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WHAT GENETIC AND GERMPLASM STOCKS ARE WORTH CONSERVING?

Major M. Goodman

Abstract: *Essential genetic stocks range from world germplasm collections of our major crops to genetic stock collections of experimental species such as* Drosophila melanogaster. *Not every accession of every major and minor crop, nor even all genetic stocks of our most important food crops can be conserved indefinitely. Nor can every ecological niche be protected, even though they may be harboring potentially useful and important but nondomesticated species. Even in the absence of scientific criteria for selecting appropriate germplasm accessions and assembling appropriate experimental genetic stocks, germplasm and genetic stock curators must constantly make critical decisions upon which entries are to be conserved on a constant basis. This discussion provided a framework for assigning some priorities.*

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I appreciate the opportunity to address the possibilities of choosing appropriate collections for maintenance, especially considering the problems that we are faced with in maintaining these very large collections. Obviously progress from plant and animal breeding depends upon germplasm, and indirectly it also depends upon genetic stocks. There are some big differences between germplasm stocks and genetic stocks in terms of difficulty and expense of maintenance and in the degree of demand for samples.

Germplasm stocks, generally speaking, usually consist of farmer varieties, landrace accessions, and wild or weedy or feral relatives of economically important (or potentially important) plant and animal species. Germplasm stocks may be used in basic research, but their most frequent use is for applied research involving, at least conceptually, improved plant and animal lines, breeds, varieties, or hybrids. Progress from breeding, genetics, physiology, and biochemistry depends to a great deal upon basic research conducted using our genetic stocks. These are mutant stocks, translocation and inversion stocks, various marker stocks, linkage tester stocks, *etc.* The two sets of stocks (germplasm and genetic) have to be handled very differently and represent very different sorts of problems and very different sorts of potentials, but they are both extremely important. But ultimately, in either case, future forms of these stocks depend on available genetic variations.

Germplasm stocks of most of our major agricultural and horticultural crops are being used for both breeding and basic experimental work. Table 1 lists the currently most utilized germplasm collections, while Table 2 lists the most important genetic stock collections. Animal germplasm collections are much less centralized than plant collections, but exotic (imported) landrace stocks of cattle and swine are making important contributions to breeding programs. Major animal species are not generally used to establish genetic stocks (such as markers and mutations) in the way that maize and tomato have been. Mice and *Drosophila* serve as substitutes.

Table 1. *Germplasm Collections Being Used Extensively for Breeding and/or Experimental Work*

Coffee	Maize	Potato	Sugar Cane
Conifers	Millet	Rice	Tobacco
Cotton	Oat	Sorghum	Tomato
Fruits/Nuts	Peanut	Soybean	Wheat

The use of the germplasm stocks listed in Table 1 varies greatly over time, depending upon the demands imposed by various disease and insect epidemics. Wheat has traditionally suffered periodic epidemics of both diseases and insects; thus, wheat germplasm stocks have been widely used for breeding. In contrast, maize germplasm stocks tend to be used as much for basic research as they are for applied research; maize has had many fewer widespread epidemics than wheat.

The uses of rice, potato, tomato, soybean, and sorghum germplasm for applied research is also extensive. For tomato and potato, use has even been made of wild relatives in breeding work, a practice that is extremely rare — virtually non-existent — with maize's relatives (teosinte and tripsacum).

In the past, humankind depended on an estimated three- to five-thousand species of plants. That has a message to us because today we are using only several hundred species of plants. In fact, we are obtaining the most part of our caloric intake from roughly 15 species of plants. These include most importantly cereals, grain legumes, and potatoes. The future of humankind depends vitally on those particular stocks.

Within a given species, as plant breeding has progressed, we have begun depending on fewer and fewer cultivars. I can speak with authority on only one crop, and that is maize. In the New World there are something like 300 races of maize. But, in fact, the maize of commerce represents only six of those 300 races, and the maize of commerce of the United States represents only one. We are relying on the use of a very narrow germplasm base in the United States and in the world. Within that one maize race used in the US there were, in the early 1900s, thousands if not ten thousands of open-pollinated varieties of maize distributed all over the US Corn Belt. Essentially farmers or regions had their own group of varieties used for specialized purposes. With the large-scale development of plant breeding in the early 1900s and the development of inbred lines for use in hybrids, only a few of those open-pollinated varieties were widely used in corn breeding programs. In particular, only two or three made very substantial contributions to corn breeding. Many of our hybrids today are represented by crosses between lines derived from the open-pollinated variety Reid crossed with inbred lines derived from the open-pollinated variety Lancaster. It is virtually impossible to find a hybrid that lacks a parent from either Reid or Lancaster. There are about six inbred lines and their close relatives that are represented in a very high percentage of all US hybrids. I cannot give you an exact percentage because it is not documented, but it probably represents well in excess of 50% of the planted acreage.

