HortScience 41(5):1188–1194. 2006.

Fruit and Nut Genebanks in the U.S. National Plant Germplasm System

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Additional index words. genetic resources, clonal repository, genetics, conservation, disease resistance, environmental adaptation

***Abstract*. The year 2005 marked the 25th anniversary of the establishment of the U.S. Department of Agriculture (USDA) National Plant Germplasm System (NPGS), repositories devoted to clonally propagated, horticultural fruit and nut crops. During this quarter century, facilities in Hilo, Hawaii; Mayaguez, PR.; Miami, Fla.; and Riverside, Calif. were developed to preserve collections of tropical and subtropical fruit and nut crops; facilities in Brownwood, Texas; Corvallis, Ore.; Davis, Calif. and Geneva, N.Y. preserve the temperate crops. Each of these facilities now has internationally recognized, globally diverse collections of genetic resources for their assigned genera. Germplasm of unique genotypes are maintained as growing plants, evaluated for phenotypic and genotypic traits, documented in a national public germplasm database, and freely distributed as clonal propaggules to researchers and other germplasm users around the world. Seed collections represent wild populations for some crop relatives. These 8 genebanks maintain 30,000 accessions representing 1600 species of fruit and nut crops and their wild relatives. The genebanks distribute more than 15,000 accessions annually to international researchers. Although originally conceived as working collections for crop improvement, NPGS genebanks have also become invaluable in providing the raw materials for basic plant genetic research, reservoirs for rare or endangered species or vulnerable landraces, archives of historic cultivars, and field classrooms for educating the public. These collections preserve botanical treasures as well as the American horticultural heritage for now and for future generations.**

History of U.S. National Fruit and Nut Repositories

Before 1980, fruit and nut germplasm collections in the United States were largely developed and maintained by individual plant breeders at universities and were often lost when scientists retired, changed the focus of their research, or encountered funding shortfalls (Brooks and Barton, 1977). As a result, collections composed of irreplaceable material and assembled through years of effort were routinely lost, producing an erratic and insecure network for fruit and nut germplasm conservation. That germplasm insecurity lessened in 1980 with the establishment of the first U.S. National Clonal Germplasm Repository in Corvallis (Jahn and Westwood, 1982; Westwood, 1982). Over the next several years, this unit was followed by the construction of 7 additional repositories at specifically chosen sites throughout the country (CAST, 1985; Westwood, 1986, 1989).

The USDA Agricultural Research Service (ARS) has operated 4 regional PI stations in Ames, Iowa (established 1947), Pullman, Wash. (established 1947), Geneva, N.Y. (established 1948), and Griffin, Ga. (established 1949) to receive, preserve, and distribute seed of vegetable and agronomic crops (Fig. 1). Several additional repositories were later added for special crops such as cotton, potatoes, and soybeans. In 1958, the National Seed Storage Laboratory (now the National Center for Genetic Resource Preservation) opened in Fort Collins, Colo., to ensure the long-term "base, backup" preservation of seeds from each of the "working" or actively distributing collections (White et al., 1989). This network of federal genebanks came to be known as the National Plant Germplasm System (NPGS). Clonal repositories were added to the NPGS as a result of the efforts of ARS pear breeder Howard Brooks, who chaired a visionary group of researchers who forwarded this cause. Dr. Brooks formed an *ad hoc* clonal committee after a workshop at the 1974 meeting of the American Society for Horticultural Science (White et al., 1989). Brooks asked each committee member in 1977 to develop a plan for a national repository for crops important in their region of the country. He requested that the plans specifically itemize the necessary space for land, greenhouses, laboratories, and offices needed to safeguard the germplasm of the regional crops (Brooks and Barton, 1977). During the next winter, armed with these plans, Brooks appeared before the U.S. Congressional Committee on Agriculture in Washington, DC, to request federal funding to establish a system of National Clonal Repositories. The congressmen approved the concept and asked Brooks to develop a more specific plan to be presented to them in the next year. They were very impressed when he opened his briefcase and pulled out the detailed plans that his committee had already assembled for 12 repository sites (M.N. Westwood, Nov. 2005, personal communication). During that very same session of Congress, a $2 million federal appropriation was approved to begin building a system of National Clonal Germplasm Repositories. This request was to be a joint effort matched through mutual agreement with State Agricultural Experiment Stations at Land Grant Universities. The Corvallis, Ore. Repository was selected as the first to be constructed because of the large collections of pears, hazelnuts, and small fruits already present at that site. The very active involvement of Dr. Wilson Foote, Associate Director of the Oregon State University Agricultural Experiment Station, pomology Professor, Dr. Melvin Westwood, and hazelnut breeder, Dr. Maxine Thompson, encouraged this choice. Dr. Westwood was later appointed as National Technical Advisor for Clonal

