Future Sources of Plant Breeders for Industry[1]

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Introduction

In order to talk about sources of plant breeders for industry, it will be helpful first to present a brief discussion of the nature of the seed industry, how it operates, what products it needs, what kinds of people are needed for plant breeding, and, most importantly, what plant breeding is like today and what it may be like tomorrow.

Description of seed industry and its needs for plant breeders

The term "seed industry" covers a broad range of activities. Today's seed industry is comprised (at the least) of large international seed companies, small regional seed companies, seed production and distribution companies with affiliations to independent "breeding-only" firms, "germplasm brokers" (companies that transfer germplasm from suppliers to users), seed companies that are wholly owned by agricultural chemical companies, closely affiliated but independent agricultural chemical companies and seed companies, and specialty biotechnology companies that provide technical service on contract to seed companies.

Description of plant breeding, yesterday, today, and tomorrow

Plant breeding started as purely an art (i.e., experience and good sense). It moved on to become a science-based technology that used statistical theory for field plot testing, quantitative genetics to plan breeding operations, and that made some use of single factor genetics.

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It has continued to evolve, and now is highly mechanized and computerized. Hand labor is nearly eliminated for many operations, and large portions of the data now are gathered computer-ready in the combine, or in robotized and computer-run laboratory operations.

Most recently, biotechnology has become an essential tool for insertion of novel genes, for tracking germplasm movement in backcrossing programs, and for precise identification of genetic material that is protected with intellectual property rights.

None of the early technologies have been dropped, all remain necessary. Therefore, a well-rounded plant breeder today must know many more kinds of science and technology than were required as recently as 10 years ago, not to mention 20 or 30 years earlier. In actuality, no one person can master all of the science and technology that is needed for efficient plant breeding for the late 1990s. At best. a well-rounded breeder will know some of the specialties, and know how to converse and collaborate with specialists in other parts of plant breeding.

Description of farming as food production, yesterday, today, and tomorrow

Farming, like plant breeding, has become broader in its compass and more specialized in its technology and science. Today's crop and fiber production is much more specialized than in earlier decades. Production is done on a larger scale, and with greater sophistication of machinery and agronomic practices. And farmers are more highly educated and more sophisticated than in earlier years, even in comparison to the 1970s.

Although farm sizes on the average are larger, a significant number of producers grow high value specialty products on relatively small acreages. They grow new crops such as kenaf or quinoa, or old crops in new ways (or with new adaptations of old ways), e.g., "organic " crops (crops grown without use of synthetic chemical pesticides or fertilizers) to be used for food or animal feed.

Crop agriculture can be divided into three broad categories: (a) production of major commodity crops such as wheat, corn, and soybeans, (b) production of crops with a smaller market (sometimes called minor crops) such as grain sorghum, sunflower, and forage grasses, and (c) production of specialty crops such as canola (nearly out of the specialty class), kenaf, or organically grown grains, fruits and vegetables. Plant breeders are needed for genetic improvement in all three crop categories; their goals are similar but emphases vary — yield is of predominant importance for corn, oil percentage for sunflower, and disease and insect tolerance are highly important for organically grown crops.

A new sub-category is appearing, at the moment only in the major crops. Markets are beginning to develop for biochemically differentiated forms of soybeans and corn, e.g., soybeans with different oil qualities, or corn with higher oil content. Breeders talk of lowering the phytate content of feed grains to increase availability of phosphorus in animal feeds. Eventual market size of these products is unknown; some forecast that they will dominate the markets; others are think they will be less important.

Discussion

Needs of the plant breeding industry

National vs. international

To some extent large international seed companies have different needs from regional, smaller companies. International companies need to have some breeders with language skills, or who are natives of countries where the international companies operate. But on the whole, the geographic scale of operation does not determine the kind of breeder skills that are needed; plant breeders in the USA, France, India, Zimbabwe, or Argentina all need the same

basic skills and all find instant compatibility when they discuss their trade over a cup of coffee, or a beer.