Most crops are not hybrid crops and they do not depend on inbred lines, but the general story is true of virtually every crop. We have a wide diversity of genetic variability among primitive cultivars and historic cultivars. We have a much lower degree of diversity among our recent and prospective cultivars. Basically we are increasing productivity at the cost of variability; this is true of virtually every crop. It is also true of all our domestic animals. Furthermore, most of our breeding work consists of crosses of elite lines by elite lines. When things turn desperate, we search our more primitive materials for a source of disease or insect resistance, and then go through a backcrossing scheme to backcross that insect or disease resistance into elite materials. For this purpose we badly need access to adequate germplasm collections, but this need does not really serve as sufficient motivation to broaden our germplasm banks.

Disease and insects show no signs of ceasing to evolve around cleverly designed defense mechanisms, whether they be plant resistance imposed by traditional breeding or pesticides engineered by Du Pont or Monsanto. While molecular genetics may temporarily change this, plant and animal breeders, who, after all, have practiced genetic engineering for a century now, recognize that most resistance is temporary. As a result, germplasm stocks in demand today are likely to remain in demand tomorrow. There are a number of germplasm collections which are widely used. Dr. Rick is going to speak to you next, I believe, about the extremely important collections of tomato that he maintains. In fact, tomato is one of our pleasanter stories in germplasm collection, maintenance, evaluation, and utilization. In addition, potato has an interesting story behind it. Those collections have been very well maintained, but for many other crops the status of germplasm accessions is much less pleasant a story.

...critical germplasm

Answering the question of which germplasm stocks are important to maintain is reasonably easy. We can quickly answer which ones are critical: most of those in Table 1. What we cannot do as easily is respond to the problem of which accessions and which geographic areas need sampling and how many accessions are actually needed. For that, more scientific information is needed than we often have available. That a choice must be made is reasonably obvious, and I would like to use an example, again from maize. A maize breeder in a given year can adequately maintain about 30 collections (500 plants per collection, 250 hand pollinations per collection, 100 good harvested ears per collection). Thus, in a lifetime a maize breeder can maintain about a thousand collections. In the New World alone there are about 30,000 maize accessions, and there are four scientists doing the work. A very small amount of arithmetic says that some choices have to be made.

...composite and core collections

There are excellent germplasm facilities available that allow us to keep seeds of most germplasm accessions for a very long time. However, if we are going to have active distribution from these facilities, then we must have some way of replenishing the seed. There are several methods of tackling this problem that lessen its impact. One is to make geographic composites. Another, in the case of maize, is to make racial composites. Another is to identify sets of core collections, *i.e.*, representative collections that span the range of genetic and ecogenetic variability present, and to work more intensively with those collections. Thus, those collections would be distributed routinely in preference to a larger set of backup collections which would be held for essentially final insurance purposes rather than for routine distribution.

An important point needing to be made is that whenever these germplasm collections are sampled, only a very few, usually one to five percent (often much less), meet the criteria that the particular investigator is looking for. Nevertheless, it is desirable for crop germplasm curators to select and emphasize a subset of accessions representing the diversity of a crop. It would be desirable to have identified and available sets of 25, 50, and 100 accessions, each set representing, as much as possible, the diversity of the crop, in order to respond to the most typical types of requests. Such requests usually begin, "Please send me the (10, 15, 20, 50, or 100) accessions of (maize, wheat, rice, *etc.*) which most encompass the variation of the crop."

If it is impossible to evaluate, adapt, or in the worst of cases, regenerate all accessions, then first emphasis should be placed upon core collections. While composite populations which represent combinations of individual accessions, such as the racial composites in maize, are often helpful for screening for general utility of germplasm materials, maintenance of individual accessions is essential, both for plant breeding and for basic research. Most genes of special interest are important because of specific rare alleles or, worse, specific combinations of rare alleles; the common alleles have already been captured by breeders, geneticists, pathologists, *etc.* Studies by numerous population biologists, many trained at Davis, California, by our chair, Bob Allard, have clearly demonstrated that many, if not most, such rare alleles are present in a few accessions at high frequency. Thus, screening individual accessions has a very high probability of identifying rare alleles, even in cases where replicated tests are needed for identification. In composite populations, such rare alleles must first be reisolated by the establishment of inbred or semi-inbred lines before screening can even be initiated. In addition, there is a high probability of loss of rare alleles through sampling during composite formation and maintenance.

genetic stocks...

