

Chapter 8

Crop Wild Relatives of Root Vegetables in North America



Justin E. Anderson, Alexandra Campbell, and Michael B. Kantar

Abstract Root and tuber crops are staples in diets across the world. They are favored due to a large yield associated with the small acreage needed to grow. Generally, they tend to be fairly robust to insect and disease pests and have historically been used as starvation food. Some root and tuber crops, such as potato, sweet potato, or cassava, are the primary source of daily calories for many cultures worldwide. Some tuber crops are only partially domesticated, facilitating the use of crop wild relatives (CWR). Many different cultures have their favorite root crops, but culinary preparation techniques often allow for different tubers to be used, making the acceptance of these crops fairly rapid. Here, we explore the origins and uses of eight tuber and root crops that are important to world diets and have many related wild species in North America.

Keywords Tubers · Species richness · Germplasm · Plant breeding

8.1 Introduction

Root vegetables are an important source of calories in many parts of the world. The favored root vegetable, as well as the preparation, varies depending on country or culture. Many root vegetables have been transported across the world, becoming naturalized in different areas. It is difficult to make many generalizations about root crops due to the large number of species and vegetative organs that are classified under this broad definition (Table 8.1). Here we explore the CWR of carrot

J. E. Anderson
Department of Molecular Genetics and Physiology of Plants, Ruhr University Bochum,
Bochum, Germany

A. Campbell · M. B. Kantar (✉)
Tropical Plant and Soil Science, University of Hawaii at Manoa,
Honolulu, HI, USA
e-mail: colferab@hawaii.edu; kant0063@umn.edu

Table 8.1 Tuber crop production by country over the most recent 5 years available in FAOStat (FAO 2014)

Country	Crop	Total yield each year (Hg/Ha)				
		2009	2010	2011	2012	2013
Canada	Carrots and turnips	429,415	497,517	506,502	474,370	449,091
	Potatoes	313,126	316,055	295,863	310,155	325,123
	Sugar beet	603,394	495,575	640,496	592,772	672,697
Mexico	Carrots and turnips	260,679	246,947	269,620	264,475	271,622
	Cassava	143,440	131,579	127,352	122,330	146,398
	Potatoes	277,374	277,578	262,734	268,098	267,752
	Roots and tubers, nes ^a	282,617	274,131	266,843	260,069	261,937
	Sugar beet	NA	NA	250,000	180,000	140,000
	Sweet potato	190,454	206,653	201,465	175,168	183,965
	Yautia (cocoyam)	340,000	393,725	421,176	460,502	493,286
United States of America	Carrots and turnips	397,254	421,786	383,489	400,226	384,494
	Potatoes	464,446	452,767	447,140	458,242	463,577
	Sugar beet	581,309	621,142	533,929	655,763	636,939
	Sweet potato	225,200	228,628	233,019	234,472	245,411

^aRoots and tubers, nes: “Including inter alia: arracacha (*Arracacia xanthorrhiza* Bancr.); arrow-root (*Maranta arundinacea* L.); chufa (*Cyperus esculentus* L.); sago palm (*Metroxylon* spp.); oca and ullucu (*Oxalis tuberosa* Molina and *Ullucus tuberosus* Caldas); yam bean, jicama (*Pachyrhizus erosus* (L.) Urb., *P. angulatus* DC.); mashua (*Tropaeolum tuberosum* Ruiz and Pavón); Jerusalem artichoke, topinambur (*Helianthus tuberosus* L.). Because of their limited local importance, some countries report roots and tubers under this commodity heading that are classified individually by FAO” (FAO Stat 2014)

(*Daucus carota* L. subsp. *sativus* (Hoffm.) Schübl. & G. Martens), sweet potato (*Ipomoea batatas* L.), potato (*Solanum tuberosum* L.), Jerusalem artichoke (*Helianthus tuberosus* L.), jicama (*Pachyrhizus erosus* L.), cocoyam (*Xanthosoma sagittifolium* L.), cassava (*Manihot esculenta* (L.) Lam.), and beet (*Beta vulgaris* L.); these eight common root vegetables are known for their economic importance and occurrence of wild relatives in North America.

The concept of gene pools in plant breeding dates back to Harlan and De Wet in the 1970s (Harlan and de Wet 1971). This concept defines boundaries between crops and the often numerous related species remaining in the wild. Experts working to define these pools for all major crop species in the Germplasm Resources Information Network (USDA, ARS 2017) of the US National Plant Germplasm System (NPGS) and the Harlan and De Wet Inventory (<http://www.cwrdiversity.org/checklist>; Dempewolf et al. 2017) of the Global Crop Diversity Trust have collaborated to create online resources making this valuable plant breeding information readily accessible. These combined databases were used as the basis for the gene pools defined in this review. Through ongoing plant breeding, many of the CWR belonging to these gene pools have contributed valuable traits important to modern crop production. Crop wild relatives are known to harbor many valuable traits,

including resistance to biotic stresses, such as plant diseases or herbivores; tolerance to abiotic stresses, such as drought or frost; and even breeding and agronomic traits like yield and male sterility. These valuable traits are considered “potential breeding uses” when witnessed in the CWR and “confirmed breeding uses” when the trait has been crossed into the domesticated crop (Dempewolf et al. 2017). Crop wild relative exploration continues to suggest great potential in these and many other crop traits.

8.2 Carrot (*Daucus carota* L. subsp. *sativus* (Hoffm.) Schübl. & G. Martens)

8.2.1 Introduction

Carrot (*Daucus carota* subsp. *sativus*), $2n = 2x = 18$, is an important vegetable from the *Apiaceae* family, known for its high nutritional content (provitamin carotenoids). Breeding efforts have significantly increased carotenoid concentration and recently unlocked the underlying mechanism (Iorizzo et al. 2016). There are several other important crops within the *Apiaceae* family, including celery, parsley, fennel, dill, coriander, aniseed, cumin, and caraway. In addition to food uses, many different carrot species have traditionally been used for medicinal purposes (Grzebelus et al. 2011). Carrot, generally grown as a biennial, was domesticated in Central Asia around 1,100 years ago (Iorizzo et al. 2013). Originally yellow or purple, the iconic orange carrot wasn't reported until the 1600s in Europe (Simon 2000).

8.2.2 Crop Wild Relatives and Wild Use

Domestic carrot has widely hybridized with wild carrots from North America and Europe, even suggesting that the origin of the only North American CWR, *Daucus pusillus* Michx., might actually have been an introduction of wild carrot from European settlers (Iorizzo et al. 2013). Current commercial materials are hybrid cultivars, developed using a cytoplasmic male sterility (CMS) system, a trait discovered in CWR (Alessandro et al. 2013). While we focus on North American wild relatives here, carrot has many non-North American relatives (31) that have a long history of breeding use. Carrots respond well to nitrogen applications and irrigation, but there is a need for advancing tolerances to abiotic stresses as the cultivated area increases. Major pests include carrot root fly, hoverflies, and leaf blight (Grzebelus et al. 2011). In carrot breeding, CWR have been an important source of resistance to these pests and helpful in overcoming other breeding limitations (Table 8.2). Ongoing characterization of genetic resources will continue to increase accessibility for breeders.

Table 8.2 Carrot wild relatives, gene pool classification, and breeding use

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Tertiary	<i>Daucus pusillus</i> Michx.	C, M, U	Gene transfer, sandy soil tolerance, soil salinity tolerance	37	NA	13	46	Well conserved	Camadro et al. (2007, 2008)

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)^bUSDA, ARS (2017)^cAAFC (2017)^dBGCI (2017)^eGlobal Crop Diversity Trust (2014) GENESYS^fBased on occurrence points relative to distribution maps and published literature

8.2.3 Conservation Status

Wild carrot species have long been a popular species for collection and utilization, both for food and medicinal purposes, in both North America and Europe (Banga 1957). The wild carrot species in North America is well conserved in ex situ germplasm collections. The most recent collecting trip by the USDA-ARS in 2010 resulted in the addition of 21 accessions of *D. pusillus* to the NPGS collection. This species has a large distribution and is represented across the southern and western United States, as well as western Canada; due to its broad presence, there are no specific concerns about its conservation status or current efforts to conserve it in situ.

8.3 Sweet Potato (*Ipomoea batatas* (L.) Lam.)

8.3.1 Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.) is one of the most important root crops in the world with 104 million metric tons produced in 2014 (FAO Stat 2014). Sweet potato is thought to have long been a staple in the human diet with archeological remains dating back 4,000 years (Solis et al. 2001). The crop also is highly nutritious and popular, being grown in over 100 countries (Khoury et al. 2015). The major constraints on production are viruses (SPVD) and insects (*Cylus* spp.), which can decrease yield between 60% and 100% (Khoury et al. 2015). Many of the close relatives of sweet potato show resistance to both biotic and abiotic stress (Table 8.3). Crossing relationships within *Ipomoea* are not well characterized; additionally, utilization is complicated by ploidy differences within and between species (Nimmakayala et al. 2011).

8.3.2 Crop Wild Relatives and Wild Use

The genus *Ipomoea* contains ~500 species, and taxonomic relationships within *Ipomoea* remain unresolved, which is in part due to the large amount of interspecific hybridization. This implies that as new data are generated, the exact relationships of wild relatives to *Ipomoea* are likely to change. The CWR species present in North America include *I. lacunosa* L., *I. leucantha* Jacq., *I. tenuissima* Choisy, *I. cordatotriloba* Dennst., *I. tiliacea* (Willd.) Choisy, *I. splendor-sylvae* House, and *I. trifida* (Kunth) G.Don (Table 8.3; Fig. 8.1). These species occupy ecological niches that may provide adaptation to diverse biotic and abiotic stresses (Table 8.3). There has been a history of eating many of the different wild sweet potato species, as well as using them for medicinal purposes (Austin and Huáman 1996; Pío-León et al. 2017).

