Leafy Vegetables Crop Germplasm Committee Report
January 2004

I. Introduction

This report deals with the germplasm status of four major genera: *Lactuca* - lettuce and related species; *Apium* - celery and related species; *Spinacia* - spinach; and *Cichorium* – chicory and endive. The report is restricted to the status of public sector collections of the National Plant Germplasm System (NPGS). These collections comprise cultivars, landraces and wild species, which are tracked in the Genetic Resources Information Network (GRIN) databases once they have been assigned an NPGS Plant Introduction (PI) accession number.

A. Lettuce - This is economically the most important crop of the group. It is the most valuable fresh market vegetable grown in the U.S., with an estimated value of $2.26 billion in 2002. It is used exclusively as a fresh product, marketed mostly as a whole head. A significant portion of the crop, about 30%, is shredded or chopped for sale in a container to the restaurant trade or in consumer salad packs. The rising popularity of value-added salad products in recent years has resulted in a significant increase in acreage and value of the crop. Almost all lettuce is grown in California (75%) and Arizona (24%). In addition to its economic value, lettuce is increasing in importance as a research tool, in the areas of basic biology, physiology, and comparative genomics.

B. Celery - This is the second most important of the four leafy vegetables in terms of value, worth $242 million in 2002. Over 90% is produced in California, the remainder mostly in Michigan. Most celery is grown for fresh market, in the form of whole green stalks, or as hearts. Some is processed for inclusion in canned soup or juice mixtures or lightly processed as pre-cut sticks.

C. Spinach - Although the value of the U.S. spinach crop is less than that of celery ($179 million in 2002), the acreage devoted to spinach is higher, approximately 44,000 acres. About 30% of the acreage (but only 7% of the value) is for canning or freezing, while 70% is for fresh market, including increasing use as a raw salad vegetable. Prepackaged spinach has become increasingly important. Most fresh market production is in California or Arizona (78%) with a small amount in other states, whereas spinach grown for processing is grown almost exclusively in California (56%) or Texas (34%).

D. Chicory and endive - Most of the U.S. production (60%) of chicory and endive is from California, New York and Ohio. Although minor crops in this country, their value as a specialty crop was over $27 million in 2002. The bulk of world production is in four European countries: Italy, France, Belgium, and the Netherlands. Endive is produced in two forms, narrow leaved (endive) and broad-leaved (escarole). Chicory is forced in the dark (witloof), grown as a green leaf or red leaf (radicchio) vegetable, or grown for its root, which is used as a coffee additive or substitute. The root is also a source of high-fructose syrup and inulin, a food additive that functions as a filling agent and fat replacement and to prolong shelf life.

II. Present germplasm activities

A. Lettuce

Principal germplasm activities are in Salinas, CA; Pullman, WA; Davis, CA; Fort Collins, CO; and Geneva, NY. Pullman is the official NPGS station for *Lactuca*, housing PI accessions of *L. sativa* and several related species. The NCGRP (formerly NSSL) at Fort Collins houses a

collection of cultivars and a back-up collection of PI accessions held at Salinas and Pullman. The collection at Salinas is the largest in the U.S., containing cultivars, PI lines, genetic stocks and breeding lines, and is both a working collection and repository. Salinas and Pullman both distribute seeds upon request. The collections at Davis and Geneva are similar to the Salinas collection but smaller. Recent collection trips have been by Whitaker and Provvidenti in 1982, Seiler in 1990, and Hannan in 1996. Over 200 cultivated and wild lettuces were collected in Greece, Turkey, four former Soviet republics, and Bulgaria.

The status of the lettuce collections in Salinas and Davis has been documented in "Genetic Resources of Lettuce and *Lactuca* Species in California", by a task force assembled by the Genetic Resources Conservation Program of the University of California, Davis (1993).

B. Celery

The principal collections are at Geneva, NY; Davis, CA; and Fort Collins, CO. Geneva houses the official P.I. collection; Fort Collins has cultivars of celery and celeriac. The Davis collection is both a working collection and repository. A working collection that was formerly maintained in Belle Glade, FL, is now being maintained in the private sector. The most recent collecting trip was by Orton in 1980.