Received for publication 3 Mar. 2006. Accepted for publication 7 Apr. 2006.
We thank Mel Westwood for his oral history and for reviewing the manuscript. We thank the technical staff at each of the NPGS Clonal Repositories for their dedicated stewardship of these invaluable collections.
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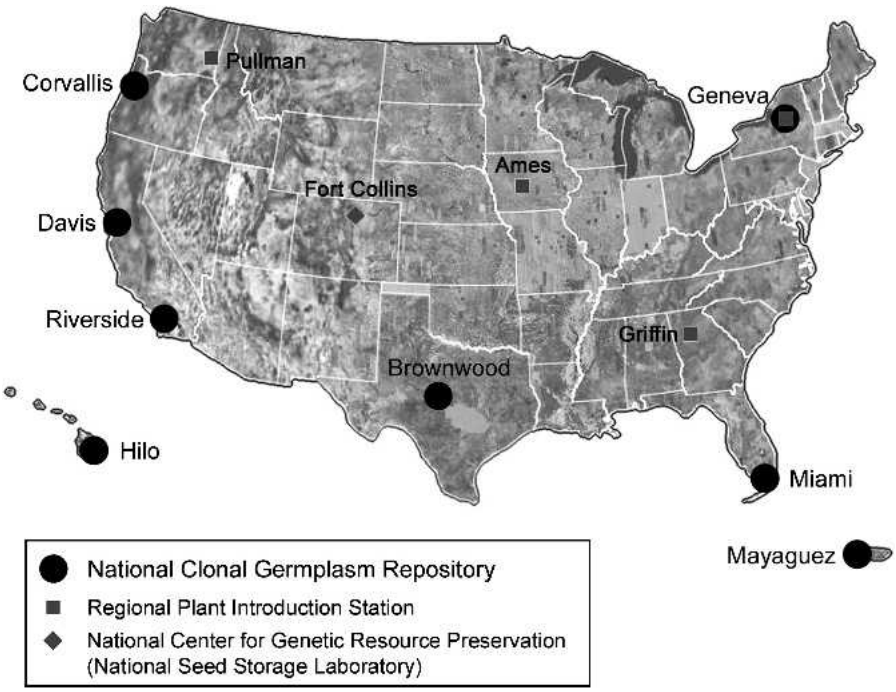

Fig. 1. Locations of USDA National Plant Germplasm System clonal genebanks for fruit and nut crops.

Germplasm during the construction of the clonal repositories and developed an operations manual to guide new staff in establishing their facilities (Westwood, 1986). Funding was ultimately approved for 8 of the 12 originally planned clonal repositories (Fig. 1). Two *Citrus* repositories, one in Orlando, Florida, and one in Riverside, California, were originally established as a result of quarantine restrictions between the 2 states but were later consolidated at Riverside. In 1987, the National Arboretum in Washington, DC, was designated as a clonal repository for woody landscape crops.

NPGS 'Clonal' Repositories

The mission of NPGS genebanks includes the acquisition, documentation, preservation, evaluation, enhancement, and distribution of plant genetic resources. This conservation activity improves the quality and production of economic crops important to U.S. and world agriculture (NPGS, 2005a). The U.S. clonal genebanks house wild relatives as well as improved genotypes for their assigned crops and currently maintain 30,000 accessions representing 1600 species (Table 1). For some temperate crops, seed collections are used to represent wild species populations in addition to the genotypes that must be preserved clonally. Many nut crops and tropical or subtropical species have recalcitrant seeds that do not retain viability when stored so that clonal living plant conservation is required. The original plan for fruit and nut gene banks suggested maintenance and preservation as primary objectives followed by research and evaluation (Brooks and Barton, 1977; Westwood, 1989). Preservation remains the primary focus of the NPGS fruit and nut repositories, which are described subsequently in the order that they became established. Contact information and crop responsibilities for each site are provided (Table 2), and number of accessions and collection locations by genus are itemized (Table 1).

Corvallis, Ore., established 1980

NCGR–Corvallis is operated in collaboration with Oregon State University and is located on the grounds of their Horticultural Research Farm at 44.55° N latitude. NCGR–Corvallis maintains germplasm collections of more than 26 genera, including several agronomic and specialty crops. *Actinidia*, *Corylus*, *Cydonia*, *Fragaria*, *Pyrus*, *Ribes*, *Rubus*, and *Vaccinium* are the main assigned fruit and nut genera (Table 2). The Repository maintains more than 8300 clones and 3300 seedlots. The largest clonal collections are *Pyrus* with 1900 and *Fragaria* with 1300 accessions. Because *Rubus* and *Vaccinium* are highly diverse, each having between 600 and 800 species worldwide, much variability for these genera is represented with seedlots. Currently, 970 *Rubus* and 570 *Vaccinium* seedlots are maintained in addition to a greater number of clones (Table 1).

Primary clonal collections of *Fragaria*, *Rubus,* and *Vaccinium* are maintained as potted plants in screenhouses for protection from virus vectors. Primary clonal collections for *Actinidia*, *Corylus*, *Cydonia*, *Pyrus*, and *Ribes* are maintained in field collections on 26 ha of land available to the Repository east of Corvallis. Much of the *Ribes* and *Vaccinium* collections are duplicated in both screenhouse and field. In vitro culture of growing shoots provides backup for approximately 10% of the collection with priority given to core accessions, frequently requested accessions, and accessions that may

Table 1. Fruit and nut collections at the 8 USDA NPGS Clonal Repositories (NPGS, 2006).