Table 8.3 Sweet potato's crop wild relatives, gene pool classification, and breeding use

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGR ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>Ipomoea batatas</i> (L.) Lam. var. <i>apiculata</i> (Martens & Galeotti) McDonald & Austin	M	Drought tolerance	NA	NA	NA	NA	Poorly conserved	McDonald and Austin (1990)
Secondary	<i>Ipomoea batatas</i> (L.) Lam.	M	Drought tolerance; heat tolerance; waterlogging tolerance	NA	NA	NA	NA	Poorly conserved	Khoury et al. (2015)
Secondary	<i>Ipomoea littoralis</i> Blume	U	Drought tolerance; heat tolerance; sandy soil tolerance; waterlogging tolerance; dry matter yield; yield improvement; black rot resistance; scab resistance; weevil resistance	2	NA	1	2	Poorly conserved	Iwanaga (1988); Khoury et al. (2015)
Secondary	<i>Ipomoea tabascana</i> McDonald & Austin	M	Heat tolerance; waterlogging tolerance	1	NA	1	1	Poorly conserved	Khoury et al. (2015)

Secondary	<i>Ipomoea trifida</i> (H.B.K.) G. Don.	M	Drought tolerance; heat tolerance; waterlogging tolerance; dry matter yield; yield improvement; black rot resistance; root knot nematode resistance; root lesion nematode resistance; scab resistance; weevil resistance; high starch content; protein content	46	NA	1	137	Moderately conserved	Sakamoto (1976); Iwanaga (1988); Shiotani et al. (1991); Lebot (2010); Khoury et al. (2015)
Tertiary	<i>Ipomoea cordatotriloba</i> Dennst. var. <i>cordatotriloba</i>	U	Cold tolerance; sandy soil tolerance	NA	NA	1	NA	Poorly conserved	Khoury et al. (2015)
Tertiary	<i>Ipomoea cordatotriloba</i> Dennst. var. <i>torreyana</i> (A. Gray) D. F. Austin	M, U	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Ipomoea cordatotriloba</i> Dennst.	M, U	NA	5	NA	6	34	Moderately conserved	NA
Tertiary	<i>Ipomoea lacunosa</i> L.	U	Cold tolerance; drought tolerance; gene transfer	7	NA	3	8	Poorly conserved	Khoury et al. (2015); Austin (1978)

(continued)

Table 8.3 (continued)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGR ^c	Number of accessions conserved in BGCJ ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Tertiary	<i>Ipomoea leucantha</i> Jacquin	M, U	Drought tolerance; heat tolerance; sandy soil tolerance; gene transfer	NA	NA	NA	NA	Poorly conserved	Khoury et al. (2015); Austin (1978)
Tertiary	<i>Ipomoea ramosissima</i> (Poir.) Choisy	M	Cold tolerance; waterlogging tolerance	4	NA	1	1	Poorly conserved	Khoury et al. (2015)
Tertiary	<i>Ipomoea splendens</i> House	M	Drought tolerance; heat tolerance; waterlogging tolerance	1	NA	1	1	Poorly conserved	Khoury et al. (2015)
Tertiary	<i>Ipomoea tenuissima</i> Choisy	U	Cold tolerance; heat tolerance; sandy soil tolerance	1	NA	1	1	Poorly conserved	Khoury et al. (2015)
Tertiary	<i>Ipomoea tiliacea</i> (Willdenow) Choisy in D.C.	M	Heat tolerance; waterlogging tolerance	15	NA	2	16	Poorly conserved	Khoury et al. (2015)
Tertiary	<i>Ipomoea triloba</i> L.	M	Drought tolerance; heat tolerance; soluble sugar	36	NA	5	67	Moderately conserved	Khoury et al. (2015); Yang et al. (2009)

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)

^bUSDA, ARS (2017)

^cAAFC (2017)

^dBGCI (2017)

^eGlobal Crop Diversity Trust (2014) GENESYS

^fBased on occurrence points relative to distribution maps and published literature

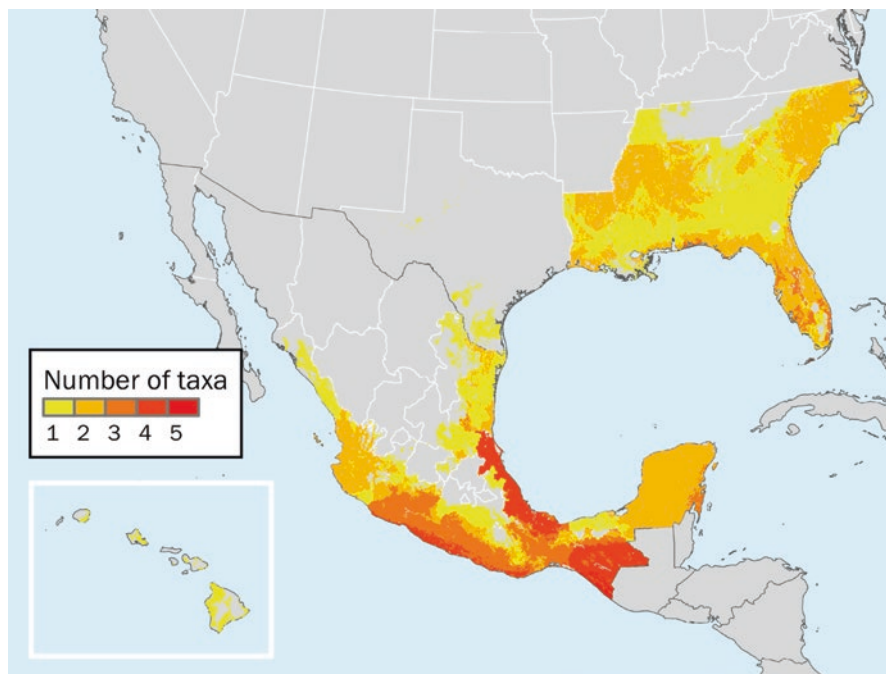


Fig. 8.1 Species richness map of modeled potential distributions of North American *Ipomoea* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

8.3.3 Conservation Status

The major challenge to using the CWR is the limited number of accessions available in ex situ collections. Recent work has identified that 70% of the CWR of sweet potato have only limited numbers of individuals currently preserved in ex situ collections and therefore are in great need of further collection (Khoury et al. 2015). Currently, there are only 749 germplasm accessions available in germplasm banks (Khoury et al. 2015). Increasing the number of accessions available and the creation of genetic stocks that contain introgressions from wild relatives at the correct ploidy level could prove valuable to ongoing breeding efforts. Due to the difficulty and expense in conservation, the CWR of sweet potato have lagged behind those of other crops in availability.

There is a great need to conserve the wild relatives, especially as the specialty markets of sweet potato increase in value. Several members of the *Ipomoea* genus are listed by NatureServe as vulnerable (*I. tenuissima* Choisy, *I. thurberi* A. Gray, *I. plummerae* var. *cuneifolia* (Gray) MacBride) or imperiled (*I. tuboides* O. Deg. & van Ooststr., *I. shumardiana* (Torr.) Shinnery, *I. microdactyla* Griseb.) in their native ranges across North America (www.natureserve.org; NatureServe 2017); however of these, only *I. tenuissima* has a known breeding use.

8.4 Potato (*Solanum tuberosum* L.)

8.4.1 Introduction

Potato (*Solanum tuberosum* L.) is the fourth most widely produced crop in the world by yield and the most widely produced tuber (Ramsay and Bryan 2011). In 2014, 385 million metric tons were produced (FAO Stat 2014). Potato underwent a single domestication event in the Andean mountain range in Peru from the *Solanum bukasovii* Juz. species complex around 8,000 years ago (Spooner et al. 2005; Ramsay and Bryan 2011). There are a multitude of CWR in potato (Table 8.4), many of which have valuable resistance to the limiting factors to modern potato production, including diseases (e.g., blight, bacterial wilt, verticillium wilt), pests (potato beetle), and abiotic stress (Srivastava et al. 2016). These diverse CWR have been extensively used in potato improvement (Table 8.4), despite limitations of ploidy differences and different endosperm balance numbers. There is a long history of many different wild potato species being consumed, with many different species having specific uses (Ladio 2001).

8.4.2 Crop Wild Relatives and Wild Use

A recent examination of accessions of *Solanum* wild relatives in germplasm repositories found many species are in high need of further collection, including four native to North America: *S. clarum* Correll, *S. hintonii* Correll, *S. hjertingii* Hawkes, and *S. hougasii* Correll (Castañeda-Álvarez et al. 2015). Several species were further identified as having a moderate need for collection, including the North American species: *S. iopetalum* (Bitter) Hawkes, *S. lesteri* Hawkes & Hjert, *S. morelliforme* Bitter & Muench, *S. oxycarpum* Schiede, *S. polyadenium* Greenmam, *S. schenckii* Bitter, *S. tarnii* Hawkes & Hjert, and *S. verrucosum* Schldtl (Castañeda-Álvarez et al. 2015). Unfortunately, several of these same CWR are threatened by habitat destruction and climate change (Fig. 8.2). It is becoming increasingly important to conserve the species underrepresented in genebanks that are being impacted in their native habitats. Despite potato's economic importance and long history of CWR use, many of the CWR have not been evaluated for beneficial traits. Advances in pre-breeding, improved cisgenic techniques, and new genotyping and phenotyping methods will help to continue to unlock the agronomic potential found within these wild relatives, making their conservation ex situ more useful and efficient (Castañeda-Álvarez et al. 2015).

