# Plant Breeding: Research and Education Agenda[1]

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## *Introduction*

I want to start this paper by explaining my biases and my current position. This will be helpful in understanding my position and perspectives on research and education in public plant breeding. I am the director of the Raymond F. Baker Center for Plant Breeding and the Pioneer Distinguished Chair in Maize Breeding. Both the center and the chair have been funded with gifts from either a private company or an individual that worked for a private company.

As a maize breeder I work with a crop that has the largest private investment in breeding of all crops. Frey (1996) showed that 25% of all the breeders in the U.S. were corn breeders. Much of my funding comes from the private sector and I have done paid consulting with the private sector. It is important to note, for me at least, that my interaction with the private sector rarely if ever involves germplasm exchanges. Most of my interactions with the private sector involve statistics, breeding methodology, and basic quantitative genetic research.

My general policy has been not to incorporate private germplasm into my breeding program. We do, however, use private inbred lines as testers for evaluating our elite inbreds in hybrid combinations. We do this to demonstrate performance to private industry breeders. Although you must sign a contract to access our new germplasm, you are free to breed with the germplasm and farmers may use it on their farms as long as nothing gets sold.

My assignment for this paper was to explore what kind of research and education agenda we need in plant breeding and how we go about implementing the agenda. The fact that we have to ask this question implies that something is or may be wrong with the current research and education agenda in public plant breeding. Whether or not a problem exists is probably more of a function of where you are at in the system and your perception of your impact and success. If you are a plant breeder at a public institution or agency you will measure success by funding, publication output, and germplasm releases. If you are a producer you will measure plant breeding success primarily by the availability of new cultivars that fit you requirements and perhaps in amount of information that flows your way.

My biggest discomfort during my 23 years in the

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plant breeding business has been the inability of plant breeders to document their impact. If we cannot demonstrate and articulate to the public at large, and this includes other scientists in the public sector, the impact of plant breeding programs, then the discipline of plant breeding as described by Tracy (2003) will almost surely disappear. As I look at the nationwide loss of corn breeders since I joined the business as a graduate student in 1980, I can only conclude that the elimination of public corn breeding positions by administrators was due to a perceived or real lack of impact in the breeding program. The administrative rationale for this is not hard to imagine. A corn breeder at a public institution retires, the administrator sees many private sector corn breeders, producers purchase nearly 100% of their corn seed from the private sector, the administrator does not see any evidence of past, immediate, or future impact of the position, the constituent groups are passive and do not speak up for various reasons, and the position gets converted from a breeder to something that at least seems to have a higher profile, ability to attract funding, and more immediate impact.

Versions of this scenario have been repeated many times and in many crops independent of whether there is a commercial sector involved with the crop. Little has been done to objectively analyze why this trend is occurring, except to blame it on a lack of funding for public plant breeding. The lack of funding is almost always the reason given for the demise of public plant breeding and for the inability of plant breeders to do their job. The question that then comes to mind is "if we give base level support to public plant breeding programs will that improve the output and quality of our public plant breeding programs?" My immediate answer is funding alone would have little or no impact on the output or quality of our public plant breeding programs.

This paper will be divided into several sections with each section addressing a pertinent question pertaining to the research and education agenda in public plant breeding. The questions will be: What is plant (and animal) breeding? What are the research and education models currently used in public plant breeding? What is needed to be successful? What about education? Why are there fewer plant breeders today? What are the major research questions that need answers? What is the role of the commercial sector in public plant breeding?

## *What is plant (and animal) breeding?*

Tracy (2003) has given an excellent overview of what plant breeding is and how it is conducted. Rather than reiterate what he has said I just want to make two points about plant breeding. My standard definition is that plant breeding is the art and science of plant improvement. The root of the word art is doing and the root of the work science is knowing. Together this implies that plant breeding is done by people who have actively studied or are researching the underlying biological mechanisms involved in plant improvement. The art and science of plant breeding brings together the application, educational, and research aspect of plant breeding.

The practice of plant breeding, however, has been primarily concerned with separating the environmental component of phenotype from the genetic component of phenotype. Much of the research done over the past 75 years has been devoted to the statistical and quantitative genetic aspects of understanding this fundamental relationship. This is usually referred to as understanding the inheritance of the traits that are of interest. Unless this relationship is understood and appreciated it is doubtful that much genetic progress can be made in crop improvement.