C. Spinach

The official NPGS collection is at Ames, IA. There is a collection of cultivars and PI accessions at Fayetteville, AR. The NCGRP at Fort Collins houses only a back-up collection of PI lines.

Beginning in 1994, accessions were sent from Ames to Salinas as a cooperative effort by the USDA and Sakata Seeds to regenerate the collection in isolation chambers. This has been very successful in reducing; 92 % of the 401 accessions are available for distribution. Regenerations were not made in 2003-2004 because so few accessions remain to be grown. The cooperative effort can be resumed when needed. The wild-species accessions have yielded poorly in the cooperative regeneration protocol seed regeneration system; only 27% of the 22 wild-species accessions are available for distribution. An effective protocol for regenerating seeds of wild *Spinacia* is a critical need.

D. Chicory and endive

The official NPGS collection and over 100 European cultivars are housed at Ames, IA; other collections are at Salinas, CA and Geneva, NY. The Salinas collection is primarily for preservation. The Geneva collection is also a working collection, primarily for virus resistance research. A small cultivar collection and a back-up collection of PI accessions are located at Ft. Collins.

III. Status of Crop Vulnerability

A. Lettuce

The size and redundancy of the known collections in this country and elsewhere make it extremely unlikely that the crop species will be subject to a drastic change in its genetic diversity (Tables I and II). The diversity itself is at a relatively high level. Lettuce occurs in seven major forms: crisphead (iceberg), butterhead, cos, leaf, stem, oilseed, and Latin types. The importance of these types varies from country to country; crisphead remains the most important in the U.S., butterhead is the principal type in northern Europe, cos in southern Europe, etc. There is

therefore a built-in maintenance of variability on a geographic scale. On the other hand, the increase in worldwide popularity of crisphead and romaine lettuce cultivars with a relatively narrow genetic base does threaten the diversity of the cultivar base, and therefore, the proper maintenance of collections assumes greater importance.
In the public sector, only the University of California and the USDA/ARS in Salinas, CA have active breeding and genetic research programs. Lettuce is subject to many diseases, in part due to extremely intensive monocultural production systems in the primary growing regions of CA and AZ. A major vulnerability is the worldwide dependence on single genes for resistance to downy mildew (*Bremia lactucae*), which have been rapidly overcome following their deployment.

B. Celery

The genetic base of celery is quite narrow. Most U.S. cultivars derive from 2 or 3 European introductions. The use of a wider germplasm base to breed for disease resistance is just starting. For example, celeriac is being used as a source of *Fusarium* resistance.

C. Spinach

There are few spinach breeding programs. In the public sector, only the University of Arkansas and the USDA/ARS in Salinas, CA have active breeding and genetic research programs. The program at Salinas was initiated in 2001, and represents a significant increase in research activity targeting the needs of this crop. As with lettuce, spinach is affected by many diseases and the production system is currently very vulnerable due to dependence on single genes for resistance to rapidly evolving races of blue mold (*Peronospora farinosa*). Also, since spinach is grown in the fall, winter and early spring, environmental hazards, particularly excess moisture, sudden freezes and high temperature periods, may be severe. The present germplasm base remains vulnerable.

D. Chicory and endive

As relatively minor crops, cultivars of these species may rest on a narrow genetic base, despite substantial morphological diversity. The known collections, composed primarily of European cultivars, are relatively small both here and elsewhere in the world. *Cichorium* is native to the Eastern Mediterranean basin, and the acquisition of wild species, landraces and obsolete cultivars should be a high priority.

IV. Germplasm needs

1. Collection

A. Lettuce

A combination of periodic collection trips (most recently to Greece, Turkey, Bulgaria, and four former Soviet republics) and good germplasm storage have kept the *Lactuca* holdings in relatively good shape. However, there are important gaps in the geographic coverage: notably from Eqypt, Iraq, Syria, and China. Stem type lettuces are important in Egypt and China. These lettuces are historically old and should be evaluated for possible contribution to breeding, most specifically in earliness of market maturity and of seed stalk elongation. Within *L. sativa*, landraces and primitive forms should be collected. Other traits for which collections are providing sources for improvement are: *Sclerotinia* resistance, *Botrytis* resistance, additional sources of resistance to lettuce mosaic, yellowing virus diseases, *Verticillium* wilt, pea leafminer, cucumber mosaic, verticillium wilt, lettuce aphid, and broad bean wilt, as well as genes for

improved quality and nutritional value. Of the four species that make up the present breeding pool, *Lactuca sativa* is well represented in the collections. *L. serriola, L. saligna,* and *L. virosa* are less well represented. In the future, genetic transformation and other technologies are likely to facilitate the use of a wider gene pool, or more distant relatives. In preparation, species that are not sexually compatible with these four should be collected, primarily from Africa, the Middle East and the Far East.