I would now like to talk about genetic stocks (Table 2) as opposed to the germplasm stocks. These are being used in essentially an exponentially increasing fashion, mostly by the people who are working in molecular genetics. There has been a fairly constant demand for these genetic stocks from classical geneticists over the years, but in the past few years there has been tremendous demand put upon these stocks by the molecular geneticists. The stocks which are most important are maize and *Drosophila*. More mapping and related genetic research have been done with these taxa than with any others. Numerous

Table 2. ***Genetic Stock Collections Being Used Extensively***

Bacteria	Maize	Pea	Tobacco
Barley	Mice	*Petunia*	Tomato
Drosophila	Paramecia	Rat	Wheat
Lettuce			

organisms used for genetic work have no practical utility whatsoever. Mice, *Drosophila* again, and jimson weed (*Datura*) come to mind, but they have all been important in the study of questions of inheritance, biochemistry, *etc.*

These genetic stock collections are of increasing importance. The public stock collections have proved to be inadequate, so a number of private companies have actually had to start their own private stock collections to supplement the public ones. Integrated genetic maps are badly needed and not available. The University of Missouri is attempting to mitigate this in the case of corn by attempting to integrate the RFLP maps with the morphological marker maps, but this is a long, tedious, and expensive process.

One of the problems with maintaining these genetic stocks is that the viability varies greatly from stock to stock. In addition, taking care of these stocks requires constant expertise. Every season they are grown they need expert attention. Many of them cannot be maintained in a homozygous condition. Virtually all of the genetic stocks are very high risk stocks. A season or two of a collection in the hands of the uninterested or the marginally competent may result in the instantaneous loss of stocks accumulated painstakingly since the 1930s.

...genetic stocks at risk

The next question I would like to address is which genetic stocks are most at risk: they are not the ones that you might expect. In fact, the stocks that are most at risk are the ones that have been assembled by a single individual or by a single organization with no apparent person to take over once that individual retires. There is even some question in my mind as to what will happen to Charley Rick's stocks once they are no longer under his care.

Examples abound of stocks that have been lost or endangered because of the retirement of leading workers in the field. Perhaps the most important set that has ever been lost as a result of a loss of a team leader were the stocks that were assembled in the 1920s and 1930s by the Russian expeditions of Vavilov. When he fell, virtually all of those stocks were lost.

Another thought which I would like to develop is that a germplasm system which merely acquires material and does not have facilities for evaluation and utilization is really not a system at all. In fact, many of the national germplasm banks that have been set up around the world fall into this category. Unfortunately, even some of the collections that we "maintain" (*i.e.*, have acquired) in the states, fall into this category, because we really do not have facilities for regeneration or distribution, particularly for tropically adapted plants requiring short-day growing conditions. In many cases, I would maintain that seed banks holding such collections are really seed morgues. What goes in, is not going to come out alive. If we cannot regenerate and evaluate or adapt the existing collections, despite the clear need to do so, the obvious, but much less desirable, alternative is to drop back to a set of core collections which would be feasible to handle.

...seed morgues

Without means of regeneration, evaluation, and utilization, we are fighting various battles, nationally and internationally, to acquire still more germplasm in a war that we long ago lost. Probably the only instances we have won are in the cases of rice, potatoes, and tomatoes.

For virtually every other major crop, we are just in various stages of losing.

The costs of not maintaining an adequate germplasm system are far greater than maintaining one. A single resistance factor in a major crop will more than pay for virtually all our agricultural research for a very long period of time. The set of wheat varieties which center around the variety Arthur have been documented as accounting for about $14 billion. Our annual public agricultural research costs are about $450 million. We are running our national germplasm system at somewhere around $20 million a year, which is about one tenth the cost of one B2 bomber. The national germplasm system cannot function adequately at less than twice its current funding levels. As a result, what we now have is a façade, not a system.