Commodities vs. special "value-added" traits

Breeders of crops with "value-added" traits such as "low-sat" soybeans, or Bt corn[3] need extra skills or more likely they need to know how to work collaboratively with scientists with special skills in biochemistry, genetic transformation, or molecular marker technology. Perhaps one might say, alternatively, that breeders who are experts in inserting and tracking value-added genes into crop plants need to know how to work collaboratively with scientists who are skilled in field plot technique and in artful manipulation of germplasm to make farmer-acceptable varieties.

Intellectual property rights

Starting with the Plant Variety Protection Act (PVPA) of 1970, and progressing to use of patents to protect germplasm of all sorts, plant breeding has become thoroughly mired in intellectual property matters. Plant breeders do not need to be lawyers but they need to know how to collaborate with lawyers who are skilled in intellectual property matters. They need to know when to protect their products, and what procedures should be followed for patenting or PVP. And even more, they need to know how to safeguard their protected products. Unauthorized use of protected materials — whether by accident or on purpose — is an inevitable byproduct of patenting and PVP.

Integration in complex corporations vs. interpolation as independents in a complex food production system

The food production system is more integrated than it used to be. Final points of sale have more and more control over supplies, all the way down the chain to the farm. Contracts, sometimes outright ownership, and other kinds of

[3] "Low sat" soybeans have a different kind of oil; Bt corn has a particular kind of genetically engineered insect resistance.

organization are used to give better assurance of product delivery when needed, in desired amounts, and with desired quality. Seed companies find themselves in the middle of these new chains of supply. In some cases, plant breeding departments are included as one part of a wholly-owned, vertically integrated food chain, from farm to super market, or some portion thereof. More typically, seed companies work with contracts or carefully crafted alliances with producers and processors up and down the chain. ("Network" might be a better term than "chain", for essential connections in the food supply system are horizontal as well as vertical; a picture of the entire food supply system might resemble a fish net — or a lace curtain — more than a linked chain.) In any case, plant breeders need to know much more about the food supply system and its operators than used to be the case. Dealing with farmers alone is no longer sufficient.

Role of land grant institutions in training plant breeders

Land grant universities train plant breeders, but the task is much more complicated than it might seem, from the outside.

Research vs. teaching

The land grant universities have a dual responsibility for agriculture: research and teaching are mandated simultaneously, and teaching is subdivided into on-campus teaching of students, and off-campus teaching through the extension services. From the beginning, it has been hard for universities to strike a balance among these mandated duties that pleases everyone. Seed companies, for example, want the universities to produce graduates who can add value to the seed companies, but they also want certain kinds of research products, either finished varieties, breeding stocks, or useful new knowledge about genetics and breeding. But, not surprisingly, the seed companies don't speak with one voice; the needs of smaller regional companies may be different from those of seed companies that are part of an international agricultural chemical company.

Companies dealing with corn or soybeans have a different point of view from those that produce and sell turf grass seed.

Sources of funds

Funding for the land grant universities has changed drastically during the past two or three decades. Assured sources of funds for long term research projects (such as plant breeding) are reduced to the point that they are nearly invisible. Both federal and state funding have been reduced, countrywide, although states vary greatly with regard to how much state support is supplied, and for what purposes. Research success in the universities depends on an adequate supply of materials and facilities but it also requires an adequate supply of industrious, intellectually curious laborers, that is, university research depends heavily on the work of graduate students. Funding support for home-grown graduate students in plant breeding has dwindled or even disappeared; in many programs the majority of graduate students are foreign nationals on stipends from their governments or from foreign aid agencies.

Nearly all biological research, including that in crop science, now depends on peer-reviewed grants, usually with a three-year life span, and no guarantee of renewal. Granting agencies place great emphasis on projects that promise to increase basic knowledge in the science, and discriminate against routine, long-term projects that merely turn out useful products, such as new plant varieties or improved germplasm for use by plant breeders.

In some states, commodity groups raise money, as through check-offs, that is ear-marked for plant breeding and allied research for that commodity. There is no nation-wide uniformity in this practice, and there are no formal guarantees that such practices will continue, even where they are in effect.