B. Celery

Collections of *Apium graveolens* are adequate, particularly at Davis, CA, but less so at Geneva, NY. The greatest need is for collection of related wild species, at least 20 of which are known only through herbarium specimens. The primary area for collection is South America, particularly from Chile and Argentina. Collecting should also be done in South Africa, Australia and New Zealand. Disease resistance (*Septoria* and *Fusarium*) and insect resistance (leafminers) are the greatest specific needs.

C. Spinach

In this country, limited collections are located at the University of Arkansas, Fayetteville, AR, at the NCGRP in Fort Collins, CO, at the NC-7 Station in Ames, IA, and at Salinas, CA. The collection at Ames emphasizes landraces in a region stretching from Yugoslavia to India. Northern European and Russian landraces are not well represented. There are very few cultivated materials from Japan, Korea, and southeast Asia. The two wild species of *Spinacia* (*S. tetrandra and S. turkestanica*) are now represented, but should be acquired from more areas. These deficiencies should be addressed through exploration and exchange with other gene banks in order to better represent genetic diversity.

D. Chicory and endive

All existing collections in the U.S. (Ames, Salinas, NCGRP) consist primarily of modern European cultivars. About 85% of the collection at Ames is made up of cultivars of *C. endivia* and *C. intybus*. The base of the *Cichorium* collection should be broadened by acquiring wild and landrace accessions from the Eastern Mediterranean.

2. Evaluation

The primary need in all crops is to proceed with evaluation of useful or potentially useful characters. In all crops, certain traits have been evaluated reasonably well, others not at all. For the leafy vegetable species, unlike for tomato, wheat and other major crops, there are relatively few researchers among whom to distribute evaluation assignments. Support is necessary to enable the few research groups to maximize their coverage of traits for evaluation. The lettuce group is the largest, with 10 to 12 people able to carry out evaluation assignments. Celery and spinach are researched by very few people and evaluation of more than a few of the more important traits would be difficult. There is very little research on chicory and endive in this country, although their consumption is increasing. In all crops, evaluation for disease resistance is the main evaluation activity and at the same time continues to be the area of greatest need. Insect resistance and basic physiological studies (bolting) are also important needs. The CGC is in the process of developing an up-to-date priority lists for evaluation.

3. Enhancement

Depending upon the crop and the situation, both public and private institutions have been involved in germplasm enhancement. Present activity in lettuce includes all stages of enhancement including official release of germplasm and cultivars. Cultivar release is done in both public and private sectors. In celery, California researchers have emphasized production of breeding lines that are stable for specific traits. Proper enhancement in spinach requires increased emphasis on public breeding. The needs for chicory and endive are as yet undetermined, but should be assessed.

4. Preservation

Seed storage facilities range from adequate to excellent. The lettuce collections in Salinas and at Fort Collins are stored at –18ºC. Other storages are at 4-5ºC at various levels of relative humidity control. The level of redundancy is very good for lettuce and spinach, good for chicory and endive, and fair for celery. This is outlined in Table I.

V. Recommendations

A. Lettuce - Evaluation and acquisition should remain top priority. There have been three recent collection trips; these should be continued, perhaps in conjunction with the collection of other species. Evaluation of disease and insect resistance, bolting activity, and reaction to environmental stresses are of paramount importance. Future evaluation should also include nutritional value. Significant advances in documentation of existing materials have been made in the last two years with extensive field and greenhouse plantings. New data, including disease resistance evaluation results, should be routinely entered into the GRIN system. Enhancement should continue in several programs and the quality of the storage facilities should be maintained.

