

PLANT BREEDING IN THE 21ST CENTURY

>This is a time of significant change for plant breeding and those who practice it. Biotechnology, internationalization, and commercialization, as well as social and environmental concerns, are significantly affecting the profession and endowing it with new strengths and responsibilities. But, even as understanding of the new power and utility of plant breeders spreads to members of the concerned public, the funding base for plant breeding is being curtailed and greatly altered in morphology and mode of action. Challenges to adjust and change are widespread throughout the plant breeding network. The most difficult challenge relates to efficient administration of plant breeding programs and wise selection of appropriate policies, rather than to the technical and scientific capabilities of plant breeders.

by Donald N. Duvick

Genetics and plant breeding have traveled hand in hand ever since genetics became a science. But, to date, genetics has contributed comparatively little to the art of plant breeding, apart from giving plant breeders the conviction that their work was based on scientific fact. It still is true today, just as it was yesterday, that when plant breeders want to raise yields, increase drought tolerance, impart durable pest resistance, improve flavor, increase genetic diversity, improve standability, or broaden adaptation, they rely primarily on art and experience, not on genetics, to get the job done.

Even so, today's plant breeders could not do their job without genetics and geneticists. Ask any soybean breeder or wheat breeder how they would get along without knowledge of the genetics of nematode resistance or stem rust resistance.

It also is true that applications of genetics to plant breeding have increased in number over the years. The list of useful applications grows longer, decade by decade. But also the list of forces affecting plant breeding becomes longer and the forces become more demanding, year by year. The rapidly emerging forces of biotechnology, internationalization, commercialization, and social and environmental concerns create new challenges, especially for administrators of plant breeding programs and makers of policies to guide those programs and the use of their products.

Biotechnology

We now are on the threshold of even greater utilization of genetics in plant breeding. Biotechnology—molecular genetics

and cell biology—promises to accelerate the pace of the advance of genetics into plant breeding. Of course, that promise has been with us for some 15 years. Annually, we note that the sciences that support biotechnology have progressed farther and faster than predicted, while the application of biotechnology to plant breeding is said, once again, to be just around the corner. But now, with insect-resistant transformants in field tests and with molecular marker maps pinpointing the chromosomal location of important quantitative traits in major crop plants, we really are getting close. We soon will have a large new inflow of genetics into plant breeding. Biotechnology is going to be responsible for initiation of that increased inflow.

This prospective increased use of genetics should be viewed with recognition that the emphasis and scope of plant breeding

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have changed through the years. Plant breeders at first aimed only to raise yielding ability of major farm and horticultural crops. Early successes led to monocultural production of a few varieties. Diseases and insects specifically adapted to the widely grown varieties soon appeared and multiplied, and the new varieties succumbed to these pests, sometimes in spectacular fashion. Breeding for pest resistance then became a major preoccupation of plant breeders, and it is still.

Breeders next found that they could develop varieties with adaptation to local or regional conditions. In early efforts to develop varieties for their own locale, they discovered that some varieties were adapted much more widely than had been intended.

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Breeders then were given not only the task of developing varieties for specific environments in specific locales, but also they were asked to develop superior varieties with very broad adaptation.

From the start, breeders were placed under strong pressure to develop varieties that suited the demands of processors and consumers. Wheat breeders had to satisfy the diverse demands of millers and bakers. Cotton breeders had to be concerned about length and quality of staple. So, plant breeders added a long list of quality traits to their set of selection criteria.

Then, just in time for the environmental movement, came the famous 1970 epidemic of southern corn leaf blight. This epidemic convinced the public at large (not just environmentalists) of the dangers of genetic uniformity and the need to increase genetic diversity of crop plants. Plant breeders, after being castigated for causing the lack of diversity, were given the task of increasing diversity.

Internationalization

Still another field of action has opened up for plant breeders and plant breeding institutions. During the past 30 years plant breeding has become international. This is true especially for plant breeders in developed countries like the United States. Breeding methods and even germplasm developed in the United States have found wide application in other parts of the world, in tropic as well as temperate zones, and in developing as well as developed countries.

Many plant breeders in developing countries have come to the U.S. or Europe for training. U.S. breeders frequently have visited developing countries in a professional capacity, and many have spent much time abroad, conducting programs or advising breeders.

As has been stated many times, nearly all of our U.S. crop species originated in other countries, most of which happen to be developing countries. During especially the past 100 years, crop germplasm has moved from developing countries to developed countries to be used in modern breeding programs.

But now a reverse flow, actually a circular flow, of germplasm has developed. For example, sorghum germplasm from Africa has been refined in the United States, gone to tropical India, thence to Latin America, and back again to Africa, with important changes and additions of germplasm occurring at each stopover. The implications of this new mobility of elite germplasm are not yet known. Some believe it will result in an even greater narrowing of the germplasm base, as great expanses of closely related genotypes are grown globally. Others believe it will result in not only more productive but also genetically more diverse varieties and breeding pools, as the world's germplasm base becomes available for all to use.