8.4.3 Conservation Status

The coverage of wild potato in ex situ collections is uneven, and better characterization of the many different potato species is needed. There have been extensive efforts to collect *Solanum* species in the United States; these collection efforts were

Table 8.4 Potato's crop wild relatives, gene pool classification, and use in potato breeding

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>Solanum agrimonifolium</i> Rydb.	M	NA	NA	NA	NA	NA	Poorly conserved	
Secondary	<i>Solanum clarum</i> Correll	M	NA	14	NA	1	18	Poorly conserved	
Secondary	<i>Solanum demissum</i> Lindl.	M	Blackleg and soft rot resistance, potato leaf roll virus resistance, late blight resistance, Colorado potato beetle resistance, cyst nematode resistance, frost tolerance, potato virus Y resistance, wart resistance	164	NA	2	665	Well conserved	Jansky (2000); Bradshaw et al. (2006); Hajjar and Hodgkin (2007); Jansky et al. (2013); Srivastava et al. (2016)
Secondary	<i>Solanum guerrerense</i> Correll	M	Spindle tuber viroid resistance	2	NA	1	14	Well conserved	Srivastava et al. (2016)
Secondary	<i>Solanum hintonii</i> Correll	M	NA	1	NA	1	2	Poorly conserved	
Secondary	<i>Solanum hjertingii</i> Hawkes	M	Blackleg and soft rot resistance, root knot nematode resistance, spindle tuber viroid resistance	13	NA	1	6	Poorly conserved	Jansky (2000); Srivastava et al. (2016)

(continued)

Table 8.4 (continued)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>Solanum hougasii</i> Correll	M	Root knot nematode resistance, potato virus Y resistance, late blight resistance	10	NA	1	116	Poorly conserved	Spooner and Bamberg (1994); Jansky (2000); Inglis et al. (2007)
Secondary	<i>Solanum topetalum</i> (Bitter) Hawkes	M	Late blight resistance	60	NA	1	NA	Moderately conserved	Jansky (2000)
Secondary	<i>Solanum lesteri</i> Hawkes & Hjert.	M	NA	3	NA	2	NA	Moderately conserved	
Secondary	<i>Solanum moreliforme</i> Bitter & Munch	M	NA	20	NA	1	6	Moderately conserved	
Secondary	<i>Solanum oxycarpum</i> Schiede	M	NA	20	NA	1	NA	Moderately conserved	
Secondary	<i>Solanum polyadenium</i> Greenman	M	Colorado potato beetle resistance, Late blight resistance	18	4	3	6	Moderately conserved	Srivastava et al. (2016)
Secondary	<i>Solanum schenckii</i> Bitter	M	NA	15	NA	1	2	Moderately conserved	

Secondary	<i>Solanum stoloniferum</i> Schltdl. & Bouche	M, U	Late blight resistance, potato virus Y resistance, aphid resistance, drought tolerance, heat tolerance, potato leaf roll virus resistance	485	1	3	2	Well conserved	Ross (1979); Bradshaw et al. (2006); Hajjar and Hodgkin (2007); Jansky et al. (2013); Srivastava et al. (2016)
Secondary	<i>Solanum verrucosum</i> Schltdl.	M	Late blight resistance	46	NA	2	4	Moderately conserved	Liu and Halterman (2009); Srivastava et al. (2016)
Tertiary	<i>Solanum bulbocastanum</i> Dunal	M	Blackleg and soft rot resistance, late blight resistance, root knot nematode resistance, aphid resistance, cyst nematode resistance, drought tolerance, early blight resistance, heat tolerance	56	NA	1	161	Well conserved	Jansky (2000); Hodgkin and Hajjar (2008); Suszkiw (2009); Srivastava et al. (2016)
Tertiary	<i>Solanum cardiophyllum</i> Lindl.	M	Late blight resistance, root knot nematode resistance, cyst nematode resistance	11	NA	2	78	Moderately conserved	Srivastava et al. (2016)
Tertiary	<i>Solanum ehrenbergii</i> (Bitter) Rydb.	M	NA	28	NA	1	38		

(continued)

Table 8.4 (continued)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Tertiary	<i>Solanum jamesii</i> Torr.	M, U	Colorado potato beetle resistance, common scab resistance	165	NA	1	82	Well conserved	Srivastava et al. (2016)
Tertiary	<i>Solanum pinna-tisectum</i> Dunal	M	Blackleg and soft rot resistance, chip making from cold, Colorado potato beetle resistance, drought tolerance, heat tolerance, late blight resistance	19	NA	1	NA	Moderately conserved	Srivastava et al. (2016)
Tertiary	<i>Solanum stenophyllidium</i> Bitter	M	Frost tolerance	25	NA	2	4	Moderately conserved	Srivastava et al. (2016)
Tertiary	<i>Solanum tar-mii</i> Hawkes & Hjert.	M	Colorado potato beetle resistance, late blight resistance, potato virus X resistance	11	NA	1	2	Poorly conserved	Thieme et al. (2008)
Tertiary	<i>Solanum trifidum</i> Correll	M	NA	14	NA	1	24	Moderately conserved	

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)^bUSDA, ARS (2017)^cAAFC (2017)^dBGCI (2017)^eGlobal Crop Diversity Trust (2014) GENESYS^fBased on occurrence points relative to distribution maps and published literature

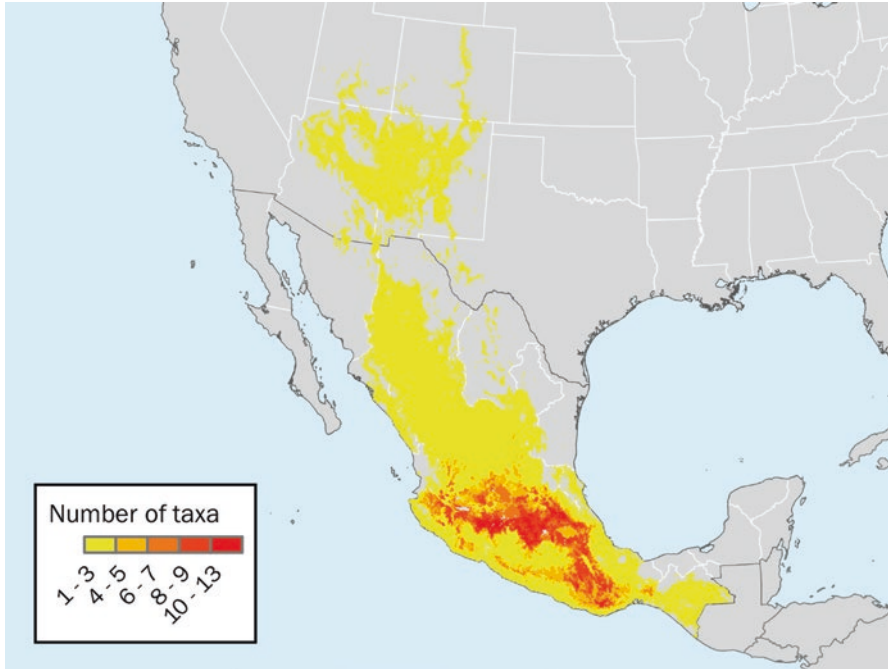


Fig. 8.2 Species richness map of modeled potential distributions of North American *Solanum* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

led by the USDA-ARS and have focused on *Solanum jamesii* (jam) and *S. fendleri* (fen) (Bamberg et al. 2016). There is only one member of the genus that is listed as of in situ conservation concern by NatureServe; *S. jamesii* is ranked as vulnerable (www.natureserve.org; NatureServe 2017).

8.5 Jerusalem Artichoke (*Helianthus tuberosus* L.)

8.5.1 Introduction

Jerusalem artichoke, the domesticated form of *Helianthus tuberosus* L., shows reduced tuber number and increased individual tuber size relative to wild collected individuals. *Helianthus tuberosus* is native to central North America (Kays and Nottingham 2008; Rogers et al. 1982) and was domesticated in the eastern United States. *Helianthus tuberosus* is an autoallohexaploid whose progenitors are likely the autotetraploid *H. hirsutus* Raf. (an autotetraploid of *H. divaricatus* L.) and the diploid *H. grosseserratus* Martens (Bock et al. 2014). Wild sunflowers have been

collected for medicinal and food purposes since prehistory; the most common species to collect and eat are wild *H. tuberosus* and wild *H. annuus* L. (Kays and Nottingham 2008). Little is known about the extent of cultivation in North America prior to European contact due to a limited fossil record. The crop was introduced to the royal court of France in the seventeenth century and soon became a favorite of the European aristocracy (Kays and Nottingham 2008). Cultivation guides were published as early as the mid-eighteenth century (Brookes 1763), and production continued to increase until the potato largely replaced *Helianthus tuberosus* in diets. The crop is grown as a winter or summer annual. There has been little intentional interspecific introgression into domesticated *H. tuberosus*.

Helianthus tuberosus is widely resistant to both insect pathogens and diseases and has often been used as a donor species in *Helianthus annuus* (sunflower) breeding (Kantar et al. 2014). *Helianthus tuberosus* is also salt and drought tolerant and easily grown in coastal arid and semiarid areas (Ma et al. 2011) and has been used to improve soil and water conservation in desertified areas (Cheng et al. 2009). The native range of *Helianthus tuberosus* is quite large, ranging from the Mississippi River to the Atlantic Ocean and from the Gulf of Mexico to the Hudson Bay (Kantar et al. 2015). The large range provides many opportunities to find populations that are adapted to diverse climatic and biological stresses. When cultivated, *H. tuberosus* is planted using tuber parts and replanted every 3 years (Kays and Nottingham, 2008). A major limitation to production is that the species can become a volunteer weed in subsequent crops.

8.5.2 Crop Wild Relatives and Wild Use

Crop wild relatives within *Helianthus* have generally been defined with respect to *Helianthus annuus*, rather than *Helianthus tuberosus*, and are found throughout North America (Fig. 8.3). Despite this, the large species range of *Helianthus tuberosus*, the large number of species in the genus, and the large amount of hybridization within the genus make half of the species in the genus available for hybridization (Table 8.5). The major difficulty with the utilization of other *Helianthus* species is the difference in ploidy; this causes extra generations to be necessary in order to generate useful breeding material. The crop has excellent nutritional properties (Kays and Nottingham 2008), industrial applications (rubber; Seiler et al. 1991a, b, biofuel; Seiler and Campbell 2006), medicinal uses (diabetes treatment; Kays and Nottingham 2008), and forage potential (Seiler and Campbell 2004).