Genus	Site[z]	Accessions[y]	Species
Actinidia	COR	198	27
Actinidia	DAV	68	14
Aegle	RIV	1	1
Aeglopsis	RIV	1	1
Afraegle	RIV	1	1
Aleurites	MAY	2	1
Amelanchier	COR	226	15
Ampelopsis	DAV	21	6
Ampelopsis	GEN	5	3
Anacardium	MAY	1	1
Ananas	HI	160	10
Annamocarya	BRW	11	1
Annona	MAY	16	6
Annona	MIA	70	10
Antidesma	MAY	3	1
Archontophoenix	MIA	3	3
Aronia	COR	7	1
Artocarpus	HI	39	5
Artocarpus	MAY	10	7
Artocarpus	MIA	4	1
Asimina	COR	70	7
Atalantia	RIV	6	4
Averrhoa	HI	25	1
Averrhoa	MAY	19	1
Averrhoa	MIA	38	1
Bactris	HI	15	1
Bactris	MAY	3	1
Bactris	MIA	16	3
Balsamocitrus	RIV	1	1
Bertholetia	MAY	1	1
Bismarckia	MIA	1	1
Bixa	MAY	1	1
Blighia	MIA	1	1
Brosimum	MIA	1	1
Butea	MIA	1	1
Butia	MIA	11	1
Camellia	HI	18	1
Canarium	HI	16	8
Carica	HI	143	1
Carissa	MIA	1	1
Carya	BRW	1340	23
Caryota	MIA	3	1
Casimiroa	MAY	2	1
Casimiroa	MIA	3	1
Cavendishia	COR	7	4
Ceanothus	COR	37	9
Chaenomeles	COR	13	3
Chrysobalanus	MAY	2	1
Chrysophyllum	MAY	2	1
Cinnamomum	MAY	5	3
Cinnamomum	MIA	2	1
Citremocitrus	RIV	1	1
Citrofortunella	RIV	8	1
Citromicrocitrus	RIV	1	1
Citroncirus	RIV	43	1
Citropsis	RIV	4	4
Citrus	MAY	4	1
Citrus	RIV	896	86
Clausena	RIV	6	4
Clymenia	RIV	1	1
Coccothrinax	MIA	16	7
Cocos	MAY	1	1
Cocos	MIA	20	1
Coffea	MAY	1	1
Cola	MAY	4	1
Coleara	RIV	1	1
Copernicia	MIA	9	9
Cornus	COR	9	1
Corylus	COR	795	22
Corypha	MIA	2	1
Crataegomespilus	COR	3	1
Crataegus	COR	18	8
Crataemespilus	COR	1	1
Cryosophila	MIA	4	1

(Continued)

Table 1. (Continued) Fruit and nut collections at the 8 USDA NPGS Clonal Repositories (NPGS, 2006).

Genus	Site[z]	Accessions[y]	Species
Cudrania	DAV	1	1
Cydonia	COR	114	1
Dictyosperma	MIA	5	1
Dimocarpus	HI	19	1
Dimocarpus	MAY	2	1
Dimocarpus	MIA	4	1
Diospyros	DAV	103	4
Diospyros	MAY	3	1
Diospyros	MIA	9	5
Dovyalis	MAY	2	1
Duchesnea	COR	3	1
Durio	HI	3	3
Durio	MAY	1	1
Dypsis	MIA	11	6
Dyschoriste	MIA	1	1
Ehretia	MIA	2	1
Elaeis	MIA	16	1
Elaeocarpus	MIA	2	1
Empetrum	COR	8	1
Eremocitrus	RIV	1	1
Eriobotrya	DAV	29	1
Esenbeckia	RIV	1	1
Eugenia	HI	1	1
Eugenia	MAY	2	1
Eugenia	MIA	2	1
Euterpe	MIA	8	3
Feroniella	RIV	1	1
Ficus	DAV	196	4
Ficus	MIA	87	47
Flacourtia	MAY	3	3
Flacourtia	MIA	1	1
Fortucitrocirus	RIV	3	1
Fortunella	MAY	1	1
Fortunella	RIV	11	7
Fragaria	COR	1734	37
Fragotentilla	COR	3	1
Garcinia	MAY	16	12
Garcinia	MIA	22	9
Gastrococos	MIA	1	1
Gaultheria	COR	42	17
Gaylussacia	COR	15	5
Genipa	MIA	1	1
Glycosmis	RIV	4	4
Hevea	MIA	44	1
Hicksbeachia	HI	2	1
Hippophae	COR	2	1
Hyophorbe	MIA	3	1
Hyphaene	MIA	1	1
Inga	MAY	1	1
Inga	MIA	2	1
Jacaratia	HI	1	1
Juglans	COR	70	3
Juglans	DAV	425	23
Lansium	MAY	1	1
Lecythis	MAY	2	1
Leucaena	HI	7	1
Licania	MAY	2	1
Limonia	RIV	1	1
Litchi	HI	63	1
Litchi	MAY	2	1
Litchi	MIA	18	1
Livistona	MIA	23	10
Lonicera	COR	53	7
Macadamia	HI	26	5
Macadamia	MAY	1	1
Macadamia	MIA	1	1
Madhuca	MIA	1	1
Malpighia	HI	7	1
Malpighia	MIA	14	3
Malus	GEN	3994	55
Mammea	MAY	1	1
Mangifera	MAY	9	1
Mangifera	MIA	166	1

Table 1. Continued.