Increased Commercialization

Still another change, or bundle of changes, has come to plant breeding—commercialization. Professional breeders in the 19th century were observant farmers with a bent for business. But when Mendelism inspired scientific breeding, university and Federal agronomists found ready support for genetics and plant breeding activities and for development of the auxiliary sciences and technologies that support breeding. The best of these publicly employed scientists became professional plant breeders, and they speedily dominated plant breeding, turning out improved varieties with speed and skill that still amaze us as we look back to the early years of this century. These varieties were released to the public. Plant breeding became a public service performed by tax-supported public servants.

The seed companies usually did not do plant breeding. They multiplied and marketed the varieties turned out by the tax-supported public breeders.

Then came intellectual property protection. It appeared first in disguise, in the form of hybrid maize. The ability to make and keep trade secrets, that is, the possibility of developing and using proprietary inbred lines of maize (one form of intellectual property protection), inspired numerous entrepreneurs to start their own seed businesses. The seed businesses were based on sales of unique commercial hybrids, made from unique, proprietary inbreds. Gradually, private maize breeding efforts for private seed companies superseded public maize breeding efforts.

With the invention of hybrid sorghum, then hybrid sunflower, entrepreneurial companies moved into breeding as well as sale of these crop seeds. To some extent, private breeding has replaced public breeding in sunflower and sorghum, but not as completely as with maize. Hybrid wheat was tried but has all but failed, due to

The author, in 1952, as a corn breeder/geneticist examining anthers for signs of pollen sterility.



economic, not genetic, reasons. Hybrid canola (oil-seed rape) is on the horizon. It is too early to know if it will be a commercial success.

Despite commercial success in breeding and sales of corn and a few other hybrid crops, it was obvious that such commercial application could not be duplicated for many important crops, particularly self-pollinated crops. Some other method of protecting commercially bred varieties was needed. Spurred on by European counterparts, seed companies obtained passage in 1970 of the U.S. Plant Variety Protection Act, which gives intellectual property protection to developers of new varieties. Within limits, only the owner of a protected variety can produce and sell that variety. In the 20-plus years since 1970, numerous seed companies have been founded or have added product lines based on breeding and sales of protected varieties of soybeans, wheat, cotton, alfalfa, and numerous vegetable crops. Many new varieties have been placed on the market, bred and produced for sale by these commercial companies.

Progress in commercial breeding of self-pollinated crops has been uneven, however. Breeding and sales of soybean and alfalfa varieties has been a commercial success. Commercial cotton breeding, for the most part, has not been successful. The same can be said for commercial hard wheat breeding. Protection certificates for vegetable seed varieties tend to be concentrated in a few species.

Reasons for lack of success of private breeding efforts vary by crop and by region, but three reasons predominate: small profit margins, pirating (illegal sale of protected varieties), and unprofitably small markets. For some crops commercial breeding has been adversely affected by all three problems. Thus, the Plant Variety Protection Act, by itself, cannot bring about successful commercial breeding for all crops.

The Future

The Public. Plant breeding in all parts of the world has been highly successful over the years. Numerous studies, comparing successive releases of each of the major field crops, have shown steady improvements in yielding ability, as well as achievement of generally satisfactory pest and stress tolerance. The end is not yet in sight. Improvements can and will be made in practically every crop, in the years to come. These prospective gains will be generated by a greater utilization of modern genetics in plant breeding, greater globalization, and increased commercialization and its associated effects on the mix of funding.

But this prediction—that improvements will continue—depends on certain assumptions. The most important assumption is, that the public will want further improvements and embrace policies that make such improvements probable. The public's decision will determine whether people and equipment will be on hand to do the work that needs to be done. Another assumption is that breeding technologies, especially those from genetics, will continue to improve. Such improvements will be needed to overcome the diminishing returns that are bound to come from reapplication of the same old breeding methods, and use of the same old germplasm sources.

One of the most critical policy issues for this country is deciding how much to spend on research like plant breeding and how related programs should be managed. Unfortunately, the public no longer wishes to support plant breeding and genetics with tax dollars in increasing amounts, unconditionally and over the long term. True, millions still are available in continuing funds (formula funds) from state and federal sources, but in constant dollars the

federal funds decrease every year, and increases in state funding are slackening rapidly. It is the case that plant breeding now benefits to a small degree from USDA's recent emphasis on competitive grants. But the rate of increase in all public funds for plant breeding has declined and can be expected to continue to decline into the 21st century. This prospect also is the case in other developed countries, not just in the United States. And in developing countries, government support for plant breeding never has been sufficient, and it will not be in the future, either. Even the international plant breeding research centers, the CIMMYTs and ICRISATs, now are experiencing a steady downturn in funds.