Many universities now protect the products of their plant breeding and genetics programs with plant variety protection (PVP) certificates, and patents. Such practices were first instituted in about the 1980s. Intellectual property rights and their royalties can bring income to plant breeding programs, but such

income can be less than it seems, and irregular in nature. Reports have shown that when all costs are taken into account, expenses of administering intellectual property rights programs at the universities nearly always exceed the income from patents and PVP. An occasional patent or PVP certificate can earn large sums of money for a period of time, but to depend on royalties to support a university plant breeding program is somewhat like trying to make a living by playing the state lottery.

The net result of all of these changes in funding is that plant breeding research is poorly funded, and funding for graduate student assistantships (which allow for training of future plant breeders) is insufficient. A further consequence is that students who go into graduate studies in biology tend to avoid a major in plant breeding as such, because of the obvious problems in getting support, either for themselves or for the research of the professor under whom they would study.

Responsibility to general public vs. special clients, such as plant breeding industry

The land grant universities, in addition to their two mandated duties of teaching and research, have two categories of mandated clients: the general public and special groups that can use their products directly. For the general public, the universities need to do research and teaching that (for example) will help agriculture to be more sustainable and environmentally responsible. For special clients, such as farmers or plant breeding companies, the universities are expected to do research and teaching that helps the clients directly, e.g., they should give farmers information that will increase profitability of soybean production, or provide seed companies with research results, or germplasm — or well-trained breeders — that will increase the seed companies' ability to serve the farmer, at a profit.

Inevitably the universities are caught between opposing points of view: those on the one hand, who say that the universities are doing research that is

irrelevant to the needs of agricultural producers or agribusiness companies, and those on the other hand, who say that the universities are nothing but pawns in the hands of large farmers or agribusiness, spending public tax moneys for private gain of the privileged few. And seed companies themselves, as already noted, do not necessarily agree on which kind of training, or what research problems and products, are proper for the land grant universities.

Role of industry in training plant breeder employees

Industry necessarily must do some training of its plant breeders, at the least in company research procedures and sometimes in use of proprietary skills and knowledge. Often, breeders come equipped with knowledge about breeding one crop but are assigned to a different crop; the company needs to train the breeder in the biology, the genetics, and the special selection needs for that crop.

But all skills and all knowledge can become dated, usually because of advancing research and scholarship in the universities. Especially in recent years, with the explosion in scientific knowledge and technology, seed companies find that their breeders are out of touch with new knowledge and new techniques. There are two ways to update the breeding staff. One way is to fire the older, less productive breeders and hire new graduates with up-to-date skills and knowledge. Another way is to send the breeders back to school via a sabbatical, or through collaborative research and study with university staff. Both ways have been tried, but it would appear that the first method is more common, at this time. In either case, the universities are essential purveyors of education and training.

Role of non-land grant universities in training plant breeders

Especially since biotechnology became a part of plant breeding, graduates of non-land grant universities have been hired by seed companies. In most cases these graduates have had minimal knowledge of agriculture and classical plant

breeding but they were enthusiastic about learning how to use their skills to improve plant varieties. When given the right atmosphere to learn and interact with field breeders, the non-land grant graduates have been valuable additions to the plant breeding team. Their numbers are likely to increase, proportionately, in the future.

Biotechnology in medical research, how to apply to plants

Medical research today has direct application to plant breeding; genomics as developed for mammals including humans can identify genes with clear homologies to plant genes. Functions of the animal genes may or may not be markedly different from their plant homologues, but the wealth of information coming from the well-financed medical research establishment increasingly will be useful to plant breeders, even though most of the new knowledge will not have practical application for field breeding projects in the near term.

Broader educational needs: economics, business practices, sociology, languages

Plant breeders have always needed education and skills that go well beyond breeding and genetics. They need to know good business practices, practical economics, and they must be able to express themselves clearly and accurately in speaking and writing. In order to interact successfully with their now broader audience (including, nowadays, energetic critics of many products of modern plant breeding), they need to understand sociology and societal mores and norms. Skill in one or two foreign languages will always be useful, especially as foreign trade becomes more and more pervasive. These skills are needed by breeders in small as well as large seed companies, in regional as well as international companies.

Ph.D. vs. M.S., B.S. What ratios does industry desire?