An example from our research program on grain quality illustrates what I mean. In conjunction with Dr. Paul Scott, USDA-ARS, we have embarked on a selection program to improve the lysine, methionine, and tryptophan content of corn using conventional breeding methodology. We want to avoid using single genes because of known "side-effects" of these genes and instead have chosen the approach that Tracy (2003) has so well described. The major limitation in applying this methodology has been absence of cheap and fast analytical techniques for measuring amino acid content. Dr. Scott has developed some cheap high throughput methods, but before we can develop a breeding program around this technology we need to assess the repeatability of the methodology. If the measurement errors of the analytical methods are greater than the genetic variability we will not be able to make genetic progress for amino acid

content. Likewise, if there is no genetic variation for amino acid content in our germplasm we also cannot make progress from selection. Fortunately this kind of research can often be conducted simultaneously with the design and implementation of the breeding program.

### *What are the current research and education models used in plant breeding?*

Plant breeding research for most major agronomic and some horticultural crops in the U.S. has been heavily influenced by the USDA-ARS. Most of the USDA-ARS plant improvement programs that I am aware of are located in conjunction with a land-grant institution. In many cases, USDA-ARS scientists are located and housed with state scientists. In other cases, ARS scientists are housed in federal buildings on state campuses. But there are exceptions to this rule and some federal scientists are in federal labs that are not associated with a land-grant institution.

Because the USDA-ARS is a research organization without an educational component, the association of ARS scientists with land-grant institutions has in most cases increased productivity above what would have been achieved with an equivalent number of scientists of either institution alone. ARS scientists have a 100% research appointment, are not required or even allowed to teach a course, but have the benefit of being affiliated with an educational institution and being associated with graduate students. State scientists have the benefit of teaching, conducting research, educating graduate students, and being associated with well funded scientists that are research oriented. The continuation and survival of this relationship is in the hands of state and federal administrators who often seem unaware of the synergistic effect these relationships have had.

This influence of this relationship on the corn improvement program at Iowa State University started in 1922 and has continued uninterrupted to the present day. The program has frequently been cited as a model for federal-state cooperation and has been responsible for the development of the breeding infrastructure that currently exists in the corn program.

I am convinced that this cooperative federal-state model survives because of the emphasis on research that comes with being associated with the USDA-ARS programs and education that comes from the state programs. Research drives the funding in this model because output from research is much easier to document than output from breeding programs. The USDA-ARS requires its scientists to not only conduct research and but to also publish the research. State programs are often much more lenient on publication requirements especially after tenure has been received. The breeding program is then conducted to support and feed the research program. In this model research funding is what pays for the breeding program. Cultivar and line development programs can be maintained as "spin-offs" of the overall research program.

The second major model is the state breeding program with no associated federal component. These programs are funded primarily by commodity boards and/or end users such as millers or processors. Wheat and soybean breeding programs are excellent examples of these kinds of programs and frequently have strong and successful cultivar development programs. Since funding comes from end users, the focus is on breeding new cultivars or conducting breeding related research to solve producer problems. These programs also have strong research programs driven by the money obtained for breeding. Funding for this model tends to be more variable because of the source.

The third model we see is state scientists working on important and widely grown crops that are not cash crops. Most of the forages falls into this category as do the so called 'minor' crops. Because there is no strong commodity or industry support these programs are funded primarily through external grant support. Small breeding programs can be associated with programs funded in this way, but the rigors of running a grant preclude the development of strong breeding programs.

Other models exist of course and there are continuous gradations between the three models. Even within a crop we see large variation in the strength and funding levels of breeding programs. There is no single reason to which we can attribute this variation. We can however, outline the basic requirements for a program to be successful.

## *What is needed to be successful?*

I have identified five areas that are needed in order for public sector breeding programs to be successful:

- Research
- Breeding Programs Designed To Feed In To Research Programs
- Continuity In The Breeding Program – Build On Past Results
- Accountability
- Documentation of Impact (Quantify)
- Connecting With Other Areas Of Science
- Synthesis

It is clear to me that a strong research program has been a key factor common to most of the successful plant breeding programs across all crops in the U.S. It is no longer possible at most public institutions for breeders to run cultivar development programs that are not associated with strong research programs. The USDA-ARS has always used this model and has well defined research performance requirements. Although this does not maintain quality research it does keep the focus on research.

Depending on the research interests of the breeder, the breeding program can be designed to both feed the research program and develop improved germplasm. Once the breeding program is developed it is important to maintain continuity. The lack of continuity in breeding programs is frequently the cause of their poor performance. Breeders need to set and define clear objectives and design their breeding programs to obtain those objectives.

The next two requirements accountability and documentation of impact go hand-in-hand. Breeding programs must be accountable for the financial, physical, and personnel resources that have been allocated to them. We must be transparent in the use of those resources and clearly articulate what we have accomplished and why it is important. Agriculturists in general have been very modest about their accomplishments and we need to change this.

