SUGARBEET CROP GERMPLASM COMMITTEE REPORT ON THE STATUS OF *BETA* GERMPLASM IN THE UNITED STATES 2017

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Chapter 1 – *THE BEET CROP AND SUGAR PROCESSING*

Introduction to the Beet Crop[1]

Uses and types

The beet (*Beta vulgaris* L.) has been used as a source of food (leafy pot herb and root vegetable) throughout recorded history, first referred to in early Greek and Roman texts. We find reference to beet root for food and medicinal purposes during the Middle Ages, and later as a fodder plant. Today, *B. vulgaris* has a wide variety of types in addition to sugar beet, including the large mangel (fodder beet), red-, yellow-, and orange-colored table beet, and Swiss chard.

Sugarbeet is one of our newest major crop plants, having originated after a German chemist, A. S. Marggraf, first discovered sugar (sucrose) in beets in 1747. One of Margraff's students, Franz Karl Achard, with the help of Frederick Wilhelm II of Prussia, built the first sugar factory at Cunern in lower Silesia (modern day Poland). He improved the processing methods of the time, which produced poor concentrations of sucrose. He is considered the father of the sugar beet industry, because of his development of an economical beet sugar production in Europe.

Origin and adaptation[2]

The sea beet, which is the progenitor of the domesticated beet, is a native of the Mediterranean coastal areas but is found as far north along the Atlantic Coast as the U.K. and Scandinavia, as far east as India, and as far west as the Canary Islands. Sugarbeet has been adapted to many different types of climates. It is grown successfully in the temperate climates of Europe, the countries of the former Soviet Union (FSU), United States, Canada, Japan, India, and China, as well as parts of South America, North Africa, and the Near East. In the sub-tropics it is grown as a winter crop, often at elevation, while in temperate regions, it is grown as a spring-sown crop.

Introduction to the Beet Crop (Continued)

Sugar processing history

The first successful sugar factory began operations at Cunern, Silesia, in 1802, and from there, production spread from Northern Europe to the Mediterranean countries and eastward throughout the countries of the Former Soviet Union.

The first recorded efforts to extract sugar from sugarbeets in the United States on a commercial basis started in Northampton, Massachusetts, in 1838. The venture produced 1300 pounds of crude sugar in the first year of operation and went out of business 3 years later. Subsequent attempts were made in Utah, Wisconsin, Maine, Delaware, and California; and for various reasons, they were all short-lived.

In 1870, a processing plant was constructed at Alvarado, California, that proved to be the forerunner of the U.S. beet sugar industry. Expansion came rapidly, and, in the next 30 years, 39 plants were constructed. In 1986, there were 36 sugar-processing factories in operation. In 2005, there were 23 active factories in the U.S., producing more refined sugar.

Consumption and production today

In 2013/14 world sugar production was at about 179.68 Mt of which about 20% was from sugar beet and 80% from cane. In the U.S. about 55% is produced from sugar beet and 45% from cane. The U.S. produces about 85% of its own consumption of sucrose. Today, about 31% of the world sugar consumed and 47% of the U.S. sugar consumed is produced from sugarbeet.[3]

The industry has become more efficient and is processing more sugarbeets at fewer factories. In 1995, there were 34 sugarbeet-processing factories in operation, and, today, there are 22 factories in operation. Production in 2016/17 is predicted to be a record outrun of 5.371 million short tons, raw value[4].

All of the sugar beet processing in the U.S. is done by grower-owned sugar beet cooperatives with the exception of the processing plant in Worland, Wyoming. In 2002, the plant was acquired by Wyoming Sugar, an LLC which is owned by producer-investors, non-producer investors, and an association of sugar beet producers. The investment of sugar beet growers in the processing of sugar should lead to higher efficiencies through increased quality of the beets processed.

Beet Production

Value

Cash receipts for U.S. sugar growers vary with sugar yields and prices. Cash receipts for sugar beets were $2.442 billion in the 2014/15 crop year and $2.956 billion in the 2015/16 crop year[5]. The industry creates 142,000 direct and indirect jobs in 22 states, and contributes $20 billion in positive economic activity each year[6].

Production and acreage

Sugarbeets are grown in the U.S. under a wide variety of climatic conditions, from the north central states and Northern Great Plains to the low semi-tropic valleys of southern California. Approximately 270 million acres in the U. S. are estimated as suitable for sugarbeet production. See the following table for the acreages planted since 2004.

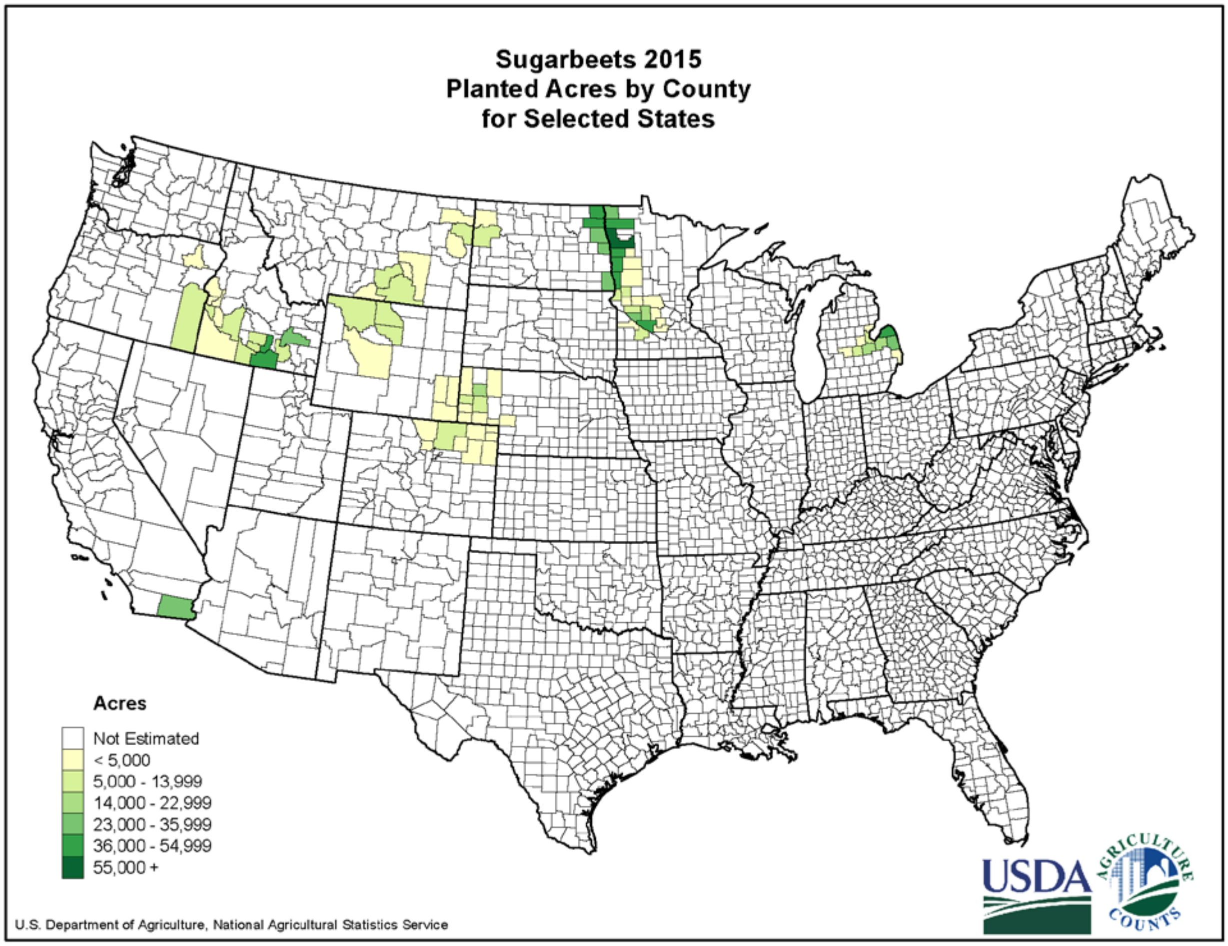
Growing Areas in the U.S.

There are four major sugarbeet growing areas in the United States, as shown in the map (Developed by the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS)) and tables following – The Great Lakes, the Upper Midwest, the Great Plains, and the Far West. Over the past 20 years, the total area cultivated to sugar beet has remained the same or shrunk a little. Nonetheless with the gains in productivity, sugar yield has keep constant with population growth[7].

The Upper Midwest Region

The largest growing area is the upper Midwest (Minnesota and North Dakota) centered along the Red River Valley, which planted about 650,000 acres in 2016. The American Crystal Sugar Company is a Minnesota agricultural cooperative corporation owned by about 3,000 sugar beet growers in the Minnesota and North Dakota portions of the Red River Valley. They own factories in Crookston, MN; Drayton, ND; Hillsboro, ND; Morehead, MN; East Grand Forks, MN; and Sidney, MT. The Southern Minnesota Beet Sugar Cooperative is a farmer-owned producer of beet sugar. The cooperative has over 500 shareholders that produce approximately three million tons of sugar beets every year. They own Factories in Renville, MN and Brawley, CA. Minn-Dak Farmers Cooperative is located in Wahpeton, a city in the southeast corner of North Dakota, in the heart of the Red River Valley. The Cooperative is owned by approximately 500 sugarbeet Shareholder-Growers who collectively grow 115,000 acres of sugarbeets. They own a factory in Wahpeton.

Map of production areas by county



Great Lakes Region

Michigan is the only state producing sugar beet in the Great Lakes Region with about 150,000 acres. Ohio has not planted sugar beet since 2004-2005. Michigan Sugar Company has more than 1,000 farmers growing sugarbeets on over 160,000 acres of land**.** It is the third largest beet sugar processor in the United States, producing an annual average of more than 1 billion pounds of sugar. They own four factories in Michigan at Caro, Bay City, Croswell, and Sebewaing.