Genus	Site[z]	Accessions[y]	Species
Manilkara	MAY	26	1
Manilkara	MIA	12	3
Mentha	COR	533	40
Merrillia	RIV	1	1
Mespilus	COR	48	3
Microcitronella	RIV	1	1
Microcitrus	RIV	19	6
Micromelum	RIV	2	1
Monstera	MAY	1	1
Morus	DAV	58	8
Murraya	RIV	3	1
Musa	MAY	112	4
Musa	MIA	73	3
Naringi	RIV	1	1
Nephelium	HI	38	6
Nephelium	MIA	1	1
Olea	DAV	139	4
Oreomunnea	DAV	1	1
Oxanthera	RIV	1	1
Pachira	MAY	1	1
Pamburus	RIV	2	1
Paramignya	RIV	2	1
Parmentiera	MAY	2	1
Parthenocissus	DAV	2	1
Parthenocissus	GEN	1	1
Passiflora	HI	34	9
Peraphyllum	COR	8	1
Persea	MIA	252	3
Phoenix	MIA	27	7
Phoenix	RIV	69	1
Pimenta	MIA	1	1
Piper	MAY	2	1
Pistacia	DAV	218	12
Pleiospermium	RIV	3	1
Poncirus	RIV	54	1
Potentilla	COR	3	1
Pouteria	MAY	27	1
Pouteria	MIA	40	5
Pritchardia	MIA	1	1
Prunus	DAV	1330	87
Prunus	GEN	106	14
Pseudananas	HI	1	1
Pseudocydonia	COR	1	1
Pseudophoenix	MIA	3	1
Psidium	HI	44	5
Psidium	MAY	4	3
Pterocarya	DAV	11	6
Punica	DAV	149	1
Pyracomeles	COR	1	1
Pyronia	COR	7	1
Pyrus	COR	2180	37
Ribes	COR	1324	109
Rollinia	MAY	1	1
Roystonea	MIA	7	4
Rubus	COR	2078	192
Rubus	MAY	2	1
Ruscus	COR	1	1
Ruta	RIV	1	1
Sabal	MIA	23	5
Saccharum	MIA	2421	18
Salacca	MAY	1	1
Sambucus	COR	183	21
Sandoricum	MAY	1	1
Sapindus	MAY	1	1
Sauropus	HI	1	1
Schisandra	COR	7	1
Severinia	RIV	11	1
Sibbaldia	COR	1	1
Sorbaronia	COR	5	4
Sorbocotoneaster	COR	1	1
Sorbocrataegus	COR	1	1
Sorbopyrus	COR	9	1
Sorbus	COR	282	60
Spondias	MIA	3	1
Swinglea	RIV	1	1

Table 1. Continued.

Genus	Site[z]	Accessions[y]	Species
Syzygium	HI	3	1
Syzygium	MAY	3	1
Syzygium	MIA	5	3
Tamarindus	MAY	1	1
Tamarindus	MIA	35	1
Terminalia	MAY	6	4
Theobroma	MAY	156	1
Theobroma	MIA	72	1
Thrinax	MIA	17	3
Triphasia	RIV	1	1
Vaccinium	COR	1579	68
Vanilla	MAY	1	1
Vasconcellea	HI	24	9
Vitis	DAV	2913	49
Vitis	GEN	1203	26
Washingtonia	MIA	1	1
Wenzelia	RIV	1	1
Zingiber	MAY	1	1
Ziziphus	MIA	4	1
Site[z]		Accessions[y]	Species
Total for BRW		1351	24
Total for COR		11,682	722
Total for DAV		5664	223
Total for GEN		5309	99
Total for HI		690	77
Total for MAY		475	104
Total for MIA		3649	224
Total for RIV		1168	151
Grand Total		29,988	1624

[z]BRW, Brownwood, Texas; COR, Corvallis, Oregon; DAV, Davis, California; GEN, Geneva, New York; HI, Hilo, Hawaii; MAY, Mayaguez, Pureto Rico; MIA, Miami, Florida; RIV, Riverside, California.

[y]Approximately 2700 Corvallis accessions are seedlots; approximately 1640 Geneva accessions are seedlots.

be at risk in the field resulting from lack of cold hardiness. Nonhardy genotypes and species originating in subtropical or tropical locations are also maintained year-round in a greenhouse. Seed collections are stored at –20 °C.

Research at Corvallis supported by base funding focuses on improving germplasm storage and maintenance, including in vitro culture and cryopreservation and development of molecular fingerprints (Bassil et al., 2005; Gupta and Reed, 2006; Lewers et al., 2005; Mehlenbacher et al., 2005; Reed, 2001; Reed et al., 2006). Other important research activities include virus and disease testing, identity verification, phenotype evaluation, propagation techniques, and strategies for seed regeneration.

Davis, Calif., established 1981

NCGR–Davis is operated in coordination with the University of California and is located at 38.54° N latitude. Fruit and nut crop genera which are represented by more than 100 clonal accessions include *Actinidia, Diospyros, Ficus, Juglans, Olea, Pistacia, Prunus, Punica,* and *Vitis* (Table 1). The Davis Repository currently holds over 5400 accessions representing approximately 15 genera and 175 species of fruit and nut crops. The two genera *Vitis* and *Prunus* account for approximately 75% of the collection with 2800 and 1300 accessions, respectively.

Table 2. Curators, latitudes, contact information, and crop responsibilities for the fruit and nut repositories in the USDA National Plant Germplasm System.