Documentation of impact in research programs is generally easier that it is in breeding programs. Impact in research programs is usually measured by the quantity and quality of published peer-reviewed manuscripts, the frequency that your manuscripts get cited, and the adoption of your science. Documentation of impact can be more difficult in breeding programs and is crop dependent. In hybrid crops like corn, where pedigrees are kept secret it is very difficult to assess the usage of germplasm from various sources – particularly if the germplasm is publicly released. One of the most important uses of germplasm licensing in hybrid crops is to track and quantify germplasm usage. If private companies want to see public hybrid breeding programs survive they must assist in this documentation. This same problem can exist in some self-pollinated crops as well, particularly if there is a strong private breeding effort. The important point is that we need to develop effective methods to convince administrators and the public that we are having an impact. If we are not having an impact why do we need to exist?

Plant breeding needs to do a better job of connecting with other areas of science. I for one, have frequently lamented the loss of funding for plant breeding to biotechnology in the 1980s. In reality I am not sure this ever happened. The important point to realize is that all biotechnology applications must be delivered through a plant breeder. Plant breeders therefore need to be part of the conversation and have a say in the type of applications that get developed. This does not mean, however, that we turn plant breeders into biotechnologists.

Plant breeding is a synthetic field which makes it very difficult for people to conceptually grasp. In this way it is very similar to the field of evolution. For example, evolutionary biologists have taken it upon themselves to write numerous popular articles and books about the subject in an attempt to explain evolutionary biology to the public. Plant breeders need to do the same. It is very difficult to get people excited about something they do not understand.

## *What about education?*

So far I have said little about education, but it is implicit in everything I have discussed. Good plant breeding education programs can only exist in the presence of high quality research programs. It is important to remember that both the M.S. and Ph.D. degrees are research degrees. In order for students to be awarded one of these degrees they must conduct a research project. What this means is that we cannot justify the existence of a plant breeding program on the need to educate (or train as many like to say) plant breeding majors. If you did not have a functional research program but did have a strong plant breeding program and someone gave you money for a graduate student, it would be very difficult to get that student a degree.

We need to do a better job of preparing undergraduates for a career in plant breeding. Many students graduating with B.S. degrees in traditional agronomy and crop science majors are not adequately prepared to obtain an advanced degree in plant breeding. These students are usually deficient in the biological sciences, mathematical sciences, chemical sciences, programming, and writing. All of these skills are required to be effective in research.

## *Why are there fewer plant breeders today?*

The most common reason given in answer to this question is funding. Funding may be the immediate and local cause but it is not the global cause. Research priorities shift and funding streams shift with them. The reasons for these shifts are numerous, but funding rarely shifts away from research that is perceived to be having an impact or is actually having an impact. I contend that at least part of the funding shift from plant breeding has to do with our failure to document impact. Another part has been due to a lack of outreach associated with this impact. We need to tell people about the good things we are doing for them, because it is unlikely they will discover this on their own.

There has also been a fundamental shift in the way land grant universities operate. State funding is becoming a smaller piece of the funding pie at land grants. Fig. 1 shows the funding sources for Iowa State University for five academic calendar years. It is clear that state appropriations are slowly going down while tuition and contract and grants are increasing in importance. Universities have also been given economic development charges from state legislatures which serve only to complicate the land grant mission.

Although the USDA-ARS has enjoyed strong funding support from congress, ARS is housed within a policy organization and research is often susceptible to shifts in public policy. This is frequently a function of the fact that plant breeders as a group have had no effective lobbying voice.

## *What are the major research questions in plant breeding?*

There are still many unanswered questions regarding plant improvement and I cannot itemize all of them. I would like to bring out a few of them particularly in the context of sustainable and organic agriculture. The questions below are ones that have come up as I have interacted with sustainable and organic farmers and scientists on the interface of corn breeding. Because breeding programs need continuity, efficiency, and good management to be effective answers to these questions are important to obtain.

### *Do we need to breed under low-input sustainable and/or organic conditions?*

Certainly the sustainable agriculture and organic community thinks that we need to and that is understandable. Unfortunately there is little evidence to support the need. I argue that we need to develop good solid scientific evidence to answer the question.

### *How do we identify and prioritize the traits that we select for?*

We need to set consistent and achievable breeding goals that matter. The more simultaneous traits that we add to our breeding goals the more time it will take to develop useful cultivars.

### *Can farmers make progress selecting their own varieties on their own farms?*

This answer depends on how you define progress

and what the expectations are. It is important for people to understand that modern cultivars have had a tremendous amount of effort put into their development.

**How do we distribute seed of publicly developed cultivars?**

This is a crop to crop problem, but is particularly acute in cross-pollinated crops such as corn and alfalfa. Even if I developed a superior corn hybrid, I have no mechanism for delivering that hybrid to farmers.

