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Source: *Plant Physiology*, Vol. 149, No. 1 (Jan., 2009), pp. 148-151
Published by: American Society of Plant Biologists (ASPB)
Stable URL: https://www.jstor.org/stable/25594919
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Cereal Germplasm Resources[1]

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The role of cereal germplasm banks is to collect, maintain, preserve, and distribute seeds representing the genetic diversity of crop species. While germplasm resources have traditionally been used in breeding efforts to improve a crop plant, they have also proved useful in both applied and basic research efforts to give insight into the biology of a crop plant (Harlan, 1975; Hyland, 1977; Sprague, 1980; Tanksley and McCouch, 1997; Damania, 2008; Johnson, 2008).

Seed collection and exchange began in prehistoric times as agriculture developed and spread. Early historical examples were found from Egypt and Babylon (Hyland, 1977). Until recently, the ability of scientists and researchers to maintain and preserve plant genetic resources was very limited. Few countries had the capability to store crop seeds for long periods. There were insufficiencies, not only in facilities and staff but also in the technology needed to collect, store, and document germplasm holdings (Harlan, 1975; Sprague, 1980).

Vavilov first called attention to the potential of crop relatives as a source of novel trait variation for crop improvement (Vavilov, 1926, 1940). It was this promise that motivated the establishment of modern germplasm banks, living seed collections focused primarily on exotic races and species that are closely related to crop cultivars in present use. Vavilov continued and expanded collection efforts that were initiated by the Russian Bureau of Applied Botany in 1894, which led to the establishment of the germplasm bank at what is now called the N.I. Vavilov Research Institute of Plant Industry (Sprague, 1980; Damania, 2008).

The introduction of potentially useful plant species and crop varieties into the United States dates back to the early 19th century when embassies were asked to collect and send these materials to the United States. A more organized effort was initiated when the Section of Seed and Plant Introduction was formed in 1898 within the U.S. Department of Agriculture (USDA). However, no provisions were made to store these materials adequately and most of these initial collections were lost over the years (Wilson et al., 1985).

Researchers working with maize (*Zea mays*) established a tradition of sharing resources and tools to further fundamental research efforts in this model biological organism (Freeling and Walbot, 1994; Neuffer et al., 1997) and formally organized the Maize Genetics Cooperation in 1932 (Kass et al., 2005). Among the aims of this organization were the collection and dissemination of unpublished data and information to interested workers and the maintenance and distribution of tester stocks. A collection of stocks was assembled and maintained and samples were supplied upon request; its first formal crop was grown in the summer of 1936 (Sachs, 2009). The Maize Genetics Cooperation Stock Center (Table III) became a model for the establishment of other model organism genetic stock centers. It also provided a model to those establishing general germplasm banks for crop species.

Subsequently, the four original Regional Plant Introduction Stations were established under the Research and Marketing Act of 1946. This was the forerunner of the USDA National Plant Germplasm System (NPGS; Table I). The North Central Regional Plant Introduction Station at Ames, Iowa (Table III), which was the first station established, began operation in 1948 (Wilson et al., 1985; White et al., 1989).

Also following World War II, the Food and Agriculture Organization of the United Nations became the main organization promoting the conservation of plant genetic resources. Its Consultative Group on International Agricultural Research (CGIAR; Table I) established the International Board for Plant Genetic Resources (IBPGR) in 1973 (Sprague, 1980). Since it began, IBPGR has worked to establish a global network of germplasm banks and has supported and stimulated the collection germplasm samples (Plucknett et al., 1987). IBPGR has also provided training, specialized equipment for storage and documentation, and advice. Today, more than 100 germplasm banks are operating in the world; many of these are located in developing countries (Tables I–III). By contrast, when IBPGR was established in 1974, only about six countries had the capability to store seeds for long periods (Plucknett and Horne, 1992).

[1] This work was supported by the U.S. Department of Agriculture-Agricultural Research Service (CRIS project no. 3611–21000–022–00).