The first professional plant breeders only rarely had received the Ph.D. degree, and many of them had no college education at all. They were successful in spite of (or maybe because of?) their lack of higher education. As years went

by, new plant breeders for industry usually were required to have at least an M.S. degree, and then a Ph. D. in plant breeding and genetics. Now, seed companies often want people who have post-doctoral experience, and they prefer that it be in a field different from the one in which they took their doctorate.

But at the same time, needs are increasing for top quality people with degrees at about the M.S. level, to do many of the skilled operations with the new kinds of highly technical machinery and scientific apparatus. A high school education is insufficient for this work, and a general purpose M.S. in agriculture or biology may be insufficient, as well.

Traditional plant breeding and biotechnology: use of each

Some people believe we are at a crossroads in regard to the kinds of training needed for plant breeding of the future. Breeders trained in classical field breeding are contrasted to breeders with primary training in biotechnology. What will be the needs for either kind of breeder in the future, or will plant breeding companies require breeders that can do both kinds of work? It will help to look at various aspects of breeding, making guesses as to what kind of breeding will be most useful in the future.

Yield potential

Yield potential, defined as maximum yield that can be achieved in a given environment when constraints to yield have been minimized, still is best increased by use of traditional breeding methods, that is, by crossing best with best, and then selecting rigorously over many environments and years, in the locale where the varieties will be grown. A combination of art and experience, using trial and error, is still the best way to develop varieties with maximum yield potential.

Yield stability

Yield stability is required for expression of maximum yield potential, assuming that one wants varieties that outyield all others, year in and year out. Therefore, developing varieties with maximum yield stability requires the same skills — art and experience — that are useful for developing varieties with maximum yield potential.

Disease and insect resistance

Genetic transformation, with Bt as its prize example, seems to have sidelined traditional methods of breeding for disease and insect resistance. Multifactorial kinds of resistance, or use of single genes from the same or closely related species, seems to be old-fashioned. But use of molecular markers will enable faster backcrossing of single genes for resistance and allow breeders to manipulate them more easily than before, therefore it seems likely that there will be much use of same-species sources of resistance for many years to come. And the probability of pathogen or insect development of biotypes able to overcome single gene resistance seems to have little bearing on the source of the gene; transformed resistance genes probably will become useless just about as fast as same-species genes for resistance. Thus, after initial enthusiasm for the silver bullets of foreign genes for major resistance, breeding will settle down into evolution of optimum mixes of multifactorial and single gene resistance, just as it did before the advent of genetic transformation.

But molecular biology gradually will unlock many secrets of ways to develop longer lasting and superior pest resistance. Major gains in developing such kinds of resistance will depend on plant breeders, entomologists, and plant pathologists with great skill — or good collaborators — in biotechnology; these specialists will be in great demand.

Special traits, grain quality, composition

Biotechnology also will give a proportionately large contribution to advances in breeding for special chemical and quality traits in grains, forages, and fiber crops. But such changes will need to be incorporated into elite genetic backgrounds and thorough testing will be required to be sure that undesired agronomic traits have not been introduced inadvertently by the transformation process, through linkage drag, or even due to pleiotropic effects of the new genes. Traditional and molecular breeders will need to work hand in hand to provide reliable products, prevent undesirable surprises, and do so with maximum speed, in order to keep ahead of the competition. And of course in the background and in the foreground will be the need to be sure that genetically altered varieties are safe for human and animal consumption, thus ties with the medical profession and nutritionists will be essential as well. People with such training will be needed, as part of the plant breeding team of the future.

A telephone survey

I spoke to representatives of seed companies, both large and small, to find out what kinds of plant breeders they need, how they judge the supply to be today, and what they think needs doing to ensure adequate numbers of the right kind of people in the future. I spoke to several university administrators and professors, asking them what they were doing to ensure adequate numbers of suitably trained plant breeders for industry. I also obtained a publicly-released report of a committee organized by a seed company during the past year; the committee specifically asked representatives of several land grant universities what they will need, to ensure continuance or enhancement of field-oriented plant breeding programs in future years. The breeding programs would be useful for training breeders as well as for development of improved crop germplasm. I will summarize the comments from the various groups.