**We need research on developing efficient screens for the traits we want to select for.**

The success of a plant breeding program is directly related to how easy it is to measure a trait. We are good at yield because we have spent years developing efficient ways to measure yield

**Where does the commercial sector fit into public plant breeding?**

This is complicated question, particularly for those crops with a large commercial presence. There is no single answer to this question. It is important to note, however, that the failure of plant breeding programs in developing countries is most often related to the collapse of public and private seed companies. Plant breeding is utterly useless if the seed cannot be gotten to farmers - and this is the role that the private sector has fulfilled in the U.S. There are all kinds of sub questions related to this one:

Do we need public plant breeding when there is a significant commercial presence?

Will public plant breeding programs be perceived as being in competition with commercial plant breeding programs?

Who are the benefactors of public plant breeding programs?

**How do public plant breeders divide their time between research and plant breeding?**

This is certainly a funding related question. As I mentioned earlier, if all of my money came from grants and contracts, I would have to spend nearly all of my time on research and managing those grants and contracts. A good balance is needed, but it will be driven by funding sources.

**Who does plant breeding outreach?**

Someone needs to be charged with telling the public about the output from plant breeding research programs. Plant breeders can do some of this, but it is very time consuming. There needs to be a reexamination of the role of extension in universities. Traditionally extension has not done much with breeding and genetics.

## *Summary*

The research and education agenda in public plant breeding must include the following features:

- Public Development of Useful Traits
- Delivery in Useful Germplasm
- Freedom To Operate
- Equal Access By All

All four of these features must be present for there to be success. These are also the same four features that must be present for public sector biotechnology to be successful.

## *Acknowledgements*

I have had the benefit of conversations with many good friends over the years that have helped to shape my opinions on plant breeding. I take full responsibility for the opinions expressed in this paper. At the risk of leaving someone out, I would like to thank: cvc

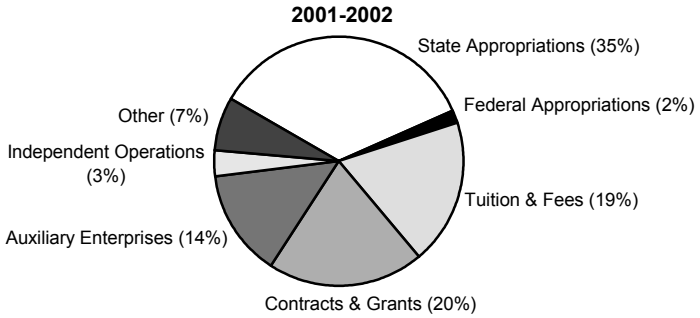
## *References*

Tracy,W.F. 2003. What is plant breeding? (this volume)

IOWA STATE UNIVERSITY

# Revenues by Source (in thousands)

*Fiscal Year*




| | 1997-1998 | | 1998-1999 | | 1999-2000 | | 2000-2001 | | 2001-2002 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DOLLARS | % | DOLLARS | % | DOLLARS | % | DOLLARS | % | DOLLARS | % |
| **Revenues** | | | | | | | | | | |
| State Appropriations | $250,297 | 39.9% | 262,550 | 39.8% | 273,627 | 39.6% | 281,459 | 38.6% | 259,648 | 35.1% |
| Federal Appropriations | 11,279 | 1.8% | 11,899 | 1.8% | 12,193 | 1.8% | 10,802 | 1.5% | 12,302 | 1.7% |
| Tuition and Fees | 98,067 | 15.7% | 102,696 | 15.6% | 109,365 | 15.8% | 118,332 | 16.2% | 139,251 | 18.8% |
| Contracts and Grants | 118,072 | 18.8% | 124,346 | 18.9% | 131,615 | 19.0% | 139,990 | 19.2% | 151,154 | 20.4% |
| Auxiliary Enterprises[1] | 79,864 | 12.7% | 85,659 | 13.0% | 94,974 | 13.7% | 103,649 | 14.2% | 101,313 | 13.7% |
| Independent Operations[2] | 25,902 | 4.1% | 26,132 | 4.0% | 26,332 | 3.8% | 25,317 | 3.5% | 24,433 | 3.3% |
| Other | 43,076 | 6.9% | 46,167 | 7.0% | 42,989 | 6.2% | 48,716 | 6.7% | 52,371 | 7.1% |
| **Total** | **$626,557** | | **$659,449** | | **$691,095** | | **$728,265** | | **$740,472** | |

[1] Auxiliary Enterprises: activities that exist to furnish goods and services to students and staff, essentially self-supporting, e.g., Iowa State Center, Residence System, University Bookstore.

[2] Independent Operations: operations that are independent of but may enhance the mission of the university: Ames Laboratory.

*Office of Institutional Research (Source: Office of Controller)*

Figure 1. The source of funding revenue by sources for Iowa State University. (http://www.iastate.edu/~inst_res_info/FB03files/finfac.html)