Site, latitude, curator	Contact info	Crop responsibilities
Brownwood, Texas 31.71° N L. J. Grauke	USDA-ARS-NCGR 10200 FM 50 Somerville, TX 77879 phone (979) 272-1402 fax (979) 272-1401 e-mail: brwlg@ars-grin.gov	*Carya* (pecan, hickory)
Corvallis, Oregon 44.55° N Kim Hummer, berries and specialty crops Joseph Postman, pome fruits	USDA-ARS-NCGR 33447 Peoria Road Corvallis, OR 97333–2521 phone (541) 738-4200 fax (541) 738-4205 e-mail: cor@ars-grin.gov	*Actinidia* (hardy kiwifruit) *Amelanchier* (service berry), *Asimina* (paw paw), *Corylus* (hazelnut), *Cydonia* (quince), *Fragaria* (strawberry), *Humulus* (hop), *Juglans cinerea* (butternut) *Mentha* (mint), *Mespilus* (medlar), *Pyrus* (pear), *Ribes* (currant, gooseberry) *Rubus* (blackberry, raspberry), *Sorbus* (mountain ash), *Vaccinium* (blueberry, cranberry)
Davis, California 38.55° N Ed Stover	USDA-ARS-NCGR One Shield Ave, UCD Davis, CA 95616–8607 phone (530) 752-7009 fax (530) 752-9659 e-mail: dav@ars-grin.gov	*Actinidia* (kiwifruit), *Diospyros* (persimmon), *Eriobotrya* (loquat), *Ficus* (fig), *Juglans* (walnut), *Morus* (mulberry), *Olea* (olive), *Pistacia* (pistachio), *Prunus* (stone fruit, almond), *Punica* (pomegranate), *Vitis* (grape)
Geneva, New York 42.88° N Phil Forsline	Plant Genetic Resource Unit Cornell University Exp. Station 630 W. North Street Geneva, NY 14456–0462 phone (315) 787-2390 fax (315) 787-2339 e-mail: Philip.Forsline@ars.usda.gov	*Malus* (apple), *Prunus cerasus* (tart cherries), *Vitis* (hardy grape)
Hilo, Hawaii 19.57° N Francis Zee	USDA-ARS-NCGR PO Box 4487 928 Stainback Hwy. Hilo, HI 96720 phone (808) 959-5833 fax (808) 959-3539 e-mail: fzee@pbarc.ars.usda.gov	*Ananas* (pineapple), *Artocarpus* (breadfruit) *Averrhoa* (star fruit), *Bactris* (peach palm), *Carica* (papaya), *Canarium* (pilinut), *Dimocarpus* (longan), *Litchi* (lychee), *Macadamia* (macadamia), *Malpighia* (acerola), *Nephelium* (rambutan, pulasan), *Passiflora* (passion fruit), *Psidium* (guava)
Miami, Florida 25.64° N Tomas Ayala-Silva and Raymond Schnell, fruits, nuts Alan Meerow, ornamentals	USDA-ARS-NCGR 13601 Old Cutler Rd. Miami, FL 33158 phone (305) 254-3635 fax (305) 969-6410 e-mail: mia@ars.grin.gov	*Annona* (cherimoya), *Cocos nucifera* (coconut), *Dimocarpus* (longan), *Diospyros digyna* (black sapote*), Ficus* (fig), *Litchi* (lychee), *Mangifera* (mango), *Manilkara zapota* (sapodilla), *Musa* spp. (banana), *Persea* (avocado), *Pouteria sapota* (mamey sapote), *Saccarum* (sugarcane), *Theobroma cacao* (cocoa), *Zizyphus* (jujube), subtropical and tropical ornamentals, *Tripsacum* and related grasses.
Mayaguez, Puerto Rico 18.20° N Brian Irish and Ricardo Goenaga	USDA-ARS-TARS 2200 Pedro Albizu Campos Ave. Suite 201 Mayaguez, PR 00680 phone (787) 831-3435 fax (787) 831-3386 e-mail: may@ars-grin.gov	*Annona* (cherimoya), *Garcinia*, *Manilkara zapota* (níspero), *Musa* spp. (plantain, banana), *Pouteria sapota* (mamey sapote), *Theobroma cacao* (cocoa), temperate/tropical bamboo, other tropical ornamentals.
Riverside, California 33.96° N Robert Krueger	USDA-ARS-NCGR 1060 Martin Luther King, Jr. Blvd. Riverside, CA 92507–5437 phone (951) 827-4399 fax (951) 827-4398 e-mail: rivrk@ars-grin.gov	*Citrus* and *Citrus* relatives, *Phoenix* (date)

All collections are maintained with 2 trees or vines per accession on a 30-ha field site in Winters, Calif. Collections of *Vitis* and *Prunus* are also maintained as potted plants in screenhouses for protection from disease vectors. Nonhardy genotypes and species originating in subtropical or tropical locations are maintained year-round in a greenhouse.

Research at Davis supported by base funding focuses primarily on use of molecular markers to fingerprint accessions, determine the distribution of genetic variability within and between taxa, and to assist in collection management (Aradhya et al., 2003, 2004, 2005). Characterization of accession phenotypes, to assist clients in selecting material for their research programs, is also an important and ongoing research activity.