B. Celery - Priority should be given to collection of wild *Apium* species. There are 20 known wild species, which are not well represented in collections. Geneva, NY has only one accession for one species and Davis, CA has only one or two for three other species. Other species are known only through herbarium specimens. The degree of danger of extinction in natural habitats is not known and should be determined. The potential usefulness of the wild species is extrapolated from the finding of several resistances to diseases and insects in available materials. A second priority is to determine cross compatibility between cultivated celery and related species.

C. Spinach - Collection of wild species and landraces from northern Europe, Russia and Eastern Asia is also important. The development of a descriptor list for *Spinacia* is underway and should be completed to make information available to the user community. During 2003 twelve descriptors were installed in GRIN and approved by the CGC. Since disease resistance is the main breeding concern, the highest priority should be given to acquiring disease resistance data on the NPGS collection for inclusion in GRIN. Insect resistance, bolting response, and adaptation to extreme environmental conditions are also important to the continued cultivation of this crop in the U.S.

D. Endive and chicory - Collection of wild species and landraces from the eastern Mediterranean is of high importance. Additional collections of European cultivars and breeding lines may be needed to fill in the gaps in these holdings. The evaluation and verification of existing cultivar collections would increase their potential utility to users as would development of a standardized descriptor list. Existing samples of cultivars may need to be selected for trueness-to-type and increased with controlled pollination. There is increasing interest in radicchio and cultivars with unusual leaf characteristics for use as specialty salad greens.

VI. Sources of funds

A. Present activity in public programs is supported largely by in-house research funds. In California, additional support for lettuce research is obtained from commodity group research funds. Portions of these funds are used for germplasm activities. It is legitimate to use these funds, as the germplasm activity supports breeding research. However, the level of germplasm preservation and characterization will always be limited by the need to make decisions about how to divide research support into research and germplasm needs. Therefore, there is a continuing need for unrestricted germplasm support through Federal funding.

Abbreviations:

NCGRP – National Center for Genetic Resources Preservation
NSSL – National Seed Storage Laboratory

Table I. Leafy vegetable germplasm collections in the United States

Location	Description of Collection	Storage Conditions
Lettuce		
Salinas, CA	1933 cultivars, 1275 PIs, 5200 breeding lines, 2900 genetic stocks; base and working	-18^{o}C, RH not controlled
Davis, CA	1600 cultivars, 1500 PIs, 1100 breeding lines, 13000 genetic stocks (DNA samples); working collection	5^{o}C, RH controlled
Pullman, WA	1287 PIs, 126 accessions	-10^{o}C, RH not controlled
Ft. Collins, CO	501 cultivars	-18^{o}C, 5-7% RH
Geneva, NY	100 cultivars, 572 PIs, 1000 breeding lines, 150+ genetic stocks	4^{o}C, 17% RH
Celery		
Davis, CA	250 PIs	5^{o}C, RH controlled
Geneva, NY	104 PIs, 107 accessions	-20^{o}C, 20-25% RH
Ft. Collins, CO	65 PIs; backup	
Spinach		
Ames, IA	401 PIs	4^{o}C, 30% RH
Fort Collins, CO	368 PIs, cultivars and hybrids	-18 C
Fayetteville, AK	600+ PIs and cultivars	-18 C, RH not controlled
Salinas, CA	779 PIs and cultivars; 65 cultivars and hybrids	-18 C, RH not controlled
Chicory/Endive		
Salinas, CA	200 cultivars, 19 PIs	-18^{o}C, RH not controlled
Ames, IA	249 cultivars and PIs	4 C, 25-27% RH
Geneva, NY	40 cultivars, 20 PIs, 100 breeding lines	4^{o}C, 17% RH
Ft. Collins, CO	158 accessions; backup	

Table II. United States production of leafy vegetables[a]

Item	States	Acres[b]	Value	Use	Export (%)
Lettuce	CA, AZ, CO, NJ	294	2261	Fresh	7
Celery	CA, MI	27	242	Fresh	12
Spinach	AZ, CA, CO, MD, NJ, TX	31	166	Fresh	9
Spinach	CA, TX	13.1	13.3	Canned, Frozen	?
Endive/ Escarole	CA, NY, OH, other	5.2	27.5	Fresh	?

[a] For endive and escarole, estimates provided are for 2001. For all others, estimates are for 2002.

[b] Figures are given in thousands of acres and millions of U.S. dollars.