhance agricultural production unless a critical mass of

plant breeders remains to translate the technologies into new cultivars.

Designing a Contemporary Education in Plant Breeding

The key to plant breeding education is the exposure to inheritance and selection of complex traits in actual plant populations (Ransom et al., 2006). To fully gauge the challenge of plant breeding, students should witness first hand the effect of selection on the inheritance of quantitative traits as well as the influence of the environment.

The essential categories of scientific knowledge needed by all plant breeders include (i) principles and practice of plant breeding; (ii) Mendelian/transmission genetics; (iii) applied statistics and experimental design; (iv) quantitative genetics and selection theory; (v) production principles and practices for agronomic, horticultural, and tree crops; (vi) pest sciences (plant pathology, entomology, and weed science); (vii) applied genomics, including marker-assisted selection; and (viii) plant reproductive biology (Bliss, 2006; Ransom et al., 2006). Additional desirable areas of lesser importance are (i) biotechnology (tissue culture, genetic transformation), (ii) evolutionary and population genetics, (iii) crop physiology and plant biochemistry, and (iv) cytogenetics. In designing a new curriculum, efforts should be made to integrate newer areas into existing courses, rather than just increasing the number of courses. Plant breeding education should also comprise several professional skills. These include (i) knowledge of other languages besides English, (ii) business management: human resources, priority setting, organizational, and budget, (iii) intellectual property rights, and (iv) leadership and teamwork.

Many university-educated plant breeders will be employed in private industry, requiring greater involvement of private sector plant breeders in public breeding educational programs. New models of collaboration are needed between universities and industry to ensure that new Ph.D. students comfortably fit into the private sector and company breeders can reenter the university as professors (Baenziger, 2006). The private sector can play an increased role in the plant breeding curriculum through (i) participation in thesis and curriculum committees, (ii) guest lectures, seminars, Q&A sessions, (iii) internships with private company breeders, (iv) endowment of professorships or breeding programs, (v) provision of scholarships, and (vi) provision of grants for research, study, or conferences. Novel collaborations could also be forged between universities and plant breeding research institutes, such as the centers of the Consultative Group on International Agricultural Research (CGIAR). The universities could provide basic education in plant breeding, whereas research institutes would provide practical and field breeding experience.

Industry demands individuals with degrees at all levels, B.S., M.S., and Ph.D. Individuals with these different degrees are involved in different types of activity, with lower degrees more involved in program support and higher degrees in technical support and especially

cultivar development. Several other types of education or training in plant breeding are needed: (i) M.S. or M.B.A. degree geared to working breeders; (ii) updates for plant breeders on new technologies such as applied genomics and marker-assisted selection, as well as intellectual property rights and biosafety; (iii) nondegree course work training for agronomic professionals in topics such as breeding practices, basic genetics, and selection theory; and (iv) participatory plant breeding training for farmers (parabreeders) in developing countries with an important subsistence sector.

Supporting Plant Breeding Education Programs

To maintain a critical mass of graduate education programs, new funding sources are needed to support the existing programs (Ransom et al., 2006; Terpstra et al., 2006). The private sector would greatly benefit from more generously supporting the public education programs on which they depend for future plant breeders (Bliss, 2006). One approach is to establish a national fund for graduate fellowships and undergraduate internships in plant breeding that is supported by contributions from many different corporations. Individual companies could also increase the amount of grants they award for cooperative research that directly benefits them. For example, a public breeder is given a grant to evaluate native germplasm that will be used later by an industry breeder for cultivar development, or to identify novel quantitative trait loci for use by the company in marker-assisted breeding.

The federal government also needs to increase support for plant breeding education (Ransom et al., 2006; Terpstra et al., 2006). Federal funds should be used to directly support the elite education programs, stimulate educational linkages between universities, and encourage public–private sector collaborations. The only national program that we are aware of which can be accessed to support this type of education is the most recent National Needs Fellowship Program of the USDA. Many students interested in plant breeding are supported on federal competitive grants, but these funds are generally awarded for very basic projects that are far downstream from actual cultivar improvement. In reality, the students supported by these programs generally get little practical plant breeding experience, as they are committed to finishing projects at the bench.

Addressing the Critical Needs of Breeding of Specialty Crops

Specialty and subsistence crops are characterized by a limited acreage and/or low gross income (Weebadde and Mensah, 2006). However, they fulfill niche markets important for local economies or address specific human or societal needs. Support for subsistence crops presents a particularly thorny problem, as little profit is gained from their development. Such crops are often most important in countries with limited resources. Because of the low gross income, they are generally neglected by the private sector as lacking sufficient potential for eco-

conomic return. As a consequence, the responsibility for research on these crops often falls to public universities and CGIAR centers whose funding base continues to erode. For example, the number of public sector breeders working on fruit and vegetable crops in the USA has declined by 43% over the last decade (Traxler et al., 2005).