Mayaguez, P.R., established 1984

The Repository at Mayaguez is one of 4 NPGS genebanks devoted to the preservation of tropical and subtropical crops (Ayala-Silva et al., 2004). The Tropical Agriculture Research Station (TARS) at Mayaguez is located at 18.20° N latitude and dates back to 1908. With the establishment of NPGS Clonal Repositories, TARS was designated as a site for the preservation of a number of tropical fruit and nut crops (Table 2). NPGS clonal germplasm activities in Mayaguez were initially administered by the curator in Miami, but this site now has its own curator and is no longer considered a substation of the Miami Repository. The Mayaguez genebank maintains more than 900 accessions of tropical fruit, nut, and ornamental landscape accessions representing 256 genera and over 400 species. The 450 clonal fruit and nut accessions maintained in field plots and greenhouses include primary collections of *Manilkara* (sapodilla), *Musa*, *Pouteria* (mamey or mammee sapote), *Theobroma*, several species of *Annona* and *Garcinia,* as well as temperate and tropical bamboos (Table 1). Some accessions are duplicated as backups for the Miami, Hilo, or Riverside Repositories. Research goals are directed toward maintenance of clonal germplasm collections and evaluation of accessions for phenotypic and genotypic descriptors. Genotypic characterization is focused on molecular approaches to determine genetic diversity baselines and clonal fingerprints. Development of in vitro tissue culture propagation for some collections will improve efficiency of propagation, ease of distribution, and lower the risk of pathogen dissemination.

Miami, Fla., established 1984

The Miami Repository is located at 25.64° N latitude at the Subtropical Horticultural Research Station (SHRS). Approximately 5000 clonal accessions are maintained at SHRS in greenhouses, lathhouses, and field plots, representing sugar cane, *Tripsacum,* and subtropical woody ornamentals in addition to fruit and nut crops. Approximately 81 ha are available for research and germplasm preservation (Ayala-Silva et al., 2004). Important fruit and nut crops preserved at Miami include cacao, fig, lychee, mango, and other tropical and subtropical fruit species (Table 2). Accessions are maintained in field plantings, but certain new plants must be quarantined and tested for pathogens before moving to the field. Backup core collections have been established in Mayaguez or Hilo. Research at Miami is focused on improved horticultural practices to ensure the longevity of collections and on the genetic basis of important horticultural traits such as disease resistance. Molecular markers have been developed for genetic diversity analysis and for the production of molecular genetic linkage maps. Families of avocado, mango, and jackfruit have been produced that should allow the mapping of the genes involved with disease resistance, fruit quality, and yield. A candidate gene approach is also being used to find genes involved with disease resistance and for control of flowering (Ayala-Silva et al., 2004; Schnell et al., 2001, 2003).

Brownwood, Texas, established 1984

The Brownwood Repository is located at 31.71° N latitude and has been the home of the USDA ARS Pecan Research program since 1933, when Louis Romberg began collecting pecan cultivars for use in breeding. On the recommendation of an active Crop Germplasm Committee, Romberg's grafted cultivar collections have been augmented by collections from native populations of pecan from throughout the range of the species (provenance collections) (Grauke et al., 1989), and by collections of other hickory (*Carya*) species, to provide the broadest base of genetically compatible germplasm. The 22 ha of Repository collections in Brownwood were supplemented in 1987 by addition of 21 ha at a worksite in Burleson County, Texas (30.52° N latitude). There are over 400 pecan cultivars in the collection represented by grafted trees at each worksite. Provenance collections are maintained as self-rooted trees, primarily at the Burleson County worksite. Over 300 provenance accessions are represented by up to 8 seedling trees each. Small collections of other hickory species from the United States, Mexico, and Asia (Grauke et al., 1991) are also maintained, with some accessions being represented only by herbarium or nut vouchers. Accessions are characterized for nut quality, phenology of growth and flowering, and for traits such as leaf and tree form. Research is focused on the refinement of descriptors for characterizing genetic diversity in *Carya* and the development of molecular genetic methods for fingerprinting accessions and characterizing populations (Grauke et al., 2003). A long-term goal of this Repository is the designation of appropriate and useful in situ reserves to more adequately represent this important native North American genus.

Geneva, N.Y., established 1984

The National Clonal Germplasm Repository for apple, grape, and tart cherry was established in 1984 on the campus of Cornell University in Geneva at 42.88° N latitude. In 1986, the Repository merged with the Northeast Regional Plant Introduction Station (NERPIS) and has been known since then as the Plant Genetic Resources Unit (PGRU). Currently, around 20,000 accessions are held, representing nearly 200 species and encompassing both seed-propagated and vegetatively propagated germplasm. The *Malus* (apple), *Prunus cerasus* (tart cherry), and *Vitis* (grape) collection comprises 5300 accessions. The PGRU also maintains a number of seed-propagated crops, including onion, tomato, and vegetable brassicas. Research activities focus on problems related to germplasm acquisition, collection management, and germplasm utilization, including application of whole plant phenotyping, cellular, and molecular markers to assess diversity of germplasm collections; development of improved apple rootstocks; and in vitro and cryopreservation of clonal and seed propagules.

The *Malus* collection includes 4000 accessions with 2500 of these maintained as trees grafted to EMLA 7 semidwarfing rootstock. Nearly all accessions are backed up in cryogenic storage at the National Center for Genetic Resource Preservation, Fort Collins, Colo. (NCGRP) as dormant buds; therefore, only one tree of each accession is maintained in the field. This provides a major cost savings by reducing acreage nearly 50%. The other 1500 accessions are seed lots or seedling populations from wild collections (Forsline et al., 2004). Seed collections are stored at –20 °C with equal amounts at PGRU and NCGRP. In addition, over 5000 seedlings are grown out and characterized at PGRU with some of these to be selected and maintained as clones. Others are used to produce seed backups (Volk et al., 2005).