Industry. There is an expectation in the United States that in the future, private industry can and will carry much of the plant breeding load. Industry has not and probably never will pursue substantial breeding programs for many crops. Potential profits on seed sales for many crops are simply too low to attract commercial breeding activity. If genetics and breeding programs for such crops are not supported with public funds, further varietal improvement in them will cease.

Seed companies will give priority to breeding for major crops, like corn, that are important and profitable for their business, but these programs will emphasize research for the short to medium term rather than basic research with its attendant higher risks and longer term payoffs. For a few commodities (wheat and cotton may be good examples), the processing industry will find ways to divert public dollars into support of necessary public breeding, supplemented by small amounts of funds from industry itself. In a few minor crops, important for the food industry, food corporations may initiate their own in-house breeding, as part of a vertically integrated, closed system. But for many lesser crops both private and public funding will diminish. Eventually seed improvement efforts in those crops will be insignificant.

Universities and USDA. Basic plant breeding and genetics research will continue to be the priority attention of universities and USDA and in some cases other federal establishments. Such long term needs would include basic studies in genetics and related sciences, and long term novel breeding projects with low odds of success but promise of great utility if successful. However, it is likely that public formula funding—long-term funding—for plant breeding and applied genetics will continue to decline. Therefore, these research activities will need to be supported, to a much larger extent than now, with short term grants. Hopefully, these grants, competitive and peer-reviewed, will be repeatedly renewed, or newly resourced as needed, in ways that will give essentially continuing support. Competitive grants also increasingly will replace formula funds for applied research and development projects.

The process of garnering the majority of research support from competitive grants will change the base of power for influencing the direction of university and Federal research in plant breeding and genetics. In the United States, the move to competitive grants will diminish the power of state legislatures and Congress. It will mean, however, increased power for those who determine policy in major granting organizations: public, like USDA's ARS and CSRS, the NSF and NIH, and private, like the Rockefeller Foundation, private industry foundations, farm and trade associations, and perhaps environmental and social action organizations. This shift in power may or may not be a change for the better, but it will be a change. Thus, power to influence plant breeding research in public institutions will move from the elected repre-

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sentatives of the people to an oligarchy with makeup and unity of purpose that are not at all clear, at this time. What is clear, is that power struggles are likely to ensue among organizations seeking dominant positions in this new order.

Universities increasingly are assuming many of the trappings of industry, as they protect and market their intellectual products with the help of patents and plant variety protection certificates. They do so for a variety of reasons. In some cases they hope to help build new industries to contribute to the state or regional economies. In other cases the goal is to make profits for the university from patents and protection certificates, as a partial substitute for public funds. In still other cases the activities reflect ties with industry that potentially can compromise the universities' impartiality.

This is a time of transition, and it no doubt will take time for university financial officers and other university administrators to realize that patents alone do not make a profitable business, and that universities as well as faculty can have conflicts of interest. But sooner or later, provosts and deans, working with faculty, will lay out and enforce improved guidelines that help to bring in new funding and encourage efficient technology transfer to industry or other concerned parties while keeping proper emphasis on teaching and research in the public's interest.

It is likely that industry will be a force behind such changes. It needs well-educated, university-trained personnel for its own research groups, and it needs the products of university research, particularly long-term basic research in certain fields. Further, industry will be concerned about competition from public institutions. Perhaps some universities gradually may transform themselves into publicly subsidized business corporations, doing teaching and research on the side. But such changes will be contested by their competitors, the standard, non-subsidized industries.

Public Interest Groups. Another force behind the changes will be public-interest groups, operating in interest of the environment or for social change in rural communities. They will work to increase funding for those kinds of research they deem most conducive to reaching their environmental and social goals. They possibly will use some of their funds for direct support of appropriate research but they more likely will work indirectly to influence policies of other granting institutions. They also will work directly to influence research and teaching policies—and therefore the ultimate funding sources—of public and private research institutions.

Policy Importance. Thus, this country confronts serious policy issues related to plant breeding. The large investments and high payoff for plant breeding in the past cannot be taken for granted for the future.

The rate of increase in funds for public plant breeding has declined and can be expected to continue to decline. Industry funding of public plant breeding research represents only a small fraction of the total needs and typically is only for certain aspects of research.

Seed companies will fund their own breeding for profitable seed crops, but industry will not conduct breeding and research for all crops.

Sources of funding for public research (including plant breeding and genetics) are changing, from long term to short term, from program orientation to researcher orientation. These changes will affect the ability of land grant institutions to pursue their traditional goals of targeted, long term, problem-solving research. Power to influence directions of public research will shift from legislative bodies, over to granting institutions, industry, and public interest groups. C

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