Needs of seed companies

As one might expect, the size of the seed company, whether or not it does its own breeding in-house, and the nature of its major seed products, governed the needs that the seed company administrators and researchers felt to be most pressing.

Breeders of minor crops saw a general reduction in university emphasis on their crops. Trained breeders, as well as finished crop varieties or inbred lines suited to their businesses, are becoming scarce and scarcer. As a consequence, some of the companies are striking up alliances with entrepreneurial breeding firms, such that one company specializes in development of varieties that are leased out to other companies that specialize in production and sales. In this way, they are following the route long since taken by small hybrid seed corn companies in the Corn Belt. Foundation seed companies develop inbreds and recommend hybrid combinations; other companies lease the inbreds and produce and sell their own proprietary hybrids.

But in some cases, the market is too small for even specialized small breeding companies. In such cases, the seed companies say they must have products from the public sector, or they are out of business. The future does not look good for future advance in such "orphan" crops.

Seed company officials (with both large and small companies) told me that small, regional companies will be around for a long time to come; they fill niches that the large internationals can't serve well or that they don't want to serve. They are agile and imaginative, and they will devise ways to collaborate enough to survive while yet maintaining keen competition for the farmer's business. I can testify to this fact for seed corn companies. A recent book has documented that over the years their numbers have stayed high, despite the high visibility of the top five or six companies. Some companies were discontinued, or merged with others, or sold out, but others appeared and took the place of those who left the field.

Larger seed companies are more likely to want breeders with experience in biotechnology, or biotechnologists with knowledge of plant breeding. They now are looking for people with not only a Ph.D. but also with post-doctoral experience. Their representatives often said that the supply of well-trained biotechnologists is adequate, but they have to look hard to find good people trained in field breeding. So in this respect, people from small and large companies agree: the supply of top-notch people with training in field breeding is tight or even too small for comfort.

Representatives from all companies agreed that today's and certainly tomorrow's breeders cannot possibly have mastered all the skills that must be applied in a modern plant breeding program, but they at least must be acquainted with, and have some knowledge about, the full range of sciences and technologies. More importantly they must be good listeners; they must be able to hear and understand what the other specialists have to say about their contribution to the total plant breeding program.

When one tries to describe the skills and training that make a well-prepared plant breeder, it is clear that the answer for today will not be the answer for tomorrow. As one company researcher said, "Plant breeding needs a new definition; it is not like it was. Plant breeders continually will need to learn new skills, either in the company or in the universities." I think I was listening to an argument for continuing education.

Comments from university administrators

University administrators agreed in acknowledging that when biotechnology first began to promise great things for plant breeding (about 15 years ago), too much emphasis was placed on support of laboratory research and training, and field-oriented plant breeding was under-supported. Now, they say, they are placing more emphasis on training breeders in field-oriented, classical kinds of plant breeding, and feel that the balance is about right.

The administrators are worried about funding of plant breeding research and training, however. Funding support seems to evaporate in every direction they turn. For example, people in sciences that give essential support to plant breeding research (e.g., statistics, entomology, plant pathology) no longer are willing to give collaborative support to plant breeding programs. They are opting out for the usual reason — granting agencies won't support such activity because it is too routine and practical; it is not basic research. Breeders are forced to develop their own support in such fields as entomology, statistics, and plant pathology, and this depletes their already hard-pressed research funding base.

Equally important, and directly to the point of this discussion, is that funds for graduate assistantships are seriously inadequate, particularly for training in classical plant breeding. The administrators said that in a few instances private industry is ear-marking grants for such training, but that much more help is needed.

Some administrators said that it is time to consider training breeders in collaboration with industry, that industry could furnish materials and facilities for the students in ways that no longer can be done at the universities. Industry would need to work out ways to protect confidential information and germplasm, but since they already are working out agreements on the same topics for collaborative work with other members of industry, it might be fairly easy to do the same for work with students and faculty of the universities.

The university administrators are worried about how to fund research and training in breeding of the minor crops. Some suggested that the universities need to specialize and cooperate in research and training for the minor crops, dividing up the minor crops so that one university (for example) does oat breeding for several states, another handles alfalfa breeding, and so on. In some cases this kind of collaboration has begun already, but much more is needed. It is very hard for the land grant universities to break out of the habit of

serving only their own state, especially when they have to depend on state legislators for a large share of their total income.