The tart cherry collection includes approximately 100 accessions and represents the tetraploid cherries of *Prunus cerasus* and *Prunus fruticosa*. These are maintained as duplicate trees on MXM 2 rootstock. Over 50% are also backed up at NCGRP as dormant buds in cryogenic storage.

The grape collection consists of 1200 accessions, most of which are duplicated in the field as own-rooted plants. These accessions represent mostly North American native species and hybrids that are cold hardy and supplement the 2800 cold-tender *Vitis* accessions maintained in Davis, Calif. There is no cryogenic storage system for grapes, but maintaining them as own-rooted vines allows for reestablishment in the case of severe winter cold damage.

Hilo, Hawaii, established 1986

The National Clonal Germplasm Repository for Tropical Fruit and Nut Crops was initiated in 1986 as a joint cooperative project between the NPGS and the University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources. The Repository is located at 19.57° N latitude. The unit became one of the 4 research units at the U.S. Pacific Basin Agricultural Research Center (PBARC) in 1999 and was renamed the Tropical Plant Genetic Resource Management Unit. Collections include approximately 1000 accessions maintained as living plants on 13 ha of field plantings at 3 locations with selected germplasm grown in tissue culture and in greenhouses. The unit is responsible for 14 important tropical fruit and nut collections, including *Ananas*, *Artocarpus*, *Averrhoa*, *Bactris*, *Camellia*, *Canarium*, *Carica*, *Dimocarpus*, *Litchi*, *Macadamia*, *Malpighia*, *Nephelium*, *Passiflora*, and *Psidium* (Table 2). Research at Hilo focuses on germplasm maintenance, verification, and storage. Examples of research include in vitro storage, molecular fingerprinting, flower induction mechanism, fungal and bacterial diseases of tropical crops, and new crop evaluations (Keith et al., 2006; Matsumoto Brower 2006; Steiger et al., 2003).

Riverside, Calif., established 1987

The goal of the Riverside Repository is to provide the genetic diversity necessary to improve the productivity of citrus, date palms, and related taxa and to reduce genetic vulnerability of these crops for the future. This genebank is located at the University of California Riverside at 33.97° N latitude. Primary objectives are to collect, maintain, evaluate, preserve, and distribute pathogen-tested clonal germplasm of *Citrus*, 32 related Aurantioideae genera, and date palms and related *Phoenix* species. The secondary objectives are to conduct and encourage research on improved methods of maintenance, evaluation, preservation, and distribution.

The Riverside Repository is somewhat unique among the clonal repositories in that it is truly a cooperative program with the University of California (UC), Riverside. The largest number of *Citrus* genotypes is maintained in a university field collection that is shared between ARS and UC. However, as a result of the unknown pathogen status of plants in the field, ARS maintains an additional protected collection of pathogen-tested trees in screenhouses. Screenhouse trees are the primary source for clonal distributions. In addition, the Repository is accredited by USDA-APHIS and the California Department of Food & Agriculture for receiving foreign citrus introductions, which are used by both ARS and UC. Date palms are maintained by ARS at a UC facility in Thermal, Calif. Several satellite plantings of cold-sensitive genotypes are also maintained at other UC field stations. Research supporting the objectives of the Repository has focused on phytopathologic issues, including development of improved pathogen assays, investigation of abnormalities in field trees, and cooperative work with various entities toward establishing certification programs (Fang et al.,1997; Krueger & Roose, 2003). Research on molecular characterization has permitted the designation of a "core" collection.

Documentation of Collections—GRIN

The Germplasm Resources Information Network or GRIN is the national public database that provides both genebank personnel and germplasm users access to passport, characterization, evaluation, inventory, and distribution data from the national germplasm collections. In addition to plant germplasm, GRIN also supports the National Animal Germplasm System, the National Microbial Germplasm Program, and the National Invertebrate Germplasm Program (NPGS, 2005b). Each repository is responsible for entering and maintaining data for collections at their site. Several database query options are available to the public at http://www.ars-grin.gov/npgs/searchgrin.html.

Maintenance and Backup Strategies

Repositories must find a balance between maximizing diversity and minimizing the risk of loss. Some crops like apples, pears, pecans, and walnuts are economically maintained in long-lived orchard collections. Crops such as citrus, stone fruits, or strawberries are prone to insect-borne viruses and therefore must be protected in screenhouses to prevent plants from becoming infected. Maintaining multiple plants of each accession as in-house backup increases the security of the collection but reduces the space available for additional accessions. This is particularly true for potted plants maintained in screenhouses or greenhouses. Some repositories are using in vitro culture as a medium-term backup strategy for growing plants (Corvallis, Hilo, Mayaguez), and others are using cryogenic storage of either apical meristems or dormant buds for long-term backup (Corvallis, Geneva). However, for many tropical and subtropical crops, development of cryogenic or in vitro storage protocols is difficult and has not yet been implemented.