To achieve a critical mass of specialty and subsistence crop breeders, there is an obvious need to develop institutional alliances, networks, or partnerships, in the same or most likely different institutions. Each member will have their specialty within the network, including plant breeding. Specialty and subsistence crop breeders often work on more than one crop. Part of the networking may involve nontraditional alliances such as seed saver organizations or small companies. Networks may also involve local farmers or parabreeders who participate in germplasm selection with research centers or public universities (similar to participatory plant breeding). Separate local seed production microenterprises could be set up as well.

New funding opportunities must be developed to promote collaborations among different states and countries so that specialty and subsistence crop breeders work together instead of competing for funds. Federal and international grants could be directed to the special features of specialty crops rather than just the crop itself, such as close taxonomic relationships with major crops (e.g., synteny or small genome size), interesting features such as a role as a medicinal plant, a functional food, a novelty food (e.g., tropical fruit), and as alternative use (e.g., biofuel, alternative source of an industrial product). More patenting and licensing of specialty crops should also be undertaken to stimulate entrepreneurship in the private sector and provide means to collect royalties from licensing agreements. Plant breeding education could benefit significantly by improving the funding base for specialty crop breeding, as the breeders of these crops will most likely be at public institutions.

Promoting Awareness of Plant Breeding

Perhaps most critical to the future of plant breeding is documentation and publication of its key role in the tremendous increases in productivity from the 20th century onward, as documented in the introduction. Urban populations in particular need to be convinced that plant breeding plays a key role in societal well-being, through food security and high quality vegetables and fruits. Raising the awareness of plant breeding by students in urban schools at various levels, from high school to bachelors level students, is a priority. Projects can be developed with federal funding to illustrate the concepts of inheritance and selection not only of qualitative but also quantitative traits using computer models and short-cycle plants (e.g., Wisconsin Fast Plants, www.fast-plants.org, verified 14 Mar. 2006). Plant breeders should speak with a unified voice to capture the attention of the policymakers and the imagination of the public.

Given the expanded role of the private sector in plant breeding, industry organizations should be enlisted to

promote plant breeding and especially, the education of plant breeders. Among these organizations are the American Seed Trade Organization (ASTA, www.amseed.com, verified 14 Mar. 2006), the National Council of Commercial Plant Breeders (NCCPB, www.nccpb.org, verified 14 Mar. 2006), and many commodity organizations.

Plant breeders and their students should also more fully interact with grassroots movements involved in genetic conservation such as Slow Food (www.slowfood.com, verified 14 Mar. 2006), the Seed Savers Exchange (www.seedsavers.org/Home.asp, verified 14 Mar. 2006), Native Seeds Search (www.nativeseeds.org, verified 14 Mar. 2006), Southern Exposure Seed Exchange (www.southernexposure.com, verified 14 Mar. 2006), the Appalachian Heirloom Seed Conservancy (Richmond, KY), the Northern Plains Sustainable Agriculture Society (www.npsas.org, verified 14 Mar. 2006), and more local organizations.

Another source of support to tap is alumni, who can speak firsthand of the accomplishments of plant breeding and can provide advice on how to improve plant breeding education. Plant breeders should work with campus development officers to maintain contact with alumni. In addition, fundraising campaigns should be established to appeal to constituencies or stakeholders to establish endowments that will support education and field-based research.

A national plant breeding coordinating committee needs to be assembled that will establish a roadmap for the future of plant breeding. Ann Marie Thro, CSREES National Program Leader, has begun organizing such a group (www.csrees.usda.gov/nea/plants/in_focus/pbagg_if_multistate.html, verified 27 Mar. 2006). This committee should be composed of plant breeders from both the private and public sector, along with representatives of the major commodity groups and funding agencies. We hope that this group will find the outlined symposium proceedings useful in charting the future of plant breeding. A holistic strategy needs to be developed to strengthen our plant breeding capacity and it is critical that this committee finds a way to communicate the importance of plant breeding to the lay public.

In conclusion, we favor a multipronged approach to reinvigorate the plant breeding education and research enterprise. After a first century of outstanding successes, plant breeding remains a vital science which constantly reinvents itself to absorb new technical and scientific advances. Therefore, it remains an essential part of crop improvement, especially in light of increased demands for food, feed, and fiber resulting from an ever-increasing world population in this second century of plant breeding.

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