Beet Production (Continued)

Table – U.S. sugarbeet crops from 2004 through 2016: area planted, by State and region 1[8/]

Year	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
State and Region						**Area planted - 1,000 acres**							
Great Lakes													
Michigan	165.0	154.0	155.0	150.0	137.0	138.0	147.0	153.0	154.0	154.0	151.0	152.0	151.0
Ohio	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	166.9	154.0	155.0	150.0	137.0	138.0	147.0	153.0	154.0	154.0	151.0	152.0	151.0
Upper Midwest													
Minnesota	486.0	491.0	504.0	486.0	440.0	464.0	449.0	479.0	475.0	462.0	440.0	443.0	437.0
North Dakota	256.0	255.0	261.0	252.0	208.0	225.0	217.0	231.0	222.0	227.0	215.0	208.0	213.0
Total	742.0	746.0	765.0	738.0	648.0	689.0	666.0	710.0	697.0	689.0	655.0	651.0	650.0
Great Plains													
Colorado	36.0	36.4	42.1	32.0	33.8	35.1	28.9	29.4	31.2	26.8	29.6	27.5	28.1
Montana	53.7	53.9	53.6	47.5	31.7	38.4	42.6	45.0	46.6	43.4	45.1	44.0	45.6
Nebraska	49.8	48.4	61.3	47.5	45.2	53.0	50.0	52.3	51.0	46.0	49.1	47.5	48.0
Wyoming	36.4	36.2	42.8	30.8	29.7	32.4	30.5	31.0	31.8	30.0	30.9	31.3	30.7
Total	175.9	174.9	199.8	157.8	140.4	158.9	152.0	157.7	160.6	146.2	154.7	150.3	152.4
Far West:													
California	49.1	44.4	43.3	40.0	26.0	25.3	25.6	25.2	24.5	24.4	24.3	24.7	25.3
Idaho	195.0	169.0	188.0	169.0	131.0	164.0	171.0	176.0	183.0	175.0	170.0	174.0	172.0
Oregon	12.9	9.8	13.1	12.0	6.7	10.6	10.3	10.9	11.0	9.4	7.5	7.8	10.7
Washington	3.8	1.7	2.0	2.0	1.6	NA	NA	NA	NA	NA	NA	NA	2.0
Total	260.8	224.9	246.4	223.0	165.3	199.9	206.9	212.1	218.5	208.8	201.8	206.5	210.0
Others 2/	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
U.S. total	**1,345.6**	**1,299.8**	**1,366.2**	**1,268.8**	**1,090.7**	**1,185.8**	**1,171.9**	**1,232.8**	**1,230.1**	**1,198.0**	**1,162.5**	**1,159.8**	**1,163.4**

1/ Relates to year of intended harvest except for overwintered spring planted beets in California
2/ Includes Arizona, New Mexico and Washington prior to 1996.

Beet Production (Continued)

Table – U.S. sugarbeet crops from 2004 through 2016: production, by State and region 1⁹/

Year	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2010/11	2012/13	2013/14	2014/15	2015/16	2016/17
State and Region						**Production - 1,000 tons**						
Great Lakes												
Michigan	3,238	3,573	3,487	3,903	3,318	3,822	3,672	4,437	4,009	4,395	4,787	4,589
Ohio	0	0	0	0	0	0	0	0	0	0	0	0
Total	3,238	3,573	3,487	3,903	3,318	3,822	3,672	4,437	4,009	4,395	4,787	4,589
Upper Midwest												
Minnesota	9,384	11,877	11,448	9,855	10,641	11,731	8,911	12,270	11,076	9,765	12,180	12,510
North Dakota	4,568	6,318	5,706	5,102	4,796	5,671	4,613	6,020	5,693	5,093	5,747	6,242
Total	13,952	18,195	17,154	14,957	15,437	17,402	13,524	18,290	16,769	14,858	17,927	18,752
Great Plains:												
Colorado	833	889	765	758	963	823	829	944	861	917	958	927
Montana	1,143	1,310	1,161	823	1,001	1,254	1,114	1,292	1,250	1,434	1,442	1,586
Nebraska	924	1,347	1,041	843	1,294	1,131	1,285	1,457	1,313	1,336	1,329	1,411
Wyoming	801	798	658	664	678	821	859	895	876	834	939	951
Total	3,701	4,344	3,625	3,088	3,936	4,029	4,087	4,588	4,300	4,521	4,668	4,875
Far West:												
California	1,636	1,556	1,388	1,052	1,106	1,137	1,172	1,066	1,055	959	1,104	1,108
Idaho	4,526	5,928	5,745	3,619	5,591	5,270	6,054	6,425	6,299	6,304	6,588	7,038
Oregon	311	394	351	195	395	374	387	418	357	248	297	428
Washington	69	74	84	67	NA	NA	NA	NA	NA	NA	NA	91
Total	6,542	7,952	7,568	4,933	7,092	6,781	7,613	7,909	7,711	7,511	7,989	8,665
Others 2/	0	0	0	0	0	0	0	0	0	0	0	0
Total U.S.	**27,433**	**34,064**	**31,834**	**26,881**	**29,783**	**32,034**	**28,896**	**35,224**	**32,789**	**31,285**	**35,371**	**36,881**

1/ Relates to year of intended harvest except for overwintered spring planted beets in California
2/ Includes Arizona, New Mexico and Washington prior to 1996.

Beet Production (Continued)

Great Plains Region

This area is dominated by the Western Sugar Cooperative, but there is a factory in Worland, WY, run by Wyoming Sugar Company, LLC and some acreage in Western Montana processed by Sydney Sugars, a subsidiary of American Crystal Sugar Company.

Over 850 Shareholders/growers own 134,150 shares of Western Sugar Cooperative. The Cooperative has a capacity to process 3.6 million tons of sugar beet per year. They own five factories located in Fort Morgan, CO; Scottsbluff, NE; Lovell, WY; Torrington, WY, and Billings, MT.

The Wyoming Sugar Company, LLC owns and operates sugar processing facility in Worland, WY, which has a slicing capacity of 3,600 tons/day. The company was founded in 2002 and is based in Worland, Wyoming.

Far West Region

The Far West region is dominated by the Snake River Sugar Company. The only other factory is run by Spreckels Sugar® Company in Brawley. Only about 25,000 acres service this factory but this growing region is unique in North America because sugar beet is grown as a fall planted – summer harvested crop and this area produces the largest sugar yields of refined white sugar in the world on a per area basis.

Since 1997, the Snake River Sugar Company has had operating control of Amalgamated Sugar Company. Snake River Sugar Company is a cooperative comprised of over 750 sugarbeet growers in Idaho, Oregon, and Washington. Amalgamated Sugar is the second-largest US sugarbeet processor, growing sugarbeets on approximately 180,000 acres in Idaho, Oregon, and Washington. They own factories in Nampa, ID; Twin Falls, ID; and Mini-Cassia, ID.

Spreckels Sugar® Company, a subsidiary of Southern Minnesota Beet Sugar Cooperative, is the producer of Spreckels Sugar products. Spreckels Sugar operates one beet sugar factory located in Brawley, California, and a beet seed processor located in Sheridan, Wyoming.

Trends in production[10]

Sugarbeet acreage harvested has remained constant or shrunk a little over the last few years. However tons harvested per acre have increased from an average of about 20 tons acre^{-1} in 2005 to more than 30 tons acre^{-1} in 2016. Increasing yield has compensated for decreasing acreage. Sugar beet production accounts for about 55% of domestically produced sugar (sucrose) and cane sugar for the remaining 45%.[11]

Beet Production (Continued)

Sugar beet for biofuel production[12]

There is a growing interest in sugar beet for biofuel production, either as ethanol or other liquid fuels. The European Union, the United States, and many Asian countries are interested in moving to renewable energy sources, including ethanol. A USDA study on ethanol production from sugar (2006)[13] stated it is still more cost effective to produce ethanol from maize than sugar beet, although molasses may be competitive. It states that, "Over the long term, the profitability of production ethanol form sugar cane and sugar beets depends on the prices of these two crops, the costs of conversion and the price of gasoline." The other conversation that will impact biofuel production is whether or not we can take land out of food production when we have a growing world population.

Production of garden beets

Red table beet is a minor but important crop in the U.S. Because of its close relationship to sugarbeet (both are *Beta vulgaris*), red beet can be successfully grown in many of the same regions of the U.S. Production of beets in the U.S. for canning was sourced from approximately 8,000 acres in 2012. Few data are available for production of fresh market red beet; however, this comprises an important vegetable commodity for sale at local markets and adds significantly to the acreage estimate above. Wisconsin produces approximately 47% of the U.S. red beet crop, and, historically, has been a leader in beet processing.

Baby salad mix and Salad mix

In recent years, red/orange table beets and Swiss chard have increased in importance in prepared (packaged) salad mixes and in baby leaf salads. In Monterey County in California alone, beet greens for salad have more than a $4 million value. Production also is important in Yuma, Arizona and in the Imperial Valley of California

Red beets grown for betalain dye

Betalain dyes from red beet roots have been successfully used in commercial food coloring operations for a number of years, and continue to be an important source of red coloring in the food industry. Many synthetic red dyes have been either banned by the Food and Drug Administration, or are in danger of losing their permitted status due to suspected carcinogenic effects. In addition, consumer preference for natural over synthetic products has increased dramatically in recent years, suggesting the widespread level of acceptance for natural food additives derived from plant tissues.

Beet Production (Continued)

Value added products & genetically enhanced sugarbeet

Between 2008 and 2014 beet pulp prices ranged from $300 to $550 per short ton on the Kansas City commodity markets[14]. In 2005, dried pulp, molasses, and other by products were worth about $0.02366 per pound of refined sugar.[15] With the acceptance of genetically enhanced sugar beet seed, first grown commercially on a trial basis in 2006 (glyphosate resistant), widely adopted by growers by since 2008; the opportunity for growing beets engineered for pharmaceutical production or production of specialty industrial feedstocks (e.g., beets have been genetically engineered to produce fructans) becomes available. These opportunities will be released only if there is a greater public acceptance of the use of genetically modified crops.

Chapter 2 – *STATUS OF SUGARBEET CROP VULNERABILITY*

Sugarbeet Crop Vulnerability

Introduction[16]

Breeding of sugarbeet began when Franz Karl Achard, a student of Marggraf's, found that fodder beets with white, cone-shaped roots deeply set in the soil were the highest in sugar content.

Original Germplasm

The early, open-pollinated sugar beet populations, were developed from the genepool of this white fodder beet, (the "White Silesian" Fodder Beet), which, by today's standards, had a very low concentration of sucrose.

Status of the sugarbeet crop vulnerability

The narrow base of sugarbeet germplasm coming into the 21st is exemplified by the quotations given below. Although single gene resistances are available to rhizomania, sugar beet cyst nematode and sugar beet root aphid resistance to other important diseases such as cercospora leaf spot or rhizoctonia crown and root rot are multigenic.

"Although it is likely that spontaneous hybridization with cultivated leaf-beet types as well as with the wild *Beta maritima* have contributed additional genetic variation, the genetic base of sugarbeet is probably narrower than that of most cross-pollinated crops." N. O. Bosemark, 1979[17].

"The dearth of major dominant genes that condition disease resistance in sugarbeet compared to other major field crops has been observed by most sugarbeet breeders." R. T. Lewellen, 1992[18].