Distribution Policies and Procedures

Distribution of clonal germplasm is more complicated than distribution of seeds. Clonal repositories do not generally distribute finished rooted plants, but rather distribute scions or cuttings that must be propaguled by the recipient. Shipping of requested accessions is therefore dependent on the season when appropriate propagables are available. This might be early summer for strawberry runners or blueberry softwood cuttings or midwinter for grape cuttings or fruit tree scions. Propagation material of subtropical and tropical species is often available throughout the year. Germplasm is freely available from all NPGS Repositories in small quantities for research purposes. The National Plant Germplasm System distributes germplasm to foreign requesters in compliance with federal quarantine regulations and restrictions of the United States and the recipient country.

Pathogen Testing

Clonal repositories seek to distribute germplasm without disseminating germplasm-borne pathogens, including viruses, viroids, and phytoplasmas. Although not certified to be free of all known pathogens, much of the clonal germplasm in NPGS has been tested for the presence of common or important viruses and virus-like pathogens. Various testing methods are used depending on information available for each pathogen. Some pathogens can only be detected by inoculating indicator plants and observing symptoms, whereas other pathogens can be detected by modern laboratory methods (Jelkman, 2004; Martin, 2004; Postman et al., 2005; Schnell et al., 1997). Pathogen test results are often required before a phytosanitary certificate can be obtained for safe international germplasm exchange.

Characterization

Witt (1985), in his "BriefBook" on genetic diversity, quoted from a plant breeding report that compared germplasm collections with "pharmacies filled with miracle drugs without labels." We need to uncover the genes lurking in our germplasm that will allow us to develop cultivars able to overcome emerging diseases, adapt to changing climates, improve flavor, enhance nutritional value, and expand production into new environments. We must not only preserve our vanishing agricultural heritage, but also discover new sources of essential human nutrients, satisfy consumer desires for novel fruits and nuts, and implement reliable methods to identify and "fingerprint" genotypes. Identification and elimination of duplicate genotypes will allow us to make more efficient use of resources. DNA techniques have become useful tools for both identifying clones and for locating the genes associated with useful traits. Our germplasm is only as useful as the information that accompanies it. GRIN provides a place to store geographic locality coordinates that allow plant origin maps to be generated and that will associate accessions with climate and environment data. Each Repository, in consultation with a team of crop specialists, has developed a list of "descriptors" or key traits that are of interest to plant breeders. Germplasm users can query GRIN for plants with traits that meet their specialized needs whether as parents for breeding or representatives of a unique geographic area.

Technical Advisory and Crop Germplasm Committees

Brooks and Barton (1977) in their original proposal for national fruit and nut repositories proposed Technical Advisory Committees to guide the development and operation of each genebank and Crop Advisory Committees, later renamed "Crop Germplasm Committees" or CGCs to guide curators in the management of specific collections. CGCs are national working groups made up of specialists representing various disciplines and include federal, state, and private industry members. These committees help curators identify and fill gaps in U.S. collections, prioritize traits for evaluation, appraise research proposals, and help ensure the accuracy of data entered to the GRIN. CGC members also assist in the designation of core subsets (NPGS, 2005c). Fruit and nut crops represented by CGCs are:

- o *Carya*
- o *Citrus* and *Phoenix*
- o *Juglans*
- o *Malus*
- o *Prunus*
- o *Pyrus*
- o *Vitis*
- o Small fruits (berries)
- o Tropical fruits and nuts

Future Challenges

Twenty-five years after their inception, the NPGS Clonal Germplasm Repositories have established valuable national collections representing world diversity of not only commercially important fruit and nut cultivars, but also their wild relatives, which may have genetic traits of unanticipated importance. Cohen et al. (1991) defined 4 eras in ex situ crop germplasm conservation:

1. A period of exploration and acquisition from the early 1800s to approximately 1950;
2. A period of establishing conservation facilities from the 1950s to the 1980s;
3. A period focused on regeneration and research from 1980 to the second decade of the 21st century; and

4. A future era of enhanced utilization.

Workers at NPGS clonal genebanks had a late start on this roadmap, but have now entered the era where regeneration and evaluation of collections are priorities. Crop germplasm collections were originally conceived as a "hedge against starvation" (Loewer, 1991), but as collections become more complete, they become valuable for more than just crop improvement (Greene and Morris, 2001). Some species in NPGS collections are rare or endangered in the wild, making these genebanks conservators of plants that may become extinct in nature. Today's plant explorers build on knowledge of plant distributions that were often established by NPGS collectors. Secondary and tertiary gene pools captured in our genebanks are being used for basic research on evolution and genetic relationships. Patent and trademark attorneys consult the GRIN database and NPGS curators as important references on cultivar names or traits. Artists and photographers visit our collections to document accessions in other ways. Future challenges include identifying gaps in collections and acquiring plants to fill those gaps. Recent international agreements such as the Convention on Biological Diversity (CBD, 2006) and the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2006) have redefined the protocols for exchange of plant genetic resources between countries. National quarantine regulations that prevent the movement of insect and disease pests also impact international germplasm exchange. Genebank personnel will be challenged to maintain expanding collections with declining resources and transition from the acquisition phase to the evaluation phase as collections mature. Eliminating unintended redundancy, filling genetic gaps, and expanding phenotype and genotype data in GRIN will continue to enhance the value of the NPGS fruit and nut collections. Cohen's era of enhanced utilization (Cohen et al., 1991), when mature genebanks expand their partnerships with breeders, researchers, and stakeholders, has arrived for the NPGS clonal repositories.

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