8.5.3 Conservation Status

Conservation priorities differ across the genus, with ~75% of the species needing further collection for ex situ conservation (Kantar et al. 2015). There are several species that are at risk including *Helianthus paradoxus* Heiser, which is ranked

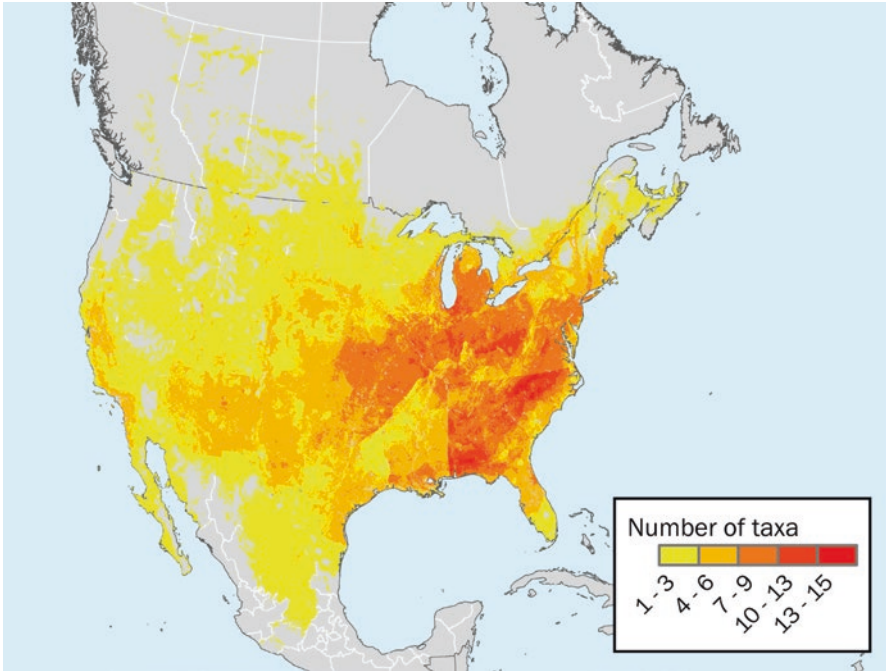


Fig. 8.3 Species richness map of modeled potential distributions of North American *Helianthus* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

threatened by the US Fish and Wildlife Service (ECOS 2016) and imperiled by NatureServe (www.natureserve.org; NatureServe 2017). *Helianthus neglectus* Heiser is ranked imperiled, and *Helianthus winteri* Stebbins is ranked critically imperiled by NatureServe (2017; www.natureserve.org). There are several species that are ranked vulnerable by NatureServe, including *H. anomalus* Blake, *H. debilis* spp. *tardiflorus* Heiser, and *H. debilis* subsp. *vestitus* Heiser (www.natureserve.org; NatureServe 2017).

8.6 Jicama (*Pachyrhizus erosus* (L.) Urb.)

8.6.1 Introduction

Jicama (*Pachyrhizus erosus* (L.) Urb.) is a tropical short day legume that is grown mostly in warm humid environments with intermediate levels of rainfall (Lim 2016). Indigenous to Mexico and Central America, jicama is now broadly grown across the tropics and neotropics (Reddy 2015). Other crops in the *Pachyrhizus*

Table 8.5 Crop wild relatives of *H. tuberosus* L. and potential breeding uses (the potential breeding uses of CWR are not well defined due to the high level of diversity both in ecological niche and biotic stress that is already present in *H. tuberosus*)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>H. annuus</i> L.	C, M, U	Pest, disease resistance, salt tolerance, drought tolerance, herbicide tolerance	3656	655	96	8539	Well conserved	Qi et al. (2012); Miller and Gulya (1988); Jyoti and Brewer (1999); Kane and Rieseberg (2007); Al-Khatib and Miller (2000); Miller and Al-Khatib (2002)
Secondary	<i>H. anomalous Blake</i>	U	NA	16	NA	3	12	Poorly conserved	NA
Secondary	<i>H. argophyllus Torr. & Gray</i>	U	Downy mildew resistance, disease resistance, salt tolerance, drought tolerance	79	NA	9	94	Moderately conserved	Seiler (1991a); Miller and Gulya (1988); Jan et al. (2004); Hulke et al. (2010); Seiler (1994)
Tertiary	<i>H. arizonensis Jackson</i>	U	NA	2	NA	1	5	Moderately conserved	NA
Tertiary	<i>H. atrorubens</i> L.	U	NA	12	NA	17	19	Moderately conserved	NA
Secondary	<i>H. bolanderi</i> A. Gray	U	NA	14	NA	4	20	Poorly conserved	NA

Secondary	<i>H. debilis</i> subsp. <i>cucumerifolius</i> (Torrey & A. Gray)	U	NA	14	NA	NA	NA	11	Poorly conserved	NA
Secondary	<i>H. debilis</i> subsp. <i>debilis</i> Nutt.	U	Powdery mildew resistance	13	NA	NA	NA	12	Moderately conserved	Jan and Chandler (1988); Seiler (1991a)
Secondary	<i>H. debilis</i> subsp. <i>silvestris</i> Heiser	U	NA	22	NA	NA	NA	24	Moderately conserved	NA
Secondary	<i>H. debilis</i> subsp. <i>tariflorus</i> Heiser	U	Resistance to broomrape	13	NA	NA	NA	9	Well conserved	Velasco et al. (2012)
Secondary	<i>H. debilis</i> subsp. <i>vestitus</i> Heiser	U	NA	11	NA	NA	NA	3	Well conserved	NA
Secondary	<i>H. deserticola</i> Heiser	U	Downy mildew resistance	24	NA	NA	1	24	Poorly conserved	Seiler (1991b)
Primary	<i>H. divaricatus</i> L.	C, U	Broomrape resistance	21	NA	NA	30	50	Poorly conserved	Jan et al. (2002)
Secondary	<i>H. exilis</i> A. Gray	U	NA	30	NA	NA	1	41	Moderately conserved	NA
Tertiary	<i>H. giganteus</i> L.	C, U	NA	26	NA	NA	33	42	Poorly conserved	NA
Primary	<i>H. grosseserratus</i> Martens	U	Broomrape resistance	46	NA	NA	21	69	Moderately conserved	Jan et al. (2002)
Primary	<i>H. hirsutus</i> Raf.	C, M, U	NA	14	NA	NA	18	26	Poorly conserved	NA
Tertiary	<i>H. maximiliani</i> Schradler	C, U	Broomrape resistance	68	3	NA	27	84	Moderately conserved	Whelan and Dedio (1980); Jan et al. (2002)
Secondary	<i>H. neglectus</i> Heiser	U	NA	40	NA	NA	1	41	Well conserved	NA

(continued)

Table 8.5 (continued)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>H. niveus</i> subsp. <i>canescens</i> A. Gray	M, U	NA	20	NA	NA	22	Poorly conserved	NA
Secondary	<i>H. niveus</i> subsp. <i>niveus</i> Benth.	M	NA	1	NA	5	14	Poorly conserved	NA
Secondary	<i>H. niveus</i> subsp. <i>tephrodex</i> Heiser	M, U	NA	11	NA	NA	11	Poorly conserved	NA
Secondary	<i>H. paradoxus</i> Heiser	U	Salt tolerance	13	NA	3	20	Well conserved	Seiler (1991a); Lexer et al. (2003); Lexer et al. (2004); Miller and Seiler (2003)
Tertiary	<i>H. pauciflorus</i> subsp. <i>pauciflorus</i> Nutt	C, U	Sclerotinia resistance	21	NA	NA	21	Poorly conserved	Miller and Gulya (1999); Jan et al. (2006)
Tertiary	<i>H. pauciflorus</i> subsp. <i>subrhomboides</i> Nutt	C, U	NA	17	NA	NA	18	Poorly conserved	NA
Secondary	<i>H. petiolaris</i> subsp. <i>fallax</i> Heiser	U	NA	61	NA	NA	31	Poorly conserved	NA
Secondary	<i>H. petiolaris</i> subsp. <i>petiolaris</i> Nutt.	C, U	Verticillium resistance; disease; sunflower moth resistance	126	NA	NA	107	Well conserved	Hoes et al. (1973); Rogers et al. (1984); Prescott-Allen and Prescott-Allen (1986); Seiler (1991a); Jan et al. (2004)

Secondary	<i>H. praecox</i> subsp. <i>hirtus</i> Heiser	U	NA	7	NA	NA	NA	8	Well conserved	NA
Secondary	<i>H. praecox</i> subsp. <i>praecox</i> A. Gray	U	Downy mildew, rust, verticillium wilt and broomrape resistance; downy mildew resistance	8	NA	NA	NA	10	Well conserved	Seiler et al. (1991a, b)
Secondary	<i>H. praecox</i> subsp. <i>runyonii</i> Heiser	U	NA	26	NA	NA	NA	27	Well conserved	NA
Secondary	<i>H. resinosus</i>	U	NA	23	NA	NA	5	34	Moderately conserved	NA
Tertiary	<i>H. salicifolius</i> A. Dietr	U	NA	19	NA	NA	52	27	Moderately conserved	NA
Tertiary	<i>H. silphiooides</i> Nutt.	U	NA	15	NA	NA	2	16	Well conserved	NA
Tertiary	<i>H. strumosus</i> L.	C, U	NA	29	NA	NA	33	46	Poorly conserved	NA
Secondary	<i>H. winteri</i> Stebbins	U	NA	NA	NA	NA	NA	NA	Poorly conserved	NA
Primary	<i>H. tuberosus</i> (wild)	C, U	Broomrape resistance; sunflower moth resistance	91	7	106	331		Moderately conserved	Rogers et al. (1984); Seiler (2000)

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)

^bUSDA, ARS (2017)

^cAAFC (2017)

^dBGCI (2017)

^eGlobal Crop Diversity Trust (2014) GENESYS

^fBased on occurrence points relative to distribution maps and published literature

genus include ahipa (*Pachyrhizus ahipa* (Wedd.) Parodi) and Amazonian yam bean (*Pachyrhizus tuberosus* (Lam.) Spreng.) (USDA, ARS 2017). Worldwide, jicama is a minor crop, but locally it is favored as part of many different types of cuisine. Generally, the plant takes approximately 6 months from planting to tuber harvest (Reddy 2015). Tubers can be eaten raw or cooked, having similar food value to potatoes; the immature seedpods can also be eaten, but the mature seeds are not consumed (Lim 2016). There are many different pests that impact crop production, including leafhopper, whiteflies, mealy bug, thrips, termites, coffee bean weevil, and pod borer (Reddy 2015). The most damaging diseases are rust and sincama mosaic virus (Reddy 2015). For acreage to increase, improved agronomic traits and pest tolerance are needed.

