**New and Industrial Crop Vulnerability Report**

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1. **Introduction**

The value of the new and industrial crops is very difficult to determine since statistical

reports are not updated for these species and new crops have little production data available. However, they remain potentially useful as major components in industrial markets such as edible oil, biofuel, medicinal products, nutritional products, fiber, gum, dyes, resins, rubber, cover crops, and other industrial uses. These species are adapted to a wide range of soil and climatic conditions. These crops can have a significant economic impact for these multi-billion-dollar industries as well as social and environmental benefits. Some of these benefits include water savings, replacement of petroleum products, domestic sourcing, and job creation.

The New and Industrial Crops Crop Germplasm Committee (CGC) is an advisory committee consisting of a group of scientists and industry representatives that provides analysis, data, and recommendations on genetic resources of new and industrial crops. The CGC assists NPGS curators in identifying gaps in the U.S. collections, helping to prioritize traits for evaluation, and assisting in regeneration activities.

New and industrial crop germplasm collections are maintained by the National Plant Germplasm System (NPGS) at several USDA-ARS sites throughout the US (see Table 1). The Plant Genetic Resources Conservation Unit (PGRCU) in Griffin, GA maintains the castor, guar, kenaf, roselle, sesame, and sunn hemp collections under one curator and one technician. The PGRCU has greenhouse facilities, laboratories, and –18°C and 4°C storage freezers on site. Greenhouse, field, and lab resources are available for regenerating and conducting biochemical analysis on the germplasm. The Plant Germplasm Introduction and Testing Research Unit (PGITRU, also call the Western Regional Plant Introduction Station (WRPIS)) in Pullman, WA maintains the *Taraxacum, Grindelia* and *Carthamus* collections in separate programs. *Taraxacum* and *Grindelia* are under the curatorial management of the Horticulture Crops and *Beta* Program, consisting of one curator and two technicians who are responsible for 12,870 accessions in four inventory maintenance groups (Lettuce, *Allium*, Miscellaneous and *Beta*) with Unit staff support and seasonal help. *Carthamus* is part of the Agronomy Regeneration and Research Program at the PGITRU. One curator and two technicians, with Unit staff support and seasonal help, manage these collections, which consist of more than 22,000 cool season grass and 2,400 *Carthamus* accessions. The PGITRU utilizes offices, laboratories, greenhouses, growth chambers, and seed storage facilities (4⁰C and -20⁰C) on the campus of Washington State University and 2 farms, one in Pullman, WA and the other at Central Ferry, WA. The facilities, greenhouse and farms, and resources of the PGITRU are sufficient to maintain the collections, except regeneration and evaluation of some species, especially the noxious weed *Carthamus oxyacantha*, is not possible with existing facilities. Facilities and equipment are adequate for regeneration and collection of morphological descriptors for PGITRU crops, but laboratory equipment for rubber, oil and fatty acid analysis is not available within the unit. Collaboration with the Washington State University Browse Lab is ongoing and enables *Carthamus* analysis to continue. The National Arid Land Plant Genetic Resources Unit (NALPGRU) in Parlier, CA maintains the guayule collection along with several other arid land industrial crops under one curator and one technician. The NALPGRU has access to field, greenhouse, shadehouse, lab and office space, as well as seed storage facilities at 4C and -18C. Back-up seed lots for all NPGS collections are maintained by the National Laboratory for Genetic Resource Preservation (NLGRP) in Ft. Collins, CO.

The majority of industrial crop accessions are acquired either from donations or through plant collection trips (USDA 2020a). Collection size and priority is based on the curator’s judgement, with advice provided by the New and Industrial Crop Germplasm Committee (CGC). Passport data are recorded in GRIN-Global and are publicly available, along with characterization data (<https://npgsweb.ars-grin.gov/gringlobal/search.aspx