I would like to close with a quotation from Donald Duvick, Director of Research from Pioneer Hi-Bred International. He says, *"Our national stinginess in collecting, storing, renewing, and describing our collections is inexcusable, not only in regard to our national obligations, but also in regard to our responsibility to the entire world."*

DISCUSSION

Question: ***Does the complexity of the genomes have something to do with the size and number of accessions that need to be maintained?***

Goodman: There is no indication that that is the case at the moment, but I am not sure that we know enough to answer the question well. There are some reasonably small genomes among our important cultivated plants, but I think with our present knowledge of genetics, we really rely more on ecogeographic diversity for enumerating the number of collections than we do on genetics. The simple reason is we cannot afford to do the kind of genetics needed to answer the questions. We are forced to rely on habitat diversity, and thus, we try to get an adequate sampling from diverse habitats. Only for a few crops, such as barley with the research that has come out of Bob Allard's lab, do we really have any sort of adequate measures of the genetic diversity available.

Question: ***You spoke primarily about plants, naturally, but my field is animal breeding and here we seem to have much greater genetic variability within strains and within breeds than you have in plants. What is the situation with animals?***

Goodman: I am far from the world's expert on animal genetics and animal breeding, but the story I get from the people who are active in artificial insemination work is that the high rates of selection that are made for things like milk production and rates of gain are greatly reducing the number of effective sires that are going into each generation of animal breeding. I have heard figures that are so low I do not want to quote them here. These unbelievably low figures on the number of effective sires for the next generation will ultimately have a very drastic limitation on genetic diversity within breeds. One of the things we do in both plant and animal breeding is to keep demanding the very best things that are available. Farmers want the most productive crops and the most productive animals; they do a very good job of choosing the most productive material. This does have a tendency over time to narrow rapidly our germplasm base. I do know the poultry producers at one time encountered some fairly narrow germplasm bottlenecks. But I am really very unfamiliar with other animal situations.

Question: ***Do you have an idea of a solution?***

Goodman: Obviously the long-term solution is to broaden the germplasm base and use a wider diversity of animals. To some extent this has occurred in, say, the beef breeds of cattle and in the less fat breeds of swine. Materials have been introduced from other countries and broadened the germplasm base rather substantially. But this may be a one-time effect. I am not sure that we can repeatedly do this sort of thing. Usually when one brings in less highly selected material it costs fairly heavily in terms of economics of production. It takes a very long time to bring new genetic materials up to the level of production of the currently available elite materials. This is true both in plants and animals. It is a costly and time-consuming endeavor.

Question: ***Have you any idea what the Europeans are doing about this problem?***

Goodman: The Europeans have some very active work going on in germplasm that is specifically of interest to them, both in vegetables and temperate crops. My guess is that they may be slightly ahead of us in terms of the things that they have an active interest in. But that is more of a guess than knowledge.

Question: ***Do you think there ought to be on a commodity basis, nationally or internationally, some kind of a network that provides for assigning responsibility for maintaining germplasm diversity at least at some stage in the breeding process?***

Goodman: I think that is almost required. The commercial breeders are not going to do this. It is simply not in their best interest to spend lots of money on maintaining a very broad germplasm base. They are going to broaden the germplasm base only as economics dictate, and that means that the public sector is going to have to be the sector that maintains a very broad germplasm base. Private industry thinks of 15 years as long term. If you think that 15 years is long term, you have not made a cross between teosinte and corn with the hope of getting anything out of it.

Question: ***When you talk about narrowing the collections down to a core group, does that mean new discoveries or new collections will result in the elimination of something old from the core collection?***

Goodman: No. The idea of core collections is not necessarily to eliminate materials. The idea would be to put entire sets of collections into essentially backup, long-term storage which would minimize the need for turnover. A set of core collections would be maintained for active distribution and routine use. Like most geneticists and plant breeders, I am the recipient of letters which say something like, "Send me the 30 most diverse collections of corn," or "Send me the 50 most diverse collections of wheat." We need to maintain sets of collections that answer such responses, because those are the most common, often constituting almost 99% of the requests. It is very rare that we need to go back to the entire set of collections; that happens to us only under the most dire of emergencies. Those entire sets can be kept under long-term storage for a sufficiently long period of time. We do not know how long we can keep collections under ideal storage conditions, perhaps several human lifetimes at the very least. This would reduce substantially the number of collections that need attention on an annual basis, and the core sets would identify specific sets of collections that need and merit substantial evaluation, characterization, adaptation, regeneration, *etc.*