8.6.2 Crop Wild Relatives and Wild Use

There is very limited data on CWR breeding uses due to the semidomesticated nature of the crop (Table 8.6). This lack of knowledge has led to lagging conservation efforts for the important wild relatives. However, since antiquity wild jicama has been collected and used as a crop (Bronson 1966), and recently it has increased in use as a specialty crop.

8.6.3 Conservation Status

In general, there is a need to increase the conservation of wild relatives of this species. Only one of the wild relatives is even moderately well conserved in ex situ germplasm collections, with the other species being poorly conserved (Table 8.6). These species have not been well explored for in situ vulnerability.

8.7 Cocoyam, Tannia, Yautia (*Xanthosoma sagittifolium* (L.) Schott)

8.7.1 Introduction

Cocoyam, tannia, and yautia are a few of the many synonymous names for the edible aroid crop *Xanthosoma sagittifolium* (L.) Schott grown in many tropical regions (Reddy 2015). Originating in the northern Amazon Basin in South America, this crop is now widely cultivated around the tropics (Quero-Garcia et al. 2010). Brought to Europe and Africa multiple times during the sixteenth and seventeenth centuries, it eventually was transported to Asia and Oceania by the nineteenth century

Table 8.6 Jicama/yam bean crop wild relatives, genepool classification and breeding uses

Gene Pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Primary	<i>Pachyrhizus erosus</i> (L.) Urb.	M	NA	7	NA	16	84	Moderately conserved	NA
Secondary	<i>Pachyrhizus ferrugineus</i> (Piper) M. Sorensen	M	NA	NA	NA	NA	1	Poorly conserved	NA
Secondary	<i>Pachyrhizus sp.</i>	M	NA	3	NA	NA	23	Poorly conserved	NA

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)^bUSDA, ARS (2017)^cAAFC (2017)^dBGCI (2017)^eGlobal Crop Diversity Trust (2014) GENESYS^fBased on occurrence points relative to distribution maps and published literature

(Quero-García et al. 2010). Cocoyam is often used as food when other sources of calories are unavailable. The traits important for cultivars include corm shape, plant architecture, plant size, corm color, and leaf color. Most of the cultivars are local heirloom types. One major limitation to production is cocoyam root rot disease; identifying resistance to this pathogen is the primary breeding objective (Reddy 2015). Currently there are a limited number of breeding programs, and breeding efforts have yet to see much success, possibly due to ploidy differences. In Cameroon, where cocoyam improvements were initiated, few viable seeds were produced (Tambong et al. 1997; Onokpise et al. 1999). DNA markers have been used to study cocoyam diversity; however, the genetic dissimilarity between the accessions was low, and the existing ex situ collection was deemed of limited value as a genetic resource (Quero-García et al. 2010).

8.7.2 *Crop Wild Relatives and Wild Use*

Current understanding of the cocoyam gene pool is limited to knowledge of species within the *Xanthosoma* genus (Table 8.7). Phenotypic characterization of current and newly collected accessions could prove most helpful for ongoing plant breeding. While cocoyam is an old crop (Bronson 1966), it is not frequently grown on a large scale; this has led to extensive wild crafting and use of different species interchangeably.

8.7.3 *Conservation Status*

Xanthosoma requires extensive collection; this group of species is very understudied despite a wide distribution across Mexico (Fig. 8.4). It is necessary to define many of the basic species relationships as well as how they can be used to improve cultivars. *Xanthosoma* species are either not well explored or secure in situ.

8.8 *Cassava (Manihot esculenta Crantz)*

8.8.1 *Introduction*

Cassava (*Manihot esculenta* Crantz) is widely cultivated in the tropics, currently providing the third highest number of calories after maize and rice (FAO Stat 2014). Cassava contains many valuable introgressions from wild relatives as there are few crossing barriers within the *Manihot* genus (Table 8.8). Cassava was domesticated ~5000 years ago in the American Tropics (Piperno and Holst 1998). There still remains

Table 8.7 Cocoyam, tannia, or yautia (*Xanthosoma sagittifolium* (L.) Schott) crop wild relatives, gene pool classification, and breeding use

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Undefined	<i>Xanthosoma mexicanum</i> Liebm.	M	NA	NA	NA	4	1	Poorly conserved	NA
Undefined	<i>Xanthosoma naritense</i> Bogner & L. P. Hannon	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Undefined	<i>Xanthosoma obtusilobum</i> Engl.	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Undefined	<i>Xanthosoma robustum</i> Schott	M	NA	NA	NA	21	5	Poorly conserved	NA
Undefined	<i>Xanthosoma wendlandii</i> (Schott) Standl.	M	NA	NA	NA	2	NA	Poorly conserved	NA
Undefined	<i>Xanthosoma yucatanense</i> Engl.	M	NA	NA	NA	NA	NA	Poorly conserved	NA

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)^bUSDA, ARS (2017)^cAAFC (2017)^dBGCI (2017)^eGlobal Crop Diversity Trust (2014) GENESYS^fBased on occurrence points relative to distribution maps and published literature

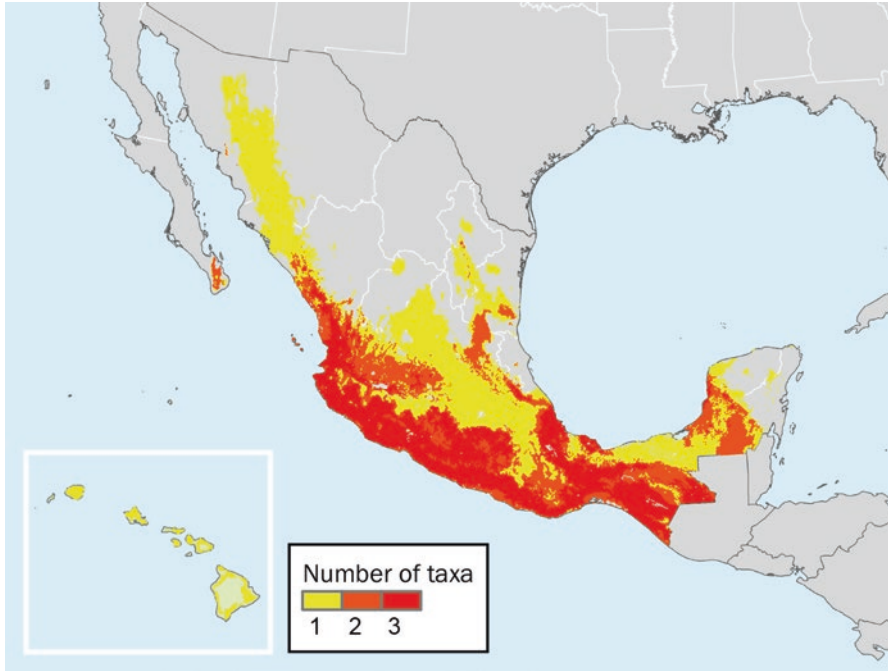


Fig. 8.4 Species richness map of modeled potential distributions of North American *Xanthosoma* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

debate over the precise geographic origin and if there was a single or multiple domestications (Bradbury et al. 2013; Olsen and Schaal. 1999). The oldest archeological evidence of cassava cultivation dates to 7000 years ago in the Andean and Caribbean regions (Piperno et al. 2000). Cassava was brought to Europe in the sixteenth century and made its way to Asia and Africa by the eighteenth century (Onwueme 2002). Although it is known for its good general drought tolerance and growth in low-nutrient environments, there are many problems that can decrease yields, including cassava mosaic virus, bacterial blight, and brown streak disease (Narina et al. 2011). Viruses can also impact propagation through affecting cuttings used for planting reducing vigor and therefore yield potential. There is limited use of wild relatives directly as food due to the presence of poisonous compounds (Nassar 1978).