Reasons for vulnerability

Vulnerability may be caused by a narrow germplasm base due to:

- Need for disease resistance, especially conditioned by more than one gene
- Single source of cytoplasmic-genetic male sterility (CMS)
- Single source of monogerm seed
- Single gene resistances (currently *Rz1* and *Rz2* deployed) to rhizomania (multigenic resistance also is available but not used)
- Single gene resistance to glyphosate

Sugarbeet Crop Vulnerability (Continued)

Important sugarbeet diseases[19, 20] & pests[21, 22]

- Aphanomyces root rot
- Curly top
- Rhizomania
- Pythium/Phytophthora
- Powdery mildew
- Virus yellows
- Cercospora leaf spot
- Fusarium yellows/wilt/stalk blight
- *Beet black scorch virus*
- Sugarbeet root aphid
- Aphids
- Root knot nematode
- Sugarbeet cyst nematode
- Sugarbeet root maggot
- Beet army worm
- Erwinia
- Rhizoctonia root rot
- *Beet soilborne mosaic virus*

Breeding for disease resistance

Developing disease-resistant germplasm is a major breeding effort because resistance to many of the important sugarbeet diseases is complex and poly-genic in inheritance. In areas with rhizomania, where resistance is conditioned by a single gene, we have seen resistance-breaking strains of the virus appear. Although these multigenic sources of resistance have proven durable, the use of a limited number of disease resistant parents could have the effect of further narrowing the potential germplasm base in those areas where disease resistance is required. This makes it important to use novel sources of disease resistance[23] to broaden the genetic base of our domestic gene pool.

Cytoplasmic-genetic male sterility (CMS)

All sugarbeet hybrids are produced by the use of cytoplasmic-genetic male sterility. Only one CMS source currently is being used, and all sugarbeet hybrids produced use this same CMS source. This tends to further narrow the genetic base of CMS females.

Monogerm seed

The female parents in all hybrids sold in this country are monogerm to allow precision planting to stand. There was a single source used of the gene for monogerm seed, which had the effect of further narrowing the genetic base of CMS females (and their O-type maintainer lines).

Single gene resistance to pests & diseases

Rhizomania (caused by *Beet necrotic yellow vein virus*) currently is controlled by the deployment of host-plant resistance. The original resistance was mediated by a single gene source of resistance, the Holly or Rizor resistance, designated[24] as *Rz1*. The original backcrossing of *Rz1* into commercial hybrids caused a drop in productivity but that has been recovered.

Another single gene resistance is to the sugar beet cyst nematode[25]. This gene provides tolerance to the sugar beet cyst nematode, i.e., allows some nematode reproduction but keeps damage to the plant below an economic threshold. This type of tolerance should be more stable than an immunity, but the possibility of nematode biotypes that could overcome the single gene resistance remains.

Resistance to the sugar beet root aphid also is conditioned by a single gene and this resistance has proven stable thus far.

Implications of New Disease & Pathogen Biotypes

Curly top

Curly top developed into a major disease problem in sugarbeet growing areas of the western United States in the 1920s, and devastated the crop[26]. Host-plant resistance developed in USDA-Agricultural Research Service (ARS) breeding programs saved the crop, nonetheless this disease still can be devastating when environmental conditions favor its development and non-resistant hybrids are grown.

Fungicide resistance in Cercospora

Cercospora leaf spot (CLS) is the most important foliar disease of sugarbeet worldwide. Fungicide resistance in *Cercospora beticola* is of critical concern to the sugarbeet industry. Strains that are resistant to nearly all classes of fungicides typically used to manage Cercospora leaf spot are present in every major sugarbeet growing region in the United States. Moreover, there is a growing population of *C. beticola* strains that are resistant to multiple modes of fungicide action. Strains resistant to the QoI class of fungicides were identified within nine years of their first use. Consequently, many growing areas have abandoned the use of this important group of fungicides. The reliance on a small number of fungicide modes-of-action for Cercospora leaf spot management does not appear sustainable. High-yielding CLS-resistant varieties are critical for the sugarbeet industry to be profitable.

Implications of New Disease & Pathogen Biotypes (Continued)

Rhizomania

In the early 1980s, Rhizomania (caused by *Beet necrotic yellow vein virus* - BNYVV) first was found in this country in California. It has since spread throughout the entire U. S. growing area. In 2007, we began seeing in the market place, rhizomania-resistant varieties[27] with yield potential comparable to susceptible varieties. However, the beet sugar industry in California has never really recovered from the devastating impact of this disease.

Resistance to rhizomania based on a single or few genes is not reliable. Resistance-breaking-strains, originally only found in a small area of France, have been identified in California and in the Red River Valley (Minnesota).[28] In these areas the resistance conditioned by *Rz1* has been overcome by changes in the pathogen. We are beginning to see in these areas 'stacked' resistance genes (*Rz1 and Rz2*) used to provide resistance. This plant-pathogen 'arms race' is what often is seen when single gene resistances are used. Furthermore, recent surveys conducted in the Red River Valley Region of ND and MN have shown that BNYVV strains have been identified in certain regions that can accumulate to high titers in varieties with stacked resistance genes (*Rz1* and *Rz2*). Resistance based on other genes will be necessary to manage this disease if these BNYVV strains become more widespread.

Powdery mildew

In 1974, a strain of powdery mildew appeared in and spread rapidly across the United States, causing 30 to 40 percent yield reductions in early infested fields. A costly spray program was put into place to check the disease. The perfect stage of this fungus was found in the U. S. in 2001[29]. This could lead to earlier infections and a more rapid breakdown of host-plant resistance.

Beet soilborne mosaic virus[30]

Beet soilborne mosaic virus (BSBMV) was first discovered in 1998 associated with BNYVV. It is another Benyvirus but separate from BNYVV, and has thus far not caused appreciable yield reduction, and therefore, no real disease management program has been developed, but the resistance is not the same as seen in BNYVV.

New and emerging diseases

In 2006, *Beet black scorch virus* was found in the U. S.[31] It previously had been reported only in China, and its potential effect on U. S. production was unknown. It has not proven to be an important problem in the U.S. since first discovered. However, with truly global commerce, it becomes difficult to predict what the next major threat may be, or where it might come from.

Implications of New Disease & Pathogen Biotypes (Continued)

Erwinia

Bacterial vascular necrosis and rot, often called Erwinia after the causal agent, (previously *Erwinia carotovora* subsp. *betavasculorum*, now *Pectobacterium betavasculorum*) has been a problem in the western U.S. (CA, OR, ID) when environmental conditions were favorable. It has become more common in areas where it has not been seen often in the past such as the Red River Valley (ND, MN). There is a report from the Red River Valley of a different species, *Pectobacterium carotovorum* subsp. *brasiliense* on beets that could be more aggressive.

Climate Change[32]

Every aspect of agriculture including sugar beet production will be impacted by climate change. Changes in temperature, rainfall, length of growing season have all been modeled. Interactions in a complex system like agriculture are hard to predict, especially the impact of change on the interaction of sugar beet and its disease causing pathogens and insect pests. There has been little research directed toward the effect of climate change on these interactions, but it is clear that we will need access to the entire diversity within the crop and its wild relatives to breed for adaptation to a changing climate.

Chapter 3 – *GERMPLASM ACTIVITIES IN THE UNITED STATES*

Section A: Historical Perspective

First breeding efforts

The first sugarbeet breeding efforts in the U.S., although short-lived, date back to 1890 when the USDA Sugarbeet Seed Experiment Station at Schuyler, Nebraska, was established. Private breeding efforts began about 1910, and, with the advent of World War I and the loss of European seed sources in Germany, major sugarbeet breeding activities developed in the 1920s and 1930s. Prior to that time, all sugarbeet seed was from European companies. Seed importation was halted again during World War II and this gave strong impetus to the development of a domestic seed production industry in the U.S.[33]

USDA-ARS breeding efforts intensified[34]

Devastating losses experienced in the 1920s from the curly top virus (not found in Western Europe) threatened the survival of significant portions of the U.S. industry. This prompted the USDA (then Bureau of Plant Industry - now Agricultural Research Service – ARS) to expand its breeding effort in 1925, concentrating on the development of sugarbeets with resistance to the curly top virus. From this time forward, sugarbeet research and breeding was of high priority and received a greater share of both public and private funds.

Cooperative breeding efforts developed[35]

Cooperation between public and private breeders resulted in curly top-resistant varieties, and developed into a cooperative breeding effort and working relationship that existed for about 40 years, with joint releases of commercial varieties. Other breeding technologies developed by USDA breeders (e.g., cytoplasmic male sterility, hybrid seed production, and monogerm seed) have been quickly adapted and utilized by private breeders.

Section A: Historical Perspective (Continued)

New emphasis of USDA-ARS breeding effort

The cooperation between ARS public breeders and commercial seed-company breeders has continued. It has grown into our current situation, where private company breeders develop hybrid varieties. There has been a transition of USDA-ARS breeding effort from commercial variety development to germplasm enhancement or pre-breeding, and high risk research. In 2017, all commercial hybrid sugar beet breeding is conducted by private companies, with the efforts of USDA-ARS geneticists are in the area of pre-breeding and introgressing genes from the crop wild relatives into sugarbeet.

Changes in the seed market

Until the late 1960s, each sugarbeet grower was obligated contractually to purchase seed from the contracting sugar company, which either produced its own varieties or had cooperative arrangements to reproduce varieties developed by the USDA-ARS. Starting in 1970, a number of European seed companies teamed up with U.S. companies to produce and sell seed in the U.S. Autonomous seed divisions of U.S. several beet processors began then to market seed to farmers producing beets for other companies. A consolidation of seed companies leaves three major players in the U. S. sugarbeet seed market (see page 21)

Erosion of USDA-ARS support

In 1970, there were 17 USDA-ARS scientists (geneticists and pathologists) involved in *Beta* pre-breeding activities. In 1996 there were 8 USDA-ARS scientists (geneticists and pathologists) involved in *Beta* germplasm enhancement activities. Currently, with the closure of the sugar beet program in Salinas, CA, there are 4 USDA-ARS geneticists/breeders involved in pre-breeding activities and 2 USDA-ARS pathologists involved in screening *Beta* germplasm for disease resistance.

University researchers

Currently there are two entomologists (sugar beet root aphid and sugar beet root maggot) and one nematologist (sugar beet cyst nematode) who screen *Beta* germplasm to support enhancement activities.

Section B: Organizations Involved in Germplasm

Sugarbeet Crop Germplasm Committee (formerly CAC)

Formation

The Sugarbeet Crop Advisory Committee (CAC), now Sugarbeet Crop Germplasm Committee (CGC), organized in 1983 as a committee of the American Society of Sugar Beet Technologists (ASSBT), consists of a national group of specialists representing federal, state, and private interests to provide critical analyses, data, and advice about the necessary activities for the effective conservation and use of *Beta* germplasm[36].