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www.plantphysiol.org/cgi/doi/10.1104/pp.108.129205

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Table I. *Germplasm systems*

Name	Web Site	Database
CGIAR	http://cgiar.org/impact/genebanksdatabases.html	Systemwide Information Network for Genetic Resources (SINGER) http://www.singer.cgiar.org/; International Crop Information System http://www.icis.cgiar.org
NPGS	http://www.ars-grin.gov/npgs/	Germplasm Resources Information Network (GRIN) http://www.ars-grin.gov/npgs/searchgrin.html
Nordic Genetic Resource Center (NordGen)	http://www.nordgen.org/ngb/	SESTO http://tor.ngb.se/sesto/
N.I. Vavilov Institute of Plant Industry	http://vir.nw.ru/	N.I. Vavilov Institute of Plant Industry Database http://vir.nw.ru/data/dbf.htm

TYPES OF GERMPLASM

General germplasm is maintained to preserve natural genetic diversity. These accessions include inbred lines, land races, open pollinated varieties, wild relatives, cultivars, and other breeding stocks. The primary importance of these germplasm accessions is that they carry undefined variation that is proving to be a valuable resource for breeders and research scientists.

Other germplasm centers concentrate on specialty germplasm such as genetic stocks (Sachs, 2009). Genetic stocks are focused upon one or a limited number of defined variations or genetic tools. Examples of what genetic stocks contain include: an allele of a specific gene (induced mutation or natural variant), a combination of mutations that give a unique phenotype, a series of mutant alleles of genetically linked genes, a variant cytoplasmic trait, a noncommercially approved transgenic insert (for research purposes, e.g. RNAi lines), a chromosomal aberration (e.g. translocation or inversion), a monosomic or trisomic aneuploid, and an alternative ploidy (e.g. tetraploid). Genetic stocks also include tools such as recombinant inbred lines for mapping gene locations and associations, active transposable element lines for generating new mutants, and reverse genetics resources (such as TILLING and sequence indexed lines) that can be used to determine the function of a gene discovered by sequence analysis.

Efforts are presently being made to exploit germplasm bank genetic resources with genomics-driven plant breeding methods such as allele mining and association genetics. This combines a comparative description of molecular polymorphisms and phenotypic variation, and the study of statistical associations and involves population structure analysis (de Vicente et al., 2005; de Vicente and Glaszmann, 2006; Varshney et al., 2005).

MAINTENANCE/DISTRIBUTION VERSUS PRESERVATION

Germplasm of cereal crops is stored in two types of collections: working collections and preservation centers. Working collections are mainly of immediate interest to plant breeders and genetics researchers. Storage conditions of seeds are kept near freezing and low humidity. Cereal seeds maintained this way can be expected to remain viable for 10 years or longer. Longer term storage of cereal seeds involves keeping them at a temperature range of $-10°C$ to $-20°C$. Seeds are carefully dried and sealed in bottles, or vacuum packed in aluminum foil envelopes or cans.

Table II. *General germplasm banks (centers and organizations that maintain germplasm for several species)*

Name	Web Site(s)	Cereal Species Maintained
Chinese Crop Germplasm Information System	http://icgr.caas.net.cn/cgris_english.html	Barley, maize, millet, oat, rice, rye, sorghum, and wheat
Institute for Cereal Crops Improvement	http://www.tau.ac.il/lifesci/units/ICCI/genebank1.html	Barley, oat, wheat
John Innes Centre - BBSRC Cereals Collections	http://www.jic.ac.uk/germplas/bbsrc_ce/index.htm	Barley, oat, wheat
National Institute of Agrobiological Science GenBank (Tsukuba, Japan)	http://www.gene.affrc.go.jp/about-plant_en.php	Rice, barley, wheat, sorghum, millet
National Small Grains Collection (GRIN; Aberdeen, Idaho)	http://www.ars.usda.gov/main/docs.htm?docid=2884 Genetics stocks: http://www.ars.usda.gov/main/docs.htm?docid=2922	Oat, rice, rye, triticale, and wheat; plus genetic stocks for barley and wheat

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Table III. *Germplasm banks with collections that focus on one or two cereal species*