8.8.2 Crop Wild Relatives and Wild Use

The closest wild relatives are *Manihot flabellifolia* Pohl and *M. peruviana* Müll. Arg, but many members of the secondary gene pool are also believed to spontaneously cross with cultivated material, including *M. irwinii* D. J. Rogers & Appan, *M. pruinosa*

Table 8.8 Cassava's crop wild relatives, gene pool classification, and use in cassava breeding

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGR ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Secondary	<i>Manihot foetida</i> (Kunth) Pohl	M	NA	NA	NA	1	NA	Poorly conserved	NA
Tertiary	<i>Manihot aesculifolia</i> Pohl	M	Robustness	NA	NA	1	NA	Poorly conserved	Jennings (1995)
Tertiary	<i>Manihot angustiloba</i> (Torr.) Müll. Arg.	M, U	Drought tolerance; gene transfer	NA	NA	1	NA	Poorly conserved	Jennings (1995); Narina et al. (2011)
Tertiary	<i>Manihot auriculata</i> McVaugh	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot caudata</i> Greenm.	M	NA	NA	NA	3	NA	Poorly conserved	NA
Tertiary	<i>Manihot chlorosticta</i> Standl. & Goldman	M	Soil salinity tolerance	NA	NA	NA	5	Poorly conserved	Narina et al. (2011)
Tertiary	<i>Manihot crassiseipala</i> Pax & K. Hoffm.	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot davisiae</i> Croizat	M, U	Drought tolerance	NA	NA	1	NA	Poorly conserved	Jennings (1995)
Tertiary	<i>Manihot mcvaughii</i> Steinmann	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot michaelis</i> McVaugh	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot oaxacana</i> D. J. Rogers & Appan	M	NA	NA	NA	NA	NA	Poorly conserved	NA

(continued)

Table 8.8 (continued)

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGR ^c	Number of accessions conserved in BGCI ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Tertiary	<i>Manihot obovata</i> J. Jimenez Ram.	M	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot pauciflora</i> Brandegee	M	NA	NA	NA	1	2	Poorly conserved	NA
Tertiary	<i>Manihot pringlei</i> S. Watson	M	Low cyanide content	NA	NA	NA	NA	Poorly conserved	Nassar et al. (2008)
Tertiary	<i>Manihot rhomboidea</i> Müll. Arg.	M	NA	NA	NA	1	NA	Poorly conserved	NA
Tertiary	<i>Manihot rhomboidea</i> Müll. Arg. subsp. <i>microcarpa</i> (Müll. Arg.) D. J. Rogers & Appan	M	NA	NA	NA	NA	1	Poorly conserved	NA
Tertiary	<i>Manihot rhomboidea</i> Müll. Arg. subsp. <i>rhomboidea</i> Müll. Arg.	M	NA	NA	NA	1	NA	Poorly conserved	NA
Tertiary	<i>Manihot rubricaulis</i> I. M. Johnston subsp. <i>isoloba</i> (Standl.) D. J. Rogers & Appan	M	NA	NA	NA	NA	1	Poorly conserved	NA

Tertiary	<i>Manihot rubricaulis</i> I. M. Johnst. subsp. <i>rubricaulis</i> I. M. Johnst.	M	NA	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot rubricaulis</i> I. M. Johnst.	M	Cold tolerance	NA	NA	NA	1	NA	Poorly conserved	Jennings (1995)
Tertiary	<i>Manihot subpicata</i> D. J. Rogers & Appan	M	NA	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot tomatophylla</i> Standl.	M	NA	NA	NA	NA	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot triloba</i> (Sessé ex Cerv.) Miranda	M	NA	NA	NA	1	NA	NA	Poorly conserved	NA
Tertiary	<i>Manihot walkerae</i> Croizat	M, U	Postharvest physiological deterioration tolerance	NA	NA	3	NA	NA	Poorly conserved	CIAT (2006). CIAT Annual Report (2006). CIAT, Cali, Colombia
Tertiary	<i>Manihot websteri</i> D. J. Rogers & Appan	M	NA	NA	NA	NA	NA	NA	Poorly conserved	NA

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)

^bUSDA, ARS (2017)

^cAAFC (2017)

^dBGCI (2017)

^eGlobal Crop Diversity Trust (2014) GENESYS

^fBased on occurrence points relative to distribution maps and published literature

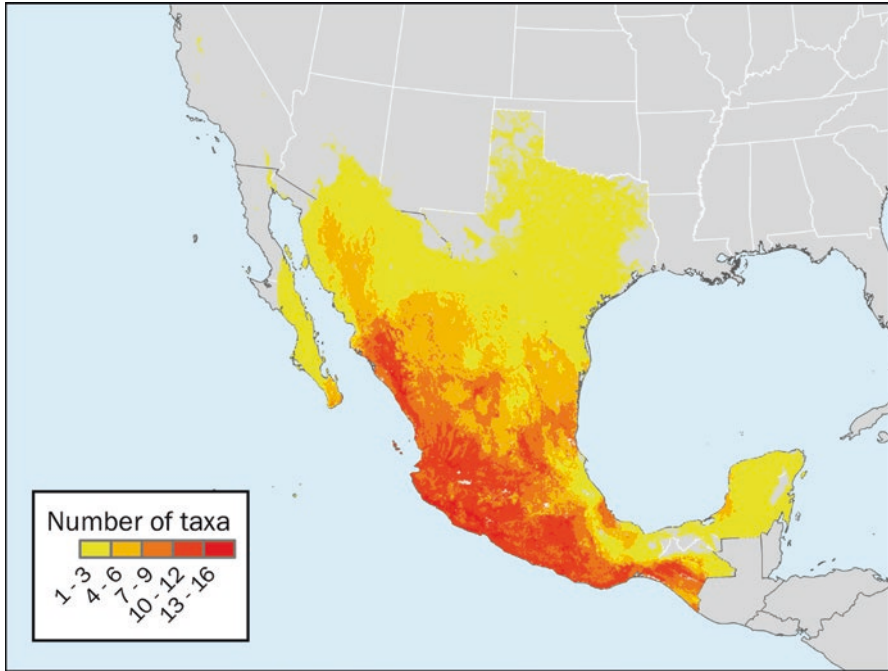


Fig. 8.5 Species richness map of modeled potential distributions of North American *Manihot* taxa, based on climatic and edaphic similarities with herbarium and genebank reference localities. Warmer colors indicate areas where greater numbers of taxa potentially occur in the same geographic localities. Full methods for generation of maps and data providers are given in Appendix 1

Pohl, *M. triphylla* Pohl, and *M. tristis* Müll. Arg (Allem et al. 2001). The wild relatives are distributed across southern North America (Fig. 8.5).

8.8.3 Conservation Status

The largest collection of cassava is housed at International Center for Tropical Agriculture (CIAT) consisting of 6024 accessions (Hershey 2010). Conservation and utilization can be improved by increasing the amount of information available on specific accessions to both conservationists and breeders. The wild relatives of cassava are all in need of further conservation; they are poorly represented in germ-plasm banks despite their well-characterized potential in breeding. *Manihot wal-kerae* Croizat is listed as endangered by the US Fish and Wildlife Service (ECOS 2016), as well as globally imperiled (critically imperiled in Texas) by NatureServe (www.natureserve.org; NatureServe 2017). The rest of the species are either secure or not well explored in situ.

8.9 Beet (*Beta vulgaris* L.)

8.9.1 Introduction

Beet (*Beta vulgaris* L.), termed “nature’s candy” due to its high sugar content, is an important vegetable, leaf, and forage crop. Cultivated beet was domesticated from wild sea beet (*Beta vulgaris* L. subsp. *maritima* (L.) Arcang.), with references to its uses dating back to ancient Rome and China (Panella and Lewellen 2007; Biancardi 2005). Beet breeding for high sucrose production increased rapidly when Napoleonic France needed a source of sugar after their access to sugarcane was cut off by the British blockade (McGrath et al. 2011). The cultivated beet originated in the Mediterranean, but the *Beta* genus contains species that are located all over the world. Europe currently cultivates the most beets with the highest production concentrated in France, Germany, and Russia, although there is substantial production in North America (FAO Stat 2014). Sugar beet, currently the most profitable cultigen, is a hybrid utilizing a cytoplasmic male sterility system and is generally grown as a biennial. Due to the importance of sugar, initial breeding efforts focused almost solely on this trait, which led to many early varieties having poor insect and disease resistance.

8.9.2 Crop Wild Relatives and Wild Use

By the mid-twentieth century there were many systematic efforts to screen wild beet species from around the world for resistance to beet leafhopper, nematodes, and leaf spot disease (Panella and Lewellen 2007). Only a few beet relatives are commonly gathered in the wild and used in cuisine, and they are generally in the primary germplasm (Ghirardini et al. 2007). Only one species is native to North America (Table 8.9).

8.9.3 Conservation Status

Increased conservation efforts for the North American wild beet species are needed (Table 8.9); while many wild relatives have been used, there is room to better conserve and characterize this species. *Aphanisma blitoides* Nutt. ex Moq. is ranked globally vulnerable by NatureServe (www.natureserve.org; NatureServe 2017) and would benefit from in situ conservation in protected areas as well as ex situ conservation.

Table 8.9 Sugar beet crop wild relatives, genepool classification, and use in sugar beet breeding

Gene pool	Taxon	Native N.A. countries ^a	Breeding use	Number of accessions conserved in NPGS ^b	Number of accessions conserved in PGRC ^c	Number of accessions conserved in BGCJ ^d	Number of accessions conserved in GENESYS ^e	Ex situ conservation status ^f	Reference
Tertiary	<i>Aphanisma blitoides</i> Nutt. ex Moq.	M, U	NA	NA	NA	NA	NA	Poorly conserved	NA

^aCanada (C), Mexico (M), USA (U), according to USDA, ARS (2017)^bUSDA, ARS (2017)^cAAFC (2017)^dBGCI (2017)^eGlobal Crop Diversity Trust (2014) GENESYS^fBased on occurrence points relative to distribution maps and published literature