None of the administrators seemed to fear that industry was unduly influencing their research and training programs. If anything, they said that industry was not talking to them enough about its needs; the administrators had to find out for themselves what needed doing, to properly serve the needs of agricultural industries.

The administrators said, however, that there still is some pressure on them to continue development and release of finished varieties. The requests come from small companies with no breeding programs of their own. But the administrators seemed disinclined to respond to those requests, saying that scarce funds need to be used in other ways that, in the long run, would be more helpful to the seed business as a whole.

Some of the administrators see problems arising in their plant breeding programs because of the current systems of allocation of royalties from PVP and patents. A usual formula is that the researcher gets a large share (perhaps one-third or even one-half of royalties, after expenses are taken out), the university administration gets a share, and the local department gets a share. In the case of plant breeding, where collaboration with many specialties and many scientists is required, many of those who made essential contributions are left out of the royalty stream. As one administrator said, “How about the extension worker who helps to advertise the variety, or the entomologist who helped to prove its worth?” Not surprisingly, this practice leads to lack of collaboration on the part of those who were left out, and to unproductive secrecy on the part of those who hope to become royalty-earning inventors. Such a trend is particularly inappropriate, now that plant breeding — both public and private — requires increasingly more cross-disciplinary collaboration.

Comments from university professors

The university professors were much more pessimistic than the administrators, about present and future prospects for training adequate numbers of plant breeders in classical techniques, but they agreed with the administrators, in saying that funding is no longer available for classical plant breeding, or for any kind of project that requires many years of single-minded effort to achieve its goals.

The professors were not happy with the current tendency, as they see it, for new faculty to be hired to do both field breeding and biotechnology in support of that breeding. They believe that it is a mistake to expect faculty to be both field breeders and laboratory investigators; they say that either of the specialties is a full-time job and that anyone who tries to do both will end up doing neither.

An extremely disturbing complaint from some of the professors was that the quality as well as the number of applicants for graduate study in plant breeding is low, and going lower. They said that the best of the science-oriented undergraduates in agriculture are going into laboratory sciences, not field-oriented plant breeding. And many top students are leaving college with an undergraduate degree, in order to take a high-paying sales job with agribusiness. In either case, they are going where the money is.

The plant breeder professors say that as a consequence, no one today can turn out a succession of field breeders in numbers and quality that were produced by now-retired plant breeders in the previous two or three decades.

They say that industry is looking for breeders but they cannot supply the demand. At the same time, they wonder how serious the seed industry really is, about wanting field-oriented plant breeders, as they look at recent layoffs of mid-career field breeders with no corresponding lay-offs of biotechnology staff. At best, the professors seem to get little encouragement or help from industry, to enable them to supply industry's needs for plant breeders of the future.

The professors are not happy with what they see as an overly-optimistic expectation at top levels of administration, for royalties on protected varieties or patented products and processes. They believe such dependence will hinder plant breeding research, both applied and basic, and this will have a correspondingly depressing effect on training of new plant breeders.

A final point, the professors think the seed industry and the commodity groups could do more, to aid them in training plant breeders for the future. They say this could be done with political pressure on legislative bodies, with in-kind aid such as on-site interning of graduate students, with industry-donated funds such as grants for graduate study, or with check-offs ear-marked for research support.

Conclusions

Plant breeding will be much broader in scope and potential than in the past, because it will incorporate new technologies and new knowledge from other fields of science

Cultivar development increasingly will be done by industry, in both large and small companies organized in various ways, with varying degrees of vertical integration and interlocking functions

Plant breeding will continue to need breeders trained in classical methods of field breeding and selection — the need will be greater than before, because products of the new sciences will be useful only when they are established in high yielding, dependable genotypes containing a multitude of other essential traits

Prospects are poor for supply of adequate numbers of top-quality, well trained plant breeders for field-oriented plant breeding, largely because previous funding sources have dried up and new sources have not been found

Industry could do more to help, both as individual companies and through its trade organizations