Cereals Maintained	Name	Web Site	Part of System (Database)
Barley	International Center For Agricultural Research in The Dry Areas (Syria)	http://www.icarda.org	CGIAR (SINGER)
	Barley Germplasm Center Research Institute for Bioresources (Japan)	http://www.shigen.nig.ac.jp/barley	
	European Barley Database	http://barley.ipk-gatersleben.de/ebdb.php3	
	Spanish Barley Core Collection	http://www.eead.csic.es/barley/index.php?lng=1	
Maize	North Central Regional Plant Introduction Station (Ames, Iowa)	http://www.ars.usda.gov/main/site_main.htm?modecode=36-25-12-00	NPGS (GRIN)
	International Maize and Wheat Improvement Center (Mexico)	http://www.cimmyt.org/research/maize/mfsgb/htm/mfsgb.htm	CGIAR (SINGER)
	Maize Genetics Cooperation Stock Center (Genetic Stocks; Urbana, Illinois)	http://maizecoop.cropsci.uiuc.edu/	NPGS (http://www.maizegdb.org/stock.php)
Millet and sorghum	Plant Genetic Resources Conservation Unit (Griffin, Georgia)	http://www.ars.usda.gov/main/site_main.htm?modecode=66-07-00-00	NPGS (GRIN)
	International Crops Research Institute for the Semi-Arid Tropics	http://www.icrisat.org	CGIAR (SINGER)
Rice	International Rice Research Institute (Philippines)	http://www.irri.org/grc/grchome/home.htm	CGIAR (SINGER)
	Genetic Stocks - Oryza Collection (Genetic Stocks; Stuttgart, Arkansas)	http://www.ars.usda.gov/Main/docs.htm?docid=8318	NPGS (GRIN)
	Rice Genetic Resources Stock Center (Genetic Stocks; Japan)	http://www.shigen.nig.ac.jp/rice/oryzabase/top/top.jsp	
Wheat	International Maize and Wheat Improvement Center (CIMMYT; Mexico)	http://www.cimmyt.org/research/wheat/whegeba/htm/whegeba.htm	CGIAR (SINGER)
	Wheat Precise Genetic Stocks (Genetic Stocks; John Innes Centre, UK)	http://www.jic.ac.uk/germplas/prec_ce/	John Innes Centre - BBSRC
	Wheat Genetic and Genomic Resources Center (Genetic Stocks; Kansas State University, Manhattan, Kansas)	http://www.k-state.edu/wgrc/	

Materials to be preserved under long-term storage (e.g. for backup purposes) are placed under cryogenic conditions. The National Center for Genetic Resources Preservation (http://www.ars.usda.gov/main/site_main.htm?modecode=54-02-05-00) is a USDA/ARS facility located in Fort Collins, Colorado. Originally designated the National Seed Storage Laboratory, it was built in 1958 to consolidate backups for the plant collections in the NPGS into a single facility that uses state-of-the-art preservation practices. The use of liquid nitrogen (cryogenic storage) to store seeds at the National Seed Storage Laboratory was introduced in 1977 and became a routine practice by 1990 (Walters et al., 2005). Another facility dedicated to backup preservation of seeds from germplasm banks is the recently opened Svalbard Global Seed Vault (Fowler, 2008; http://www.croptrust.org/main/arctic.php?itemid=211).

Seed Requests

While the mission of most germplasm banks is to make germplasm available to all bona fide basic and applied researchers, regardless of political or institutional affiliation, there may be some restrictions. While the NPGS and CGIAR centers provide germplasm free of charge, this may not be the case for other centers. The NPGS germplasm banks do not have any material transfer agreement requirements (all genetic resources available are considered to be in the public domain), but other germplasm centers do have material transfer agreement requirements. The recently adopted International Treaty of Plant Genetic Resources for Food and Agriculture endorses the principle of benefit sharing and provides mechanisms to use royalties to support germplasm collections and research (Cooper, 2002; Correa, 2006).

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When requesting seeds from another country, import permits and phytosanitary certificates may be required. For U.S. requests from other countries, one should check the requirements from the USDA Animal and Plant Health Inspection Service (http://www.aphis.usda.gov/). From other countries, the local equivalent agency should be contacted.

To obtain noncommercially approved transgenic research material for research purposes, within the United States, one must send a movement and release notification letter to Animal and Plant Health Inspection Service (http://www.aphis.usda.gov/biotechnology/brs_main.shtml). Most other countries do not have any additional rules regulating the movement of transgenic seeds, but have stricter regulations for growing this material. One should contact the appropriate government agency of their country before requesting transgenic germplasm.

MAJOR CENTERS FOR CEREAL GERMPLASM

A list of active collections for cereal germplasm is provided in Tables I to III. Additional information about cereal germplasm resources is provided by the Web sites at http://gramene.org and http://wheat.pw.usda.gov/GG2/germplasm.shtml.

Received September 2, 2008; accepted October 21, 2008; published January 7, 2009.

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