References

- AAFC Plant Gene Resources of Canada (2017) Germplasm Resources Information Network-Canadian Version (GRIN-CA) database. Plant Gene Resources of Canada, Saskatoon, SK. http://pgrc3.agr.gc.ca/search_grinca-recherche_rircg_e.html. Accessed 18 Jan 2017
- Alessandro MS, Galmarini CR, Iorizzo M, Simon PW (2013) Molecular mapping of vernalization requirement and fertility restoration genes in carrot. *Theor Appl Genet* 126:415–423
- Al-Khatib K, Miller JF (2000) Registration of four genetic stocks of sunflower resistant to imidazolinone herbicides. *Crop Sci* 40:869–870
- Allem AC, Mende RA, Salomã AN, Burl ML (2001) The primary gene pool of cassava (*Manihot esculenta* Crantz subspecies *esculenta*, Euphorbiaceae). *Euphytica* 120:127–132
- Austin DF (1978) The *Ipomoea batatas* complex-I. taxonomy. *Bull Torrey Bot Club* 105:114–129
- Austin DF, Huáman Z (1996) A synopsis of *Ipomoea* (Convolvulaceae) in the Americas. *Taxon* 45:3–38
- Bamberg J, del Rio A, Kinder D, Louderback L, Pavlik B, Fernandez C (2016) Core collections of potato (*Solanum*) species native to the USA. *Am J Potato Res* 93(6):564–571
- Banga O (1957) Origin of the European cultivated carrot. *Euphytica* 6(1):54–63
- BGCI (2017) PlantSearch database. http://bgci.org/plant_search.php. Accessed online. Accessed 10 Aug 2017
- Biancardi E (2005) Brief history of sugar beet cultivation. In: Biancardi E, Campbell LG, Skaracis GN, De Biaggi M (eds) Genetics and breeding of sugar beet. Science, Enfield, pp 3–9
- Bock DG, Kane NC, Ebert DP, Rieseberg LH (2014) Genome skimming reveals the origin of the Jerusalem artichoke tuber crop species: neither from Jerusalem nor an Artichoke. *New Phytol* 201:1021–1030
- Bradbury EJ, Duputié A, Delêtre M, Roullier C, Narváez-Trujillo A, Manu-Aduening JA, Emshwiller E, McKey D (2013) Geographic differences in patterns of genetic differentiation among bitter and sweet manioc (*Manihot esculenta* subsp. *esculenta*; Euphorbiaceae). *Am J Bot* 100:857–866
- Bradshaw JE, Bryan GJ, Ramsay G (2006) Genetic resources (including wild and cultivated *Solanum* species) and progress in their utilization in potato breeding. *Potato Res* 49:49–65
- Bronson B (1966) Roots and the subsistence of the ancient Maya. *Southwest J Anthropol* 22(3):251–279
- Brookes R (1763) The natural history of vegetables, London
- Camadro E, Cauhépe MA, Simon PW (2007) Geographical distribution of wild *Daucus* species in the natural grasslands of the Argentinian pampas. *Genet Resour Crop Evol* 54:855–863
- Camadro EL, Cauhépe MA, Simon PW (2008) Compatibility relations between the edible carrot *Daucus carota* and *D. pusillus*, a related wild species from the Argentinian Pampas. *Euphytica* 159:103–109
- Castañeda-Álvarez NP, de Haan S, Juárez H, Khoury CK, Achicanoy HA, Sosa CC et al (2015) Ex situ conservation priorities for the wild relatives of potato (*Solanum* L. Section *Petota*). *PLoS One* 10(4):e0122599. <https://doi.org/10.1371/journal.pone.0122599>. pmid:2592371
- Cheng Y, Zhou WG, Gao CF, Lan K, Gao Y, Wu QY (2009) Biodiesel production from Jerusalem artichoke (*Helianthus tuberosus* L.) tuber by heterotrophic microalgae *Chlorella protothecoides*. *J Chem Technol Biotechnol* 84(5):777–781
- CIAT (2006) CIAT Annual Report 2006. CIAT, Cali, Colombia
- Dempewolf H, Baute G, Anderson J, Kilian B, Smith C, Guarino L (2017) Past and future use of wild relatives in crop breeding. *Crop Sci*. <https://doi.org/10.2135/cropsci2016.10.0885>
- ECOS (2016) Environmental conservation online system. US Fish & Wildlife Service. <https://ecos.fws.gov/ecp/>. Accessed 29 Aug 2017
- FAO (2014) FAOstat Retrieved Nov, 2016
- Ghirardini MP, Carli M, Del Vecchio N, Rovati A, Cova O et al (2007) The importance of a taste. A comparative study on wild food plant consumption in twenty-one local communities in Italy. *J Ethnobiol Ethnomed* 3(1):22

- Global Crop Diversity Trust (2014) GENESYS. Available: <http://www.croptrust.org/content/global-information-system>. Accessed 18 Jan 2017
- Grzebelus D, Baranski R, Spalik K, Allender C, Simon PW (2011) *Daucus*. In: Wild crop relatives: genomic and breeding resources. Springer, Berlin/Heidelberg, pp 91–113
- Hajjar R, Hodgkin T (2007) The use of wild relatives in crop improvement: a survey of developments over the last 20 years. *Euphytica* 156:1–13
- Harlan JR, de Wet JM (1971) Toward a rational classification of cultivated plants. *Taxon* 20:509–517
- Hershey C (2010) A global conservation strategy for cassava (*Manihot esculenta*) and wild *Manihot* species. 98. Available from <http://www.croptrust.org/documents/cropstrategies/cassava%20strategy.pdf>. Accessed Dec 2010
- Hodgkin T, Hajjar R (2008) Using crop wild relatives for crop improvement: trends and perspectives. In: Maxted N, Ford-Lloyd BV, Kell SP, Iriondo J, Dulloo E, Turok J (eds) Crop wild relative conservation and use. CABI Publishing, Wallingford, pp 535–548
- Hoes JA, Putt ED, Enns H (1973) Resistance to Verticillium wilt in collections of wild helianthus in North America. *Phytopathology* 63:1517–1520
- Hulke BS, Miller JF, Gulya TJ, Vick BA (2010) Registration of the oilseed sunflower genetic stocks HA 458, HA 459, and HA 460 possessing genes for resistance to downy mildew. *J Plant Regist* 4:1–5
- Inglis D, Brown CR, Gundersen BG, Porter LD, Miller JS, Johnson DA, Lozoya-Saldafia H, Haynes KG (2007) Assessment of *Solanum hougasii* in Washington and Mexico as a source of resistance to late blight. *Am J Potato Res* 84:217–228
- IORIZZO M, SENALIK DA, ELLISON SL, GRZEBELUS D, CAVAGNARO PF, ALLENDER C, BRUNET J, SPOONER DM, VAN DEYNZE A, SIMON PW (2013) Genetic structure and domestication of carrot (*Daucus carota* subsp. *sativus*) (Apiaceae). *Am J Bot* 100:930–938
- IORIZZO M, ELLISON S, SENALIK D, ZENG P, SATAPOOMIN P, HUANG J, BOWMAN M, IOVENE M, SANSEVERINO W, CAVAGNARO P, YILDIZ M, MACKO-PODGÓRNI A, MORANSA E, GRZEBELUS E, GRZEBELUS D, ASHRAFI H, ZHENG Z, CHENG S, SPOONER D, VAN DEYNZE A, SIMON P (2016) A high-quality carrot genome assembly provides new insights into carotenoid accumulation and asterid genome evolution. *Nat Genet* 48:657–666
- Iwanaga M (1988) Use of wild germplasm for sweet potato breeding. In: Exploration, maintenance, and utilization of sweetpotato genetic resources. International Potato Center, Lima, pp 199–210
- Jan CC, Chandler JM (1988) Registration of powdery mildew resistant sunflower germplasm pool, PM 1. *Crop Sci* 28:1039–1040
- Jan CC, Fernandez-Martinez JM, Ruso J, Muñoz-Ruz J (2002) Registration of four sunflower germplasms with resistance to Orobanchaceae Race F. *Crop Sci* 42:2217–2218
- Jan CC, Quresh Z, Gulya TJ (2004) Registration of seven rust resistant sunflower germplasms. *Crop Sci* 44:1887–1888
- Jan CC, Miller JF, Seiler GJ, Fick GN (2006) Registration of one cytoplasmic male sterile and two fertility restoration sunflower genetic stocks. *Crop Sci* 46:1835–1835
- Jansky S (2000) Breeding for disease resistance in potato. *Plant Breed Rev* 19:69–156
- Jansky SH, Dempewolf H, Camadro EL, Simon R, Zimnoch-Guzowska E, Bisognin DA, Bonierbale M (2013) A case for crop wild relative preservation and use in potato. *Crop Sci* 53:746–754
- Jennings DL (1995) Cassava, *Manihot esculenta* (Euphorbiaceae). In: Smartt J, Simmonds NW (eds) Evolution of crop plants. Longman Group, Harlow, pp 128–132
- Jyoti J, Brewer GJ (1999) Resistance in sunflower and interaction with *Bacillus thuringiensis* for control of banded sunflower moth (Lepidoptera: Tortricidae). *J Econ Entomol* 92:1230–1233
- Kane NC, Rieseberg LH (2007) Selective sweeps reveal candidate genes for adaptation to drought and salt tolerance in common sunflower, *Helianthus annuus*. *Genetics* 175:1823–1834
- Kantar MB, Baute GJ, Bock DG, Rieseberg LH (2014) Genomic variation in *Helianthus*: learning from the past and looking to the future. *Brief Funct Genomics* 13:328–340
- Kantar MB, Sosa, CC, Khoury, CK, Castañeda-Álvarez, NP, Achicanoy, HA, Bernau, V, Kane, NC, Marek, L, Seiler, G, Rieseberg, LH. (2015). Ecogeography and utility to plant breeding of the crop wild relatives of sunflower (*Helianthus annuus* L.). *Frontiers in plant science*, 6, 841