Issues of concern to the Sugarbeet CGC*[37]*

Crop Germplasm Committees are concerned with critical issues facing the NPGS including:

1. Identifying gaps in U.S. collections and developing proposals to fill these gaps through exchange and collaborative collecting trips.
2. Assisting crop curators in identifying duplication in the collections.
3. Prioritizing traits for evaluation and developing proposals to implement the evaluations.
4. Assisting crop curators and GRIN personnel in correcting passport data and ensuring that standardized, accurate and useful information is entered into the GRIN database.
5. Assisting in germplasm regeneration projects.
6. Identifying closed out programs and other germplasm collections in danger of being lost and developing plans to rescue the important material in these programs.
7. Working with quarantine officials to identify and ensure new techniques for pathogen identification which will assist in the expeditious release of plant germplasm.
8. Maintaining current reports on the status of their crops for the Congress, ARS National Program Staff and Administrators, State administrators and other key individuals involved with the National Plant Germplasm System (**NPGS**).
9. Evaluating the potential benefits and problems associated with the development and use of core subsets.

Sugarbeet Crop Germplasm Committee (formerly CAC) (Cont'd)

Accomplishments of the Sugar Beet CGC

- Developed essential protocol for and supervised the multiplication of the *Beta* collection.

- Developed a *Beta* descriptor list and identified priority descriptors for evaluation purposes.

- Advised and sponsored an evaluation program that has evaluated about one-half of the collection for the priority descriptors. There are over 38,500 evaluation data points in the GRIN database for sugar beet, making it one of the best evaluated crop species in the U.S. genebank.

- Represents the U.S. interests in the international arena and has been influential in the organization and management of an international organization for the conservation and utilization of *Beta* germplasm (World *Beta* Network)

- In conjunction with the World *Beta* Network (WBN) and the European Cooperative Programme for Plant Genetic Resources (ECPGR), a core collection for the genus *Beta* that is composed of accessions from the various national holdings documented in the International Data Base for *Beta* (IDBB) – e.g., a "Synthetic *Beta* Core Collection" (SBCC) – was coordinated with the USDA-ARS National Plant Germplasm System's (NPGS) *Beta* core collection.[38]

- Has recommended, planned, secured funding, and carried out plant exploration missions to fill gaps in the USDA-ARS National Plant Germplasms System's *Beta* collection.

Beet Sugar Development Foundation[39]

Formation

In 1943, the Beet Sugar Development Foundation (BSDF) was founded as a non-profit organization of sugarbeet seed companies and North American sugarbeet processing companies. It immediately began supporting USDA-ARS sugarbeet research. In 1996, it consisted of five sugarbeet seed companies and nine sugarbeet processing companies. In 2017, it consists of three sugarbeet seed companies, one seed technology company, and ten sugarbeet processing companies/cooperatives.

Mission Statement[40]

The membership of the Beet Sugar Development Foundation (BSDF) consists of Beet Sugar Processing Companies and Sugarbeet Seed Related Companies. The BSDF is active in research and development, education and technical programs of common interest to its members. The BSDF has a close working relationship with the United States Department of Agriculture, Agriculture Research Service and with many of the Land Grant Universities in sugarbeet producing states. The BSDF is dedicated to the advancement of sugarbeet production and beet sugar processing through science based research and leading educational programs.

Support of USDA-ARS research

The 1995 BSDF support of 36 USDA research projects amounted to approximately $372,000. The majority of this support was in germplasm development, with the goal of enhancing current USDA research projects.

In 2006, BSDF support of 26 USDA research projects amounted to approximately $345,000. The majority of this support continues to be in germplasm development, with the goal of strengthening current USDA research projects.

The research support, through small grants and joint nursery projects has grown over the last 10 years. This support for ARS researchers helps fund projects and allows the beet sugar industry to directly indicate its knowledge of where the industry sees that research best can be focused.

Table of USDA-ARS and Public Institute Researchers with a Major Emphasis on *Beta* Germplasm

USDA-ARS		**Germplasm Activities**					
Researcher	**Location**	**Screening**	**Disease Resistance**	**Breeding Methods**	**Cyto-genetics**	**Biotechnology & Genomics**	**Introgress Wild Beet**
L. E. Hanson	**East Lansing, MI**	✔	✔			✔	
J. Mitch McGrath	**East Lansing, MI**	✔	✔		✔	✔	✔
L. D. Campbell	**Fargo, ND**	✔	✔	✔			✔
L. W. Panella	**Fort Collins, CO**	✔	✔	✔		✔	✔
C. A. Strausbaugh	**Kimberly, ID**	✔	✔			✔	
I. A. Eujayl	**Kimberly, ID**	✔	✔	✔		✔	✔
B. Hellier	**Pullman, WA**	**Curator of the NPGS *Beta* collection**					

Public Institutions

J. Bradshaw	**Scott's Bluff, NE**	✔					
M. A. Boetel	**Fargo, ND**	✔					
S. Hafez	**Parma, ID**	✔					

Beet Sugar Development Foundation

Screening of NPGS PI germplasm

Currently the BSDF works with the USDA-ARS to manage screening of Beta collection germplasm by university collaborations. They have transitioned the BSDF beet curly screening nursery to screen hybrids and breeding lines for the sugarbeet seed industry, processors, and grower seed committees to the USDA-ARS station in Kimberly, ID. BSDF member companies also have stepped up to screen germplasm accessions for agronomic quality traits and helped increase seed from biennial accessions of the *Beta* collection at no cost to the Sugarbeet Crop Germplasm Committee.

Personnel & Facilities of Sugar Beet Seed Companies in the U.S.

Betaseed Inc.

Betaseed Inc. Seed is marketed in North America under the following brands: **Betaseed, ACH Seeds**.

Engaged in sugarbeet seed breeding, production, and marketing, Betaseed, Inc. has major research facilities in Shakopee and Randolph, MN and Kimberly, ID, and seed production and processing facilities in Tangent, OR. A facility in Moorhead, MN is engaged in research and sales activities. The sugarbeet seed company ACH Seeds is a Betaseed Inc. subsidiary. Betaseed, Inc. is a member of the KWS Group (KWS Saat SE). Headquartered in Einbeck, Germany, KWS is a company with a tradition of family ownership, and has operated independently for 160 years. It focuses on plant breeding and the production and sale of seed for corn, sugarbeet, cereals, rapeseed and sunflowers. KWS uses leading-edge plant breeding methods to continuously improve yield and resistance to diseases, pests and abiotic stress. The Group has operations in Germany, France and North and South America, and sells seed in 70 countries throughout the world.. Further information is available at: httpwww.kws.com
Further information is available at:

http://www.betaseed.com/
http://www.achseeds.com/

Personnel & Facilities of Sugar Beet Seed Companies in the U.S. (Continued)

SESVanderHave USA, Inc.

SESVanderHave USA, Inc. is an international sugarbeet seed supplier. The company's US office is located in Fargo, ND, with additional research operations in Idaho and California, and commercial seed productions in Arizona, Oregon, and Washington. Global headquarters are located in Tienen, Belgium, and SESVanderHave is owned by Florimond Deprez SAS of France, a family enterprise specializing in seed since 1830. US brands include SESVanderHave and Seedex.

Commercial seeds are processed by Holly Seed in Sheridan, WY.

Special programs for the USA include development of resistance to Aphanomyces, Cercospora, Rhizomania, Rhizoctonia, Fusarium, Root Aphid, Root Maggot, and Curly Top, in addition to yield and quality. Yield trial and pest nursery systems are present in the North Dakota, Minnesota, Idaho, and California.

SESVanderHave is a member of West Coast Beet Seed Company, and also has membership in the Beet Sugar Development Fund.

For more information:
Global website: www.sesvanderhave.com
US Websites: www.sesvanderhave.com/us and www.seedexseed.com

Follow on Facebook, Twitter, and YouTube.

Personnel & Facilities of Sugar Beet Seed Companies in the U.S. (Continued)

Syngenta Seeds Inc.

Syngenta Seeds, LLC Hilleshög® Sugarbeet Seed brand

Syngenta's North American sugarbeet seed business is headquartered at 11055 Wayzata Blvd. Minnetonka, MN 55305 with offices in Longmont, Colorado, where breeding, research, and seed production activities are conducted as well as the company's state of the art seed processing plant. Additional research, trialing, and seed production sites are located in Glyndon, Minnesota; Nyssa, Oregon; and Grants Pass Oregon. Global operations are centered in Basel, Switzerland with major sugarbeet sites in Sweden, Denmark, France, and Germany. Seed is marketed under the Hilleshög® and Maribo® brands in North America.

Syngenta is a leading agriculture company helping to improve global food security by enabling millions of farmers to make better use of available resources. Through world class science and innovative crop solutions, our 28,000 people in over 90 countries are working to transform how crops are grown. We are committed to rescuing land from degradation, enhancing biodiversity and revitalizing rural communities. To learn more visit www.syngenta.com and www.goodgrowthplan.com. Follow us on Twitter at www.twitter.com/Syngenta and www.twitter.com/SyngentaUS.

Activities:
Syngenta's sugarbeet activities for seed development in North America include extensive disease nursery testing for Cercospora Leaf Spot, Rhizoctonia, Aphanomyces, Rhizomania, Curly Top, Fusarium, Root Aphid, and other diseases, as well as, yield and sugar content.

Other seed companies in the U.S. market

In addition to the above companies, the following European sugarbeet seed companies below have been listed in the U.S.

- Kleinwanzlebener Saatzucht (KWS) A.G.
- Strube GmbH & Co. KG

Section C: Sugarbeet Germplasm Research

USDA-ARS Germplasm-related Research

East Lansing, Michigan

- Develop and apply genomic tools for agronomic trait gene discovery, including whole genome sequences and expression profiles of critical developmental stages.
- Characterize diseases prevalent in the Great Lakes growing region, and ascertain host-pathogen interactions for deploying genetic resistance.
- Identify targets of opportunity for enhancing germplasm, including transfer of desirable traits, especially disease resistance, from wild and unadapted germplasm into the sugar beet gene pool.
- Identify new genetic markers, determine the genetic control and linkage relationships of morphological, biochemical, and molecular markers, and use marker assisted selection to introgress useful traits into improved germplasm.

Fargo, North Dakota

- Develop agronomically useful germplasm with resistance to the sugarbeet root maggot.
- Examine the inheritance and interrelationships among traits related to sucrose yield and extractability.
- Introduce genetic diversity from the wild relatives of sugarbeet into commercial sugarbeet and select for traits related to root yield, sucrose concentration, and resistance to prevalent diseases.

Fort Collins, Colorado

- Screen *Beta* genetic resources for novel resistance genes (esp. to rhizoctonia crown and root rot and sugar beet cyst nematode) and incorporate new sources of resistance into commercially acceptable germplasm for release.
- Create long term *B. vulgaris* ssp. *vulgaris* x *B. vulgaris* ssp. *maritima* breeding pools for disease resistance (esp. to cercospora leaf spot, sugarbeet cyst nematode, and rhizoctonia root rot).
- Use genomic & proteomic technologies to understand genetic diversity in *Beta* species and important pathogen populations.
- Determine the genes underlying important agronomic traits and active in the sugarbeet-pathogen interaction and discover molecular markers for those traits.

USDA-ARS Germplasm-related Research (Cont'd)

Kimberly, Idaho

- Develop agronomically-superior germplasm with resistance to *Beet severe curly top virus* (BSCTV) and closely related species, *Beet necrotic yellow vein virus* (BNYVV), and *Erwinia carotovora* subsp. *betavasculorum* (Ecb).
- Develop molecular markers linked to sugarbeet QTLs that confer improved resistance to pathogens.
- Screen *Beta* genetic resources to identify novel sources of resistance to BSCTV, BNYVV, and Ecb and establish the inheritance of genes associated with this resistance.
- Screen germplasm for resistance to *Leuconostoc mesenteroides* subsp. *dextranicum*, which appears to be the primary causal agent of a recently described bacterial-like root rot complex that causes problems in the field and storage.

Pullman, Washington

- Maintain and regenerate the USDA-ARS National Plant Germplasm System *Beta* collection and manage its associated information.
- Acquire new *Beta* accessions by organizing and participating in collection missions to fill gaps in the USDA-ARS NPGS *Beta* collection
- Distribute needed seed samples and associated information to the research and education communities.
- Use molecular and genomic technologies to better understand and manage the genetic diversity in *Beta* species included in the USDA-ARS NPGS collection.

Germplasm Research at Public Institutions in the U.S.

University of Wisconsin, Madison

- Breeding and development of red table beets.
- Use of classical and molecular genetic techniques to characterize the genetics of horticulture traits including pigments and flavor.
- Development of red and yellow table beet germplasm with improved sugar content, better taste, smooth root, and improved shape and color.
- Breeding for Rhizoctonia resistance in table beet.
- Genetic and biochemical studies of geosmin, the earthy flavorant in table beet.

Screening of NPGS Plant Introduction

Some researchers at public universities work with the Sugarbeet CGC to screen PI's from the NPGS *Beta* collection for resistance to various disease and insect pests. Those currently screening *Beta* germplasm are:

- Dr. M. Boetel at North Dakota State University – sugar beet root maggot.
- Dr. S. Hafez at the Univ. of Idaho R & E Ext. Center in Parma – sugar beet cyst nematode.
- Dr. J Bradshaw at the University of Nebraska Panhandle Station in Scotts Bluff – sugarbeet root aphid.

Chapter 4 – *GERMPLASM NEEDS*

Section A: Status of the Beta Collection

Background

Introduction

Beet is classified taxonomically as Dicotyledoneae, Caryophyllidae (Centrospermae), Amarantheaceae (formerly Chenopodiaceae), *Beta vulgaris* L.[41]

Center of Origin[42]

The Near East is considered the origin of the genus *Beta*. The geographical distribution of *Beta* extends from the southeast to northwest, between 8° southern and 60° northern latitude. Wild forms are found in India, Central and European Asia, along the Mediterranean coasts of Europe and Africa, and the European shores of the Atlantic Ocean.

Taxonomy of the genus *Beta*

The taxonomy of the genus *Beta* is in flux currently as molecular analyses are being executed. The genus had been divided into four sections and 12 species, the sections being *Beta* (formerly *Vulgares*), *Corollinae*, *Procumbentes* (formerly *Patellares*), and *Nanae*, (represented by a single species endemic to Greece). In the last ten years, studies indicate that Section *Procumbentes* should be separated from the genus *Beta* and have assigned it to genus *Patellifolia* A. J. Scott et al.[43] Further studies have supported this division.[44]

Background

Table comparing the taxonomy of Ford-Lloyd compared with the changes suggested by Kadereit et al.[45]

System after Ford-Lloyd[46]	System after Kadereit et al.[47] *
Beta* sect. *Beta	***Beta* sect. *Beta***
B. vulgaris L.	*B. vulgaris* L.
B. vulgaris L. subsp. *vulgaris* (all cultivated form)	
B. vulgaris L. subsp. *maritima* (L.) Arcang.	*B. vulgaris* L. subsp. *maritima* (L.) Arcang.
B. vulgaris L. subsp. *adanensis* (Pamuk.) Ford-Lloyd & Williams	*B. vulgaris* L. subsp. *adanensis* (Pamuk.) Ford-Lloyd & Williams
B. macrocarpa Guss.	*B. macrocarpa* Guss.
B. patula Ait.	
Beta* sect. *Corollinae	***Beta* sect. *Corollinae* (incl. sect. *Nanae*)**
B. corolliflora Zos. ex *Buttler*	*B. corolliflora* Zos. ex Buttler
B. macrorhiza Stev.	*B. macrorhiza* Stev.
B. lomatogona Fisch. et May.	*B. lomatogona* Fisch. et May.
B. intermedia Bunge	*B. trigyna* Waldst. et Kit.
B. trigyna Waldst. et Kit.	*B. nana* Boiss. et Heidr.
Beta* sect. *Nanae	
B. nana Boiss. et Heidr.	
Beta* sect. *Procumbentes	***Patellifolia* A. J. Scott et al.**
B. procumbentes Sm.	*P. patellaris* (Moq.) A. J. Scott et al.
B. patellaris Moq.	*P. procumbens* (Sm,) A.J. Scott et al.
B. webbiana Moq.	

* This research material lacked *Beta patula*. They did discuss species relationships however without final conclusions. In fact, Kadereit et al. proposed a phylogenetic study with the aim to fully resolve relationships within the genus *Beta* and support Curtis[48] who first suggested that *B. procumbens* and *B. webbiana* may not be distinct species.

Section *Beta*

Background

The *Beta* section is by far the largest and most important to plant breeders. From it comes all the cultivated and economic forms of beet (sugarbeet, red garden beet, leaf vegetable beet, Swiss chard, and fodder beet). It is distributed widely and believed to be the oldest section. Taxonomically, Cultivated beets are separated into four culti-groups based upon morphology and end use: (1) Leaf Beet Group, (2) Garden Beet Group, (3) Fodder Beet Group, and (4) Sugar Beet Group.[49]

Taxonomy

B. vulgaris constitutes the majority of the germplasm in this section and is further subdivided into three subspecies;

- *vulgaris* (cultivated materials)
- *maritima* (sea beet, wild forms usually occurring along the coast line)
- *adanensis* (a relatively small group in the Aegean area)

B. macrocarpa and *B. patula* are from small geographical regions with little intra-population genetic diversity. Some of the *B. macrocarpa* is tetraploid.

Most subspecies of *B. vulgaris* intercross and produce fertile offspring. It also is possible to cross other species with section *Beta*, although progeny of hybrid plants sometimes lose vigor and must be backcrossed to one or the other parent.

Eco-geographic distribution of *B. v. maritima*

B. v. subsp. *maritima* (*B.v.m.*) can be split into eco-geographic regions. It is thought that the Mediterranean provided a refugee during the last glaciation and that as the ice sheet withdrew northward, *B.v.m.* then moved north along the Atlantic Coast.

- Middle Eastern Region (India, Pakistan, Iran, Iraq)
- Eastern Mediterranean Region (coastal shores of most Mediterranean countries east of Italy, as well as the shores of the black sea)
- Western Mediterranean Region (coastal shores of most Mediterranean countries west of the Adriatic)
- North Atlantic Region (coastal shores of France, Belgium, The Netherlands, Denmark, Germany, Southern Sweden, UK, and Ireland; also south along the coasts of Spain, Portugal, Morocco and the islands of Macaronesia).

They form a wide range of diverse types, from annual and biennial to perennial, from prostrate to erect growth habit, from monogerm to eight seeds per seed ball, and have wide ranges in root and leaf size and shape, and sugar content.

Section *Beta*

Collection of *Beta* germplasm

Since 1985, representatives of the Sugarbeet CGC have conducted four systematic collection expeditions of *B.v.m.*, three of the North Atlantic *maritima* and one in Egypt. As a result, much of the genetic diversity from the North Atlantic *maritima* has been preserved. Much of the Mediterranean *maritima* also has been collected and preserved through the efforts of cooperative teams from the USA, UK, Germany, Turkey, and Greece (See APPENDIX, Page 59).

Lack of wild germplasm from Middle East

Some old landraces from the Middle Eastern Region were obtained about 50 years ago; however, recently no systematic collections of wild forms have been conducted in these countries by outside agencies. Unfortunately, political conditions hinder collection of this germplasm at the present time. Because it is the center of origin of the species, wild forms from this area represent a wealth of genetic variation and should be collected or exchanged whenever possible.

Section *Corollinae*

Background

Species of this section are found in the mountains of western Iran, Turkey, and the Caucasus Mountains. They are perennial in habit, and are believed to have diverged from the Beta section in response to the mountain climates. There are no cultivated or economic forms belonging to this section; however, monogermity and resistances to curly top, virus yellows, drought, and low temperatures may be found in species of this section.[50]

Collection efforts

Through the efforts of past curators (Coons, Stewart, and McFarlane), a limited number of accessions has been obtained from species of this section. A 1990 expedition by representatives of the USA, Germany, and Former Soviet Union revealed few wild representatives of this section are still surviving in their natural habitat. In 1999 an expedition by representatives of Germany, Russia, Iran and Azerbaijan collected in Azerbaijan and Iran[51].

The *Beta* collection located at IPK in Gatersleben, Germany, contains a more complete representative collection of this section. Other collections contain a limited representation of the *Corollinae* Section germplasm.

Top priority should be placed on obtaining additional Corollinae germplasm, particularly from Turkey, Iran, and Iraq. This could be done either through exchange or through collection of existing wild populations.

Section *Nanae*

Background

This section contains one perennial alpine species occurring on mountain slopes in Greece. Current research has confirmed that this species has a very narrow distribution and little intra-genetic diversity. There is not enough research available to decide whether this species should be moved to section *Corollinae.*

Collection effort

In 1996, the NPGS collection only had one accession from this section, which was not backed up in the NSSL and probably was not viable. A high priority was placed on acquiring additional accessions of section *Nanae*.

Acting on this recommendation, in 2005 a joint plant exploration between the United States, Germany, and Greece was undertaken. This goal of this exploration was to assess the survival status of *B. nana*, 25 years after the last survey, and to establish a base line for future population monitoring and potential *in situ* conservation. Twenty-six populations on six mountains were surveyed and 20 seed accessions were collected for *ex-situ* conservation, research, and evaluation.[52] Microsatellite markers have been used to determine the spatial scale of genetic differentiation among populations and have shown a high degree of inbreeding and most of the genetic diversity between populations on different mountain tops.[53]

Patellifolia (formerly Section *Procumbentes*)

Background

The geographic distribution of the Procumbentes section is very narrow; i.e., along the Atlantic coasts of Spain, Portugal, Morocco and the islands of Macaronesia. This section is of little economic importance and is not used for food or fiber. Though not easily crossable to the species in Section *Beta* of the genus, *Beta*, the species in *Patellifolia* (formerly *Beta*, section *Procumbentes*) are potentially a rich genetic resource for cultivated sugar beet. The *Patellifolia* collection of the USDA-ARS NPGS contains 66 accessions of 3 species: *P. patellaris, P. procumbens,* and *P. webbiana.* All of the species have resistance to Powdery mildew, Cercospora leaf spot, and *Beet severe curly top virus*[54].

There has been recent investigation into the taxonomy of this and related genera in *Chenopodiaceae* subfamily *Betoideae*. Kadereit and co-workers support Curtis's observation that there are two species in this genus, while Thulin and co-workers suggest that all the species in the genus should be considered one variable species.[55] However, this is still subject to ongoing research.

Patellifolia (formerly Section *Procumbentes*) Cont'd

Nematode resistance[56]

A chromosome translocation from *P. procumbens* has been used as a source of resistance to sugar beet cyst nematode (SBCN) in sugar beet. The best source for high SBCN resistance or immunity has involved the transfer of resistance from through a terminal translocation from *B. procumbens* to sugar beet. Sugar beet cultivars carrying this $Hs1^{pro-1}$ gene are nearly immune to SBCN but there always has been a significant yield penalty (in the absence of nematode infestation) in commercial hybrids containing this resistance.

In the last ten years, partly because of problems with *P. procumbens* resistance, there has been a serious reevaluation of tolerance to SBCN found in *B.v.m.*. Commercial hybrids also have come to market utilizing the *B.v.m.* resistance source(s)

Collection efforts

A limited number of accessions from all three species of this section are maintained in the NPGS collection, especially *P. procumbens* and *P. webbiana.* The IPGRI conducted a systematic collection expedition for species of the Procumbentes section to the Canary Islands in 1981. Samples of all three species were collected from the coasts as well as from one inland site. Unfortunately much of this seed is gone.

Patellifolia patellaris was collected along with *B.v.m.* and *Beta macrocarpa* along the coast of Morocco in 2010 and 2012 (APPENDIX), however accessions from the other locations (Canary Islands (and the rest of Macaronesia), Spain, and Portugal) should be obtained. The other two *Patellifolia* species, *P. procumbens* and *P. webbiana* are poorly represented in the collection and also should be obtained – either through plant collection (when possible) or exchange. This is critical now when ongoing research to ascertain the relationship of these species is ongoing.[57]

Section B: Collection Priorities and Efforts

Introduction

Erosion of wild germplasm

It wasn't until the 1970s and 1980s that the preservation of *Beta* germplasm became a vital concern.

Report	Problem	Causes
1972	The vast store of *Beta* diversity in **Turkey** was being eroded.	The importation of improved cultivars and the contamination of landraces with modern cultivars during the regeneration of old cultivars by local farmers.
1982[58]	Wild beet was reported to be in danger of genetic erosion.	The effects of increased population pressure and tourism in **Sicily**.
1982	Wild beet was reported to be in danger of genetic erosion.	The effects of increased population pressure and tourism in **Greece**.
1985[59]	In **southern Italy**, the native populations of *Beta* are being gradually eliminated.	Extensive farming, the cutting and burning of roadsides, and increased tourism.
1992[60]	A reduction in the distribution of wild *maritima* in some coastal regions of **Turkey**.	Increased tourism and livestock grazing.

Results of these reports

These reports prompted a significant effort to collect and preserve the native, wild germplasm. This is an ongoing effort by beet researchers from around the world. The international database for *Beta* lists more than 11,500 *Beta* / *Patellifolia* accessions in 33 gene banks worldwide. Many of these are cultivated beets but certainly there are a large number of the crop wild relatives as well.

However, because species evolution no longer takes place in an *ex situ* gene bank collection, there is no further adaptation to their natural environment. Therefore, there also is increasing interest to provide *in situ* conservation of beet wild relatives in general, and *B. maritima* in particular.[61]

Crop wild relatives, especially sea beet, provide genetic resources for the cultivated beet to resist pathogens and withstand the effects of global climate variability. As our ability to manipulate the beet genome, increases the reservoir of genetic variability provided by crop wild relatives grows in importance.

Collection Efforts

Background

In the 1980s and early 1990s, concerned scientists, with the support of several national and international organizations, conducted almost 40 systematic collections throughout the Mediterranean and North Atlantic regions. As a result, much of the wild *Beta* of the Mediterranean and North Atlantic has been collected. (See table in APPENDIX) Explorations since then have concentrated on areas that are difficult to enter (Azerbaijan[62]), on holes in the collection (*Beta nana* in Greece[63], 2005; *Beta vulgaris*, subspecies *maritima*, *B. macrocarpa*, and *Patellifolia patellaris* in Morocco, 2010[64] & 2012), or areas that are easily accessible (*B. macrocarpa* in the Imperial Valley of California[65], *B. v. maritima* and *B. v. vulgaris*, Northern California)

Areas of high priority

Because the Mediterranean Areas of the Middle East are considered the center of origin of *Beta*, and the entire Mediterranean was the major refugee during the last major glaciation, these are areas of high priority. These also are areas embroiled in civil unrest and impossible at present to collect in. However some of those nations (esp. Iran, Iraq, Egypt, and Turkey) have institutions that are active in genetic resources and could be partners in germplasm exchanges.

Joint Collections

The international climate concerning genetic resources is difficult as present and we are excited to have been able to collect the Atlantic and Mediterranean Coasts of Morocco. ARS collections are funded through the proposals to the Plant Exchange Office (PEO) in Beltsville, MD, and The Guidelines for Plant Exploration Proposals are revised annually by this office and are freely available. As we continue to evaluate and regenerate our Beta collection, the loss of seed viability or the unwillingness of some countries to participate in joint collection missions reveals the gaps in the collection. Among the areas of particular interest are Spain and Portugal for *Beta vulgaris* subspecies *maritima*, *Beta macrocarpa* and *Patellifolia* species. Also interesting are the islands of the Macaronesia ecoregion, which includes the Azores, Canary Islands, Cape Verde, Madeira, and the Savage Isle. This island ecoregion contains a diversity of *Beta* species and there are many questions about gene flow among them and between Macaronesia and the coast of Africa.

Obtaining germplasm

At present, exchanges of seed with scientists or curators of these countries seems likely, the most practical means of obtaining wild germplasm from these regions. If we encourage scientists and curators to collect and preserve their wild germplasm, cooperative exchanges might be developed where we share desirable germplasm to exchange.

International Treaty[66]

Background

The FAO International Treaty **(IT)** on Plant Genetic Resources for Food and Agriculture is a legally-binding Treaty under the UN Food and Agriculture Organization **(FAO)**, has these objectives:

- The conservation and sustainable use of **PGRFA** (Plant Genetic Resources for Food and Agriculture)
- The fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security.

More than 130 nations are Parties. The U. S. (under Pres. G. W. Bush) signed in 2002; the U. S. Senate passed a Resolution of Ratification (advice and consent) on 28 September 2016. Therefore, the U. S. will become an IT Party 90 days after deposit of its instrument of ratification at FAO in Rome.

Some of the provisions of the IT

Nations have sovereign rights over "their" PGRFA and in exercise of those rights Parties agree to:

- Establish a MultiLateral System (**MLS**) for access to and benefit-sharing of certain PGRFA for conservation and utilization for research, breeding, and training, which improves food security.
- Establish provisions for PGRFA in International Agricultural Research Centers (**IARCs**, e.g., CIMMYT, IRRI, etc.).

The MultiLateral System

The IT covers all PGRFA. But the MLS includes:

- PGRFA of 64 food and feed crops key to food security; more crops may be included in the future. See Annex 1 of the IT – **it does include beet**.
- Under the management and control of national governments (e.g., US National Plant Germplasm System), in the public domain; or held by IARCs; or
- Made available voluntarily by private entities.

Germplasm access and exchange under the MLS are via the Standard Material Transfer Agreement (**SMTA**), which includes conditions for end use (excludes non-food and non-feed), conservation, and benefit-sharing upon commercial-ization.

International Treaty (Cont'd)

Effects of the US becoming an IT Party

1. US PGRFA users, both public and private-sector, will have guaranteed access to PGRFA from other Parties and IARCs.
2. Access will be granted according to the standardized terms of the SMTA; no additional negotiations needed.
3. US government will provide access to Annex 1 NPGS PGRFA to non-US users accompanied by the SMTA.
4. Terms of access to NPGS PGRFA acquired without an SMTA would not change for US users.
5. Does not affect use of PGRFA acquired pre-IT, nor domestic US PGRFA exchange.

Section C: Evaluation

Evaluation

Early Efforts

Until the organization of the Sugarbeet CAC in 1983, there had only been sporadic evaluation of the NPGS *Beta* collection. Most of the evaluations had been conducted based on need, i.e., as new problems or diseases became important, principle researchers evaluated the collection for that particular problem or disease. The most extensive evaluation was conducted by John Gaskill, USDA-ARS, Fort Collins; C. L. Schneider, USDA-ARS; and the Ames Regional Plant Introduction Station in the early 1960s.

CGC Efforts

Descriptor list:
One of the major objectives and concerns of the Sugarbeet CGC has been valuable and meaningful evaluation. Its first actions were to develop a descriptor priority list and an evaluation plan. This list and plan have been continually examined and updated to reflect shifting priorities over time.

Evaluation:
Since its formation, one of the major priorities of the Sugarbeet CGC has been the evaluation of the NPGS *Beta* collection.

Evaluation Progress

Since the involvement of the Sugarbeet CGC, close to 50% of the wild accessions in *Beta* collection have been evaluated, including much of the *B. v.* subsp. *maritima* collection. This makes this one of the best characterized collections in the NPGS.

Hundreds of accessions have been evaluated for important disease and pest resistances, agronomic factors, morphological traits, and diversity using a number of traditional and molecular tools. In 2017, there were close to 40,000 observation data points on a relatively small collection of about 3500 accessions.

Funding for evaluation

Much of the Sugarbeet CGC evaluation had been done under an ARS Current Research Information System Project (CRIS) at Ames, IA, for this specific purpose. Unfortunately, this CRIS was lost when the collection was transferred to Pullman. Current funding is by the competitive NPGS grant program available through the USDA-ARS National Program Staff (NPS) or through research projects of ARS, university, or industry scientists.

Evaluation

Current evaluation procedures

Funding has been requested from USDA National Program Staff for funding to evaluate 30 accessions for 2017. In the past, usually enough funding to evaluate part of the 30 accession sought is granted. The table below shows the evaluators, their location, the trait evaluated, the cost per accession, and the number of accessions that the CGC would like evaluated. The changes from 2006 to 2017 also are shown.

2006 Evaluator(s)	Location	Descriptor	$/each	Number sought
R. Lewellen	Salinas, CA	Rhizomania	100	30
L. Hanson & M. McGrath	East Lansing, MI	Cercospora	100	30
L. Panella	Fort Collins, CO	Rhizoctonia	100	30
M. Boetel	Fargo, ND	Root Maggot	100	30
J. Michels	Bushland, TX	Root Aphids	100	30
S. Hafez	Parma, ID	Cyst Nematode	125	24
R. Lewellen	Salinas, CA	yellowing viruses	0	30
R. Lewellen	Salinas, CA	Morphological	0	30
R. Martens	Longmont, CO	Agronomic	0	30
BSDF	Twin Falls, ID	curly top virus	0	30

2017 Evaluator(s)	Location	Descriptor	$/each	Number sought
C. Strausbaugh	Salinas, CA	Rhizomania	100	30
L. Hanson & M. McGrath	East Lansing, MI	Cercospora	100	30
L. Panella	Fort Collins, CO	Rhizoctonia	100	30
M. Boetel	Fargo, ND	Root Maggot	100	30
J. Bradshaw	Scottsbluff, NE	Root Aphids	150	20
S. Hafez	Parma, ID	Cyst Nematode	125	20
Industry		Agronomic	0	30
C. Strausbaugh	Kimberly, ID	curly top virus	75	30

Evaluation

Needs

Why do we need to evaluate the collection? J.R. Stander gave an excellent answer to this question[67]. "The broadening of the genetic base of crops requires a system of well maintained and appropriately described collections. Classification, characterization, and pre-breeding of materials in collections will greatly stimulate their use by private plant breeders. In the absence of these activities private breeders will, in general, continue to ignore the collections."

We have concentrated on screening the 700 accessions of Beta vulgaris subspecies maritima, and as seen in the list below have done very well with some resistance traits, but there is still a way to go, especially for agronomic traits, and other morphological traits that might affect yield, e.g., drought resistance. We also have a number of sugar beet and other cultivated beets to screen for diseases such as rhizomania, which was not known when many of these cultivated accessions were entered into the GRIN system.

Disease	No. screened
Aphanomyces	388
Beet Cyst Nematode	392
Cercospora	911
Curly Top	804
Rhizoctonia	803
Rhizomania	713
Root Aphids (1 – 4)	233
Root Aphids 1 – 9)	152
Root Maggot	680

Section D: Enhancement

Introduction

Declining USDA-ARS personnel

In 1970, there were 17 USDA-ARS scientists (geneticists and pathologists) involved in *Beta* germplasm enhancement activities. In 1996 there were 8 USDA-ARS scientists (geneticists and pathologists) involved in *Beta* germplasm enhancement activities. Currently, with the closure of the Salinas, CA station, there are 6 USDA-ARS scientists (geneticists and pathologists) with the probable loss of 2 more within the next year due to retirement. If those positions are not replaced with geneticists involved in germplasm enhancement, public pre-breeding in the US will be slowed and possibly terminated.

USDA-ARS Contributions

ARS scientists have made significant contributions to the beet sugar industry in the US and worldwide. The development of monogerm and cytoplasmic-genetic male sterility by USDA breeders are landmark achievements of worldwide importance, as is the work done on rhizomania in Salinas, California by USDA-ARS. ARS scientists have released over 1,000 germplasm in the last 100 years that have been available to private and public breeding programs[68].

Although it is difficult to quantify the impact that USDA-ARS sugar beet research and germplasm releases have had on the beet sugar industry, they have had a major impact in the survival and stability of the industry[69].

CGC areas of prime importance

A major focus of the Sugarbeet CGC has been the pre-breeding of enhanced germplasm, especially when a long term commitment to introgression of novel genes is likely to be required. This has become an excellent area of collaboration between ARS breeders and the beet seed company breeders. Those areas of enhancement that are ongoing or concurrently initiated are of prime importance to insure continued progress. Emphasis has been placed on the following areas.

The major areas of focus currently are:

1. Discovering novel sources of pest resistance and accompanying molecular markers
2. Defining genetic variability of important traits within crop wild relatives

Areas of interest into which we are moving include:

3. Mapping the genes controlling important traits in the sugar beet genome
4. Discriminating the genes and genetic mechanisms responsible for pest resistance

Novel Sources of Pest Resistance

Background

Because of the polygenic nature of many of the resistances to disease and pests that have been identified, these resistances have proven durable over time. However, because of the difficulty of transferring this type of host-plant resistance (polygenic), there has been more interest in easily transferrable traits or chemical management of disease problems.

Of sugar beet's crop wild relatives, *B. vulgaris* subspecies *maritima* (*B.v.m.*) best fits the requirements for new sources of genetic variation[70,71].

1. In its native habitat, *B.v.m.* exists over a wide range of environments.
2. Its adaptation and survival to this wide range of, often harsh, environments has caused it to accumulate stress resistant and growth genes that are different from our cultivated sugarbeet.
3. Over the past 30 years, new *B.v.m*. accessions have been collected and made available for breeding purposes.
4. Many breeders have reported success in incorporating genes from this wild sea beet into sugarbeet germplasm

Resistant germplasm currently available

Single resistances are now in use for tolerance to BNYVV (rhizomania), sugar beet root aphid, powdery mildew, and sugar beet cyst nematode. When have seen the *Rz1* gene for rhizomania resistance overcome and now there are hybrids available with *Rz1Rz2* resistance genes stacked.

There also are multi-genic sources of resistance for disease like rhizoctonia crown and root rot, *Beet curly top virus,* fusarium yellows, cercospora leaf spot and others. These resistances often are used in combination with a chemical protectant, and sound cultural practices to provide growers a system to manage diseases (e.g., IPM).

Novel Sources of Pest Resistance (Cont'd)

Future Needs

In the case of almost all diseases, there is a strong need to bring in new sources of resistance. In some cases, such as with rhizomania, the single gene resistance (*Rz1*) has been overcome by some strains of the virus. The *Rz2* resistance has been able to shore up the resistance but with almost all of the US acres planted to rhizomania resistance varieties, new sources of resistance need to be sought. For some disease resistances/tolerances, such as to cercospora leaf spot, the resistance alone is not sufficient to provide the necessary protection. A new source of resistance might be stronger or might give a transgressive expression of resistance, which would be stronger than either source by itself. The introgression of genes from crop wild relatives will have the added benefit of broadening the genetic base of the commercial germplasm.

Genetic variability within crop wild relatives

Locating genetic diversity

Within sugar beet's wild relatives, locating, describing, collecting, and quantifying genetic variation is an ongoing activity of the sugar beet crop germplasm committee and the USDA-ARS's genebanks. Often a gene (or genes) controlling a trait is constituted the same within cultivated crops because only one version of that gene was introgressed. There may be a range of variation (different alleles) of that gene within the crop wild relatives, and this variation may be a source of better efficacy in the disease resistance.

If we understand how diversity is spread throughout the wild species, we can direct or efforts in collecting and screening germplasm much more efficiently. A knowledge of the geographic locations of domestication and the geographic extent of species range might allow us to look for alleles, in locations that have not yet been collected and screened.

Genetic variability within crop wild relatives

Tools for measuring genetic diversity

There are many ways to measure genetic diversity and with today's resources we can measure from the phenotype to the genotype with all of the steps in between. What we are most interested in is the phenotype (often disease resistance) and if we can develop markers (molecular or otherwise) that help us select the desired phenotype so much the better. Measuring genetic diversity per se may give us clues to the geospatial spread of the species, or the center of origin but does not necessarily provide the best means of mining alleles desired for specific agronomic traits[72]. We want to be measuring diversity in the trait of interest – phenotypically through whole plant screening, and also genetically through following the changes at the base pair level in the gene if that information is available.

Putting variation to work

The USDA-ARS research at Salinas, California, is a good example of building a robust pre-breeding program on genetic diversity for resistance to rhizomania. When rhizomania first was found in the US, it was in California. Robert Lewellen screened many of the PIs from our *Beta* collection looking for any resistance sources. That germplasm was screened, put into a useful genetic background and released to the sugar beet seed companies. By backcrossing 10 different sources into the same genetic background, tools for further analyses and molecular mapping, in addition to the large number of rhizomania resistant germplasm that were released[73].

Section E: Preservation

Background

Background

Pollination within the genus *Beta* largely is by wind. Isolation of germplasm during seed regeneration is essential to prevent cross contamination.

Historical problems with the *Beta* collection

Insufficient isolation facilities, improper climate, and lack of expertise to contain the wind-borne pollen were problems early on at the Plant Introduction Station in Ames, where the NPGS *Beta* collection had been located. Early seed increases had resulted in some germplasm mixtures because of unrestricted pollen flow. The user community had been reluctant to utilize germplasm from the *Beta* collection because of the apparent contamination of some of the accessions.

Early CGC efforts to improve the seed increase process

This problem was a major concern of the newly formed CAC. Two complementary solutions were initiated to improve the increase of Beta accession seed and insure its purity.

A total of 13 public and private geneticists regenerated about 60 accessions at no cost to the CAC.

A contract was made with a retired ARS employee, Onas Mays, with expertise in *Beta* seed regeneration.

- Done in Logan, UT, in pollen-proof tents
- 100 accessions/year under controlled isolation conditions

With the retirement of Mr. Mays there was no one in Logan that could competently continue the program

Current Process of Seed Regeneration

Importance of this program

The seed regeneration program is the most valuable link in the *Beta* germplasm program. Without it, collection and evaluation efforts would be of little value.

Implications:
Because of this, and also, because this project also has had a very positive influence in arranging seed exchanges and obtaining germplasm from foreign sources, it is imperative that the funding of this effort be increased and that there continues to be funding of the Western Regional Plant Introduction Station at least at the current level of operation.

Status of the *Beta* collection in Pullman, WA

The USDA-ARS National Plant Germplasm System (NPGS) *Beta* collection transfer to the Pullman Plant Introduction Station was completed in 1994. Dr. Alan Hodgdon was hired as curator and worked on the collection until his retirement in 2004. Barbara Hellier is the current curator for the *Beta* collections (and other collections), and, currently, is working on regenerating, characterizing, and maintaining the collection. She has headed collection trips, managed the greenhouse and field regenerations, and worked closely with the users of the collection, both within and outside of ARS.

Priorities for regeneration

In 1996, the CGC and curator of the collection prioritized the *Beta* regeneration efforts based on seed number, germinability, and age of seed – in 1996:

1. Hard seeded accessions due to low seed number and miscellaneous wild types of very low quantity.
2. Wild types and old landraces that have not been regenerated for a long time.
3. USDA/ARS releases from the NSSL.

In 2017, in collaboration with our curator, Barbara Hellier, using the same criteria, we have been:

1. Continuing to work to regenerate hard seeded wild-types
2. Increasing all of the *Beta vulgaris* subspecies *maritima* accessions for screening
3. Working with industry partners to regenerate biennial, cultivated beets
4. Assuring that all accession in Pullman are backed up in Fort Collins at the National Laboratory for Genetic Resources Preservation

Current Process of Seed Regeneration (Cont'd)

Summary of NPGS Beta Germplasm Holdings

Total number of accessions, number backed-up and number available per species in the NPGS Beta collection (includes the genus Patellifolia, formerly classified as Beta).

Taxon	Total Accessions	Accessions Backed-up	Accessions Available
Beta corolliflora	4	3	0
Beta lomatogona	29	4	2
Beta macrocarpa	55	12	28
Beta macrorhiza	19	2	1
Beta nana	21	0	0
Beta patula	3	3	1
Beta sp.	16	5	3
Beta trigyna	48	5	7
Beta vulgaris ssp. *maritima*	627	409	408
Beta vulgaris	12	2	5
Beta vulgaris ssp. *vulgaris*	1819	1549	1247
Beta vulgaris ssp. *vulgaris (NLGRP)*	19 *		
Beta x intermedia	8	1	1
Patellifolia patellaris	45	14	13
Patellifolia procumbens	13	5	5
Patellifolia webbiana	8	2	1
Patellifolia hybrid**	2	1	1

*Recent USDA-ARS releases

**One accessions *P. patellaris* x *procumbens* and one P*. procumbens* x *webbiana*

Future regeneration plans

As we continue to evaluate and characterize *B. v.* subspecies *maritima* accessions, it is important to have seed available of the screened accessions for distribution. The curator is focused on regenerating wild relatives of sugar beet, especially hard seeded types. We will continue working with our industry and ARS partners to regenerate germplasm and other *B. v.* subspecies *vulgaris* accessions. With close to 3,000 accessions in the *Beta* collection, ideally we would regenerate every 30 years, which would require the capacity to regenerate 100 accessions every year. This remains the goal of our regeneration efforts but additional infrastructure is needed to meet this goal.

Chapter 5 – *PRIORITIZED NEEDS AND RECOMMENDATIONS*

Recommendations

Goals

The ultimate goal of the entire germplasm effort is the enhancement and development of superior germplasm for the seed producer to provide superior hybrids for the grower, to insure a continued, viable industry. This will not be possible without satisfying the priorities listed below. Continued breeding progress is dependent on the availability (germplasm collection, seed multiplication, and germplasm maintenance) and evaluation of genetic resources.

Priorities

The priority of needs and actions for *Beta* germplasm are in the following order:

1. SEED REGENERATION
2. GERMPLASM EVALUATION
3. GERMPLASM ENHANCEMENT
4. GERMPLASM COLLECTION

1st Seed Regeneration

As seen in the summary table above, there still is a need to regenerate and replenish *Beta* seed stocks. Although currently at acceptable levels, use for screening and enhancement efforts require continued regeneration of seed stocks. This is especially true as more researchers are using molecular tools to look at the diversity in the *Beta* collection.

It is recommended that funding for the *Beta* collection at the Western Regional Plant Introduction Station in Pullman, be at a level to enable the continuous regeneration of 100 accessions per year.

2nd Germplasm Evaluation

There has been an excellent start in this area but there is still half of the NPGS *Beta* collection to evaluate.

It is recommended that to do this in a realistic time-frame, the amount of money made available for evaluation should be increased to at least $50,000 per year.

Recommendations (Cont'd)

3rd Germplasm Enhancement

Those areas of enhancement that should be ongoing or concurrently initiated in order to insure continued progress are of prime importance.

1. Discovering novel sources of pest resistance and accompanying molecular markers
2. Defining genetic variability of important traits within crop wild relatives
3. Mapping the genes controlling important traits in the sugar beet genome
4. Discriminating the genes and genetic mechanisms responsible for pest resistance

It is recommended that there is a critical need for more ARS Research Scientists to address the above areas. Another Category I scientist with support at each of the sugarbeet research locations would be a good start in addressing these areas. Certainly, at a bare minimum the three Category I scientists lost with the closure of the Salinas sugar beet program must be replaced.

4th Germplasm Collection

Some native populations of wild *Beta* are in danger of extinction, and a very high priority should be placed on their collection preservation. We have made a good start with the 2005 collection trip to Greece for *Beta nana.* We should also be ready to collect or exchange accessions in the Middle East whenever the political climate allows.

Section *Beta*: Since the Middle East is considered the birthplace of the species, wild forms form this area should represent a wealth of genetic variation and should be collected whenever possible, especially from those areas where an opportunity presents itself or a gap in the current collection is found.

Section *Corollinae*: Top priority should be placed on obtaining additional *Corollinae* germplasm, particularly from Turkey, Iran, and Iraq or others countries that border the Black Sea.

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Appendix

Beta/Patellifolia collection expeditions conducted since 1972 are listed in the table below.

Country	Year	Samples	Gene Banks Where Stored *	Collector, Agency
Turkey	1972	205	UK (BIRDPB), Turkey (AARI)	Williams, Ford-Lloyd, Turkey
Turkey	1978-88	47	Turkey (AARI)	Tan, PGRRI, Turkey
Greece (Isle. etc.)	1980	86	Greece (GGB)	Crombies, GGB, IBPGR
Greece (Isle. etc.)	1980	24	Greece (GGB)	Dale, GGB, IBPGR
Canary Islands	1981	93	UK (BIRDPB)	Ford-Lloyd, IBPGR
Greece (Isle. etc.)	1981	76	Greece (GGB)	Cortessi, GGB, IBPGR
Italy (Sicily)	1981	106	Italy (CNR)	Toll, Italy, IBPGR
Algeria	1982	24	UK (BIRDPB), Turkey (AARI)	Ford-Lloyd , IBPGR
Greece (Isle. etc.)	1982	46	Greece (GGB)	Cortessi, GGB, IBPGR
Greece (Isle. etc.)	1983	62	Greece (GGB)	Cortessi, GGB, IBPGR
Libya	1983	5	Germany (IPK)	IPK, CNR
Italy	1984	28	Italy (CNR)	Woodfin, IBPGR
Spain	1984	55	Germany (NEDBEG)	Nuez (VALUPV)
Tunisia	1984	22	Greece (GGB), Germany (NEDBEG)	IBPGR*Guarino), GGB(Coressi), INRAT(El Abeb)
Corsica	1985	15	USA (WRPIS), France (DYOSAP)	Doney(USDA), Laby(INRA)
Greece (Isle. etc.)	1985	32	Greece (GGB)	Cortessi, GGB, IBPGR
Italy (S. Italy)	1985	61	USA (WRPIS), Italy (CNR)	Doney(USDA), Italy
Sardinia	1985	42	USA (WRPIS), Italy (CNR)	Doney(USDA), Italy
Israel	1986	62	Israel(GB), IBPGR	
Cyprus	1986	39	Greece (GGB)	CYPARI, GGB
England	1987	99	USA(WRPIS), England(KEW)	Doney(USDA), Terry(KEW)
Ireland	1987	44	USA(WRPIS), Germany(NEDBEG)	Doney(USDA), Frese(NEDBEG)
Spain	1987	5	Germany (NEDBEG)	Freses(NEDBEG)
Syria	1987	10	Greece (GGB)	Syria, Astley (NVRS)
Belgium	1989	3	USA(WRPIS)	Doney(USDA), Vermoote(SES)
Denmark	1989	19	USA (WRPIS)	Doney(USDA), Madsen(Maribo)
France	1989	123	USA(WRPIS), France(DYOSAP)	Doney(USDA), Laby(INRA)
Portugal	1989	41	Germany (NEDBEG)	Frese(FAL), Letschert(LUW)
Spain	1989	27	Germany (NEDBEG)	de Meijer(CGN), Frese(NEDBEG)
Cyprus	1989	17	Germany (NEDBEG)	Letschert (LUW)

Country	Year	Samples	Gene Banks Where Stored *	Collector, Agency
Turkey	1989	27	Turkey (AARI)	Tan, PGRRI, Turkey
Armenia/Dagheston	1990	8	USA (WRPIS), NEDBEG, VIR	Seiler(USDA), Frese(CGN), VIR
Canary Islands	1990	12	Japan	Masutani,, Japan
Crete	1990	3	Greece (GGB)	Greek Gene Bank, Greece
Morocco	1990	15	Japan	Masutani,, Japan
Spain	1990	5	Japan	Masutani,, Japan
Turkey	1990	151	Turkey(AARI), Germany(NEDBEG)	Tan, PGRRI, Turkey, CGN
Turkey	1991-93	20	Turkey(AARI)	Tan, PGRRI, Turkey
Egypt	1992	26	USA (WRPIS), Egypt	Doney(USDA), Egypt
Italy (S. Italy)	1994	29	Germany(NEDBEG), Russia(VIR)	Frese(NEDBEG), Burenin(VIR)
Azerbaijan	1999	8	Germany(NEDBEG)	Frese(NEDBEG), Akbarov(SRIA), Burenin(VIR)
Greece	2005	26	USA(WRPIS), Germany(NEDBEG),Greece(GGB)	Hellier(WRPIS), Frese(NEDBEG), Samaras(GGB)
Morocco	2010	32	USA(WRPIS), Morocco (INRA)	Hellier, Panella(WRPIS), El Bahloul, Qariouh(INRA)
California, U.S.	2011	25	USA(WRPIS)	Hellier, Richardson(WRPIS),
Morocco	2012	56	USA(WRPIS), Morocco (INRA)	Hellier, Panella(WRPIS), El Bahloul(INRA)
California, U.S.	2015		USA(WRPIS)	Hellier, Panella, Richardson(WRPIS),

* = Gene Bank Codes used by the International Data Base for Beets (IDBB):
AARI = Plant Genetic Resources Research Institute, Izmir,Turkey
BIRDPB = University of Birmingham, Department of Plant Biology, Birmingham, England
CNR = Germplasm Institute, Bari, Italy
CYPARI = Cyprus Agricultural Research Institute, Nicosia, Cyprus
DYOSAP = Station Genetique et d'Amelioration des Plantes de Dijon, France
GGB = Greek Gene Bank, Thessaloniki, Greece
IPK = Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany
KEW = Kew Botanical Gardens, Wakehurst Place, UK
LUW = Agricultural University, Wageningen, The Netherlands
NEDBEG = Dutch-German cooperation on beet genetic resources, Braunschweig, Germany
NVRS = National Vegetable Research Station, Wellesbourne, UK
VALUPV = University of Valencia, Dept of Genetics, Valencia, Spain
WRPIS = Western Regional Plant Introduction Station, Pullman, WA, USA