- Kays SJ, Nottingham SF (2008) Biology and chemistry of Jerusalem artichoke *Helianthus tuberosus* L. CRC Press, Boca Raton, FL
- Khoury CK, Heider B, Castañeda-Álvarez NP, Achicanoy HA, Sosa CC, Miller RE, Scotland RW, Wood JR, Rossel G, Eserman LA, Jarret RL, Yencho GC, Bernau V, Henry Juarez H, Sotelo S, Stef de Haan S, Struik PC (2015) Distributions, ex situ conservation priorities, and genetic resource potential of crop wild relatives of sweetpotato [*Ipomoea batatas* (L.) Lam., I. series *Batatas*]. *Front Plant Sci* 6:251
- Radio AH (2001) The maintenance of wild edible plant gathering in a Mapuche community of Patagonia. *Econ Bot* 55(2):243–254
- Lebot V (2010) Sweet potato. In: Bradshaw JE (ed) Handbook of plant breeding, root and tuber crops. Springer, New York, pp 97–125
- Lexer C, Welch ME, Durphy JL, Rieseberg LH (2003) Natural selection for salt tolerance quantitative trait loci (QTLs) in wild sunflower hybrids: implications for the origin of *Helianthus paradoxus*, a diploid hybrid species. *Mol Ecol* 12:1225–1235
- Lexer C, Lai Z, Rieseberg LH (2004) Candidate gene polymorphisms associated with salt tolerance in wild sunflower hybrids: implications for the origin of *Helianthus paradoxus*, a diploid hybrid species. *New Phytol* 161:225–233
- Lim TK (2016) *Pachyrhizus erosus*. In: Edible medicinal and non-medicinal plants. Springer Netherlands, Dordrecht, pp 465–481
- Liu Z, Halterman D (2009) Different genetic mechanisms control foliar and tuber resistance to *Phytophthora infestans* in wild potato *Solanum verrucosum*. *Am J Potato Res* 86(6):476
- Ma XY, Zhang LH, Shao HB, Xu G, Zhang F, Ni FT, Brestic M (2011) Jerusalem artichoke (*Helianthus tuberosus*), a medicinal salt-resistant plant has high adaptability and multiple-use values. *J Med Plant Res* 5:1272–1279
- McDonald JA, Austin DF (1990) Changes and additions in *Ipomoea* section *Batatas* (Convolvulaceae). *Brittonia* 42(2):116–120
- McGrath JM, Panella L, Frese L (2011) Beta. In: Wild crop relatives: genomic and breeding resources. Springer, Berlin/Heidelberg, pp 1–28
- Miller JF, Al-Khatib K (2002) Registration of imidazolinone herbicide-resistant sunflower maintainer (HA 425) and fertility restorer (RHA 426 and RHA 427) germplasm. *Crop Sci* 42:988–989
- Miller JF, Gulya TJ (1988) Registration of six downy mildew resistant sunflower germplasm lines. *Crop Sci* 28:1040–1041
- Miller JF, Gulya TJ (1999). Registration of eight *Sclerotinia*-tolerant sunflower germplasm lines. *Crop sci*, 39(1):301–302
- Miller JF, Seiler GJ (2003) Registration of five oilseed maintainer (HA 429–HA 433) sunflower germplasm lines. *Crop Sci* 43:2313–2314
- Narina SS, Jasti M, Buyyarapu R, Bhattacharjee R (2011) Manihot. In: Wild crop relatives: genomic and breeding resources. Springer, Berlin/Heidelberg, pp 133–155
- Nassar NM (1978) Conservation of the genetic resources of cassava (*Manihot esculenta*) determination of wild species localities with emphasis on probable origin. *Econ Bot* 32(3):311–320
- Nassar NM, Hashimoto DYC, Fernandes SDC (2008) Wild *Manihot* species: botanical aspects, geographic distribution and economic value. *Genet Mol Res* 7(1):16–28
- NatureServe (2017) NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available <http://explorer.natureserve.org>. Accessed 10 Aug 2017
- Nimmakayala P, Vajja G, Reddy UK (2011) *Ipomoea*. In: Wild crop relatives: genomic and breeding resources. Springer, Berlin/Heidelberg, pp 123–132
- Olsen KM, Schaal BA (1999) Evidence on the origin of cassava: Phylogeography of *Manihot esculenta*. *Proc Natl Acad Sci USA* 96:5586–5591
- Onokpise OU, Wutoh JG, Ndzana X, Tambong JT, Meboka MM, Sama, AE, Nyochembeng L, Aguegia A, Nzietchueng S, Wilson JG, Burns M (1999) Evaluation of macabo cocoyam germplasm in Cameroon. Perspectives on new crops and new uses, 394–396
- Onwueme IC (2002) Cassava in Asia and the Pacific. In: Hillocks RJ, Thresh JM, Bellotti A (eds) Cassava: biology, production and utilization. CABI, Wallingford, pp 1–16

- Panella L, Lewellen R (2007) Broadening the genetic base of sugar beet: introgression from wild relatives. *Euphytica* 154:383–400
- Pío-León, JF, Delgado-Vargas, F, León-de la Luz, JL, Ortega-Rubio, A (2017). Prioritizing wild edible plants for potential new crops based on deciduous forest traditional knowledge by a rancher community. *Bot Sci*, 95(1):47–59
- Piperno DR, Holst I (1998) The presence of starch grains on prehistoric stone tools from the humid neotropics: indications of early tuber use and agriculture in Panama. *J Archaeol Sci* 25:765–776
- Piperno DR, Ranere AJ, Holst I, Hansell P (2000) Starch grains reveal early root crop horticulture in the Panamanian tropical forest. *Nature* 407:894–897
- Prescott-Allen R, Prescott Allen C (1986) *The first resource: wild species in the North American economy*. Yale University, New Haven
- Qi LL, Seiler GJ, Vick BA, Gulya TJ (2012) Genetics and mapping of the R 11 gene conferring resistance to recently emerged rust races, tightly linked to male fertility restoration, in sunflower (*Helianthus annuus* L.). *Theor Appl Genet* 125:921–932
- Quero-Garcia, J., Ivancic, A., & Lebot, V. (2010). Taro and cocoyam. In *Root and Tuber Crops* (pp. 149–172). Springer, New York, NY
- Ramsay G, Bryan G (2011) *Solanum*. In: *Wild crop relatives: genomic and breeding resources*. Springer, Berlin/Heidelberg, pp 259–271
- Reddy PP (2015) Yam Bean, *Pachyrhizus erosus*. In: *Plant protection in tropical root and tuber crops*. Springer, New Delhi, pp 267–279
- Rogers CE, Thompson TE, Seiler GJ (1982) *Sunflower species of the United States*. National Sunflower Association, Bismarck, pp 1–75
- Rogers CE, Thompson TE, Seiler GJ (1984) Registration of three *Helianthus* germplasms for resistance to the sunflower moth. *Crop Sci* 24:212–213
- Ross H (1979) Wild species and primitive cultivars as ancestors of potato varieties. In: Zeven AC, van Harten AM (eds) *Proceedings of the conference broadening the genetic base of crops*. Centre for Agricultural Publishing and Documentation, Wageningen, pp 237–245
- Sakamoto S (1976) Breeding of a new sweet potato variety, Minamiyutaka, by the use of wild relatives. *Jpn Agric Res Quest* 10:183–186
- Seiler GJ (1991a) Registration of 15 interspecific sunflower germplasm lines derived from wild annual species. *Crop Sci* 31:1389–1390
- Seiler GJ (1991b) Registration of 13 downy mildew tolerant interspecific sunflower germplasm lines derived from wild annual species. *Crop Sci* 31:1714–1716
- Seiler GJ (1994) Progress report of the working group of the evaluation of wild *Helianthus* species for the period 1991 to 1993. *Helia* 17:87–92
- Seiler GJ (2000) Registration of 10 interspecific germplasms derived from wild perennial sunflower. *Crop Sci* 40:587–588
- Seiler GJ, Campbell LG (2004) Genetic variability for mineral element concentrations of wild Jerusalem artichoke forage. *Crop Sci* 44(1):289–292
- Seiler GJ, Campbell LG (2006) Genetic variability for mineral concentration in the forage of Jerusalem artichoke cultivars. *Euphytica* 150:281–288
- Shiotani I, Huang ZZ, Sakamoto S, Miyazaki T (1991) The role of the wild *Ipomoea trifida* germplasm in sweet potato breeding. *Symp Trop Root Crops Dev Econ* 380:388–398
- Simon PW (2000) Domestication, historical development, and modern breeding of carrot. *Plant Breed Rev* 19:157–190
- Solis RS, Haas J, Creamer W (2001) Dating Caral, a preceramic site in the Supe Valley on the central coast of Peru. *Science* 292:723–726
- Spooner DM, Bamberg JB (1994) Potato genetic resources: sources of resistance and systematics. *Am Potato J* 71:325–337
- Spooner DM, McLean K, Ramsay G, Waugh R, Bryan GJ (2005) A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping. *PNAS* 102:14694–14699

- Srivastava A, Bhardwaj V, Singh BP, Khurana SP (2016) Potato diversity and its genetic enhancement. In: Gene pool diversity and crop improvement. Springer International Publishing, Cham, pp 187–226
- Suszkiw J (2009) Scientists use old, new tools to develop pest-resistant potato. *Agric Res* 57:11–12
- Tambong JT, Ndzana JG, Wutoh JG, Dadson R (1997) Variability and germplasm loss in the Cameroon national collection of cocoyam (*Xanthosoma sagittifolium* Schott (L.)). *Plant Genet Resour Newsl* 112:49–54
- Thieme R, Rakosy-Tican E, Gavrilenko T, Antonova O, Schubert J, Nachtigall M, Heimbach U, Thieme T (2008) Novel somatic hybrids (*Solanum tuberosum* L. + *Solanum tarnii*) and their fertile BC1 progenies express extreme resistance to potato virus Y and late blight. *Theor Appl Genet* 116:691–700
- USDA, ARS, National Plant Germplasm System (2017) Germplasm Resources Information Network (GRIN Global) Database National Germplasm Resources Laboratory, Beltsville, MD. https://www.ars-grin.gov/npgs/acc/acc_queries.html. Accessed 18 Jan 2017
- Velasco L, Pérez-Vich B, Yassein AA, Jan CC, Fernández-Martínez JM (2012) Inheritance of resistance to sunflower broomrape (*Orobanche cumana* Wallr.) in an interspecific cross between *Helianthus annuus* and *Helianthus debilis* subsp. *tardiflorus*. *Plant Breed* 131:220–221
- Whelan EDP, Dedio W (1980) Registration of sunflower germplasm composite crosses CMG-1, CMG-2, and CMG-3. *Crop Sci* 20:832–832
- Yang Y, Guan S, Zhai H, He S, Liu Q (2009) Development and evaluation of a storage root-bearing sweet potato somatic hybrid between *Ipomoea batatas* (L.) Lam. and *I. triloba* L. *Plant Cell Tissue Org Cult (PCTOC)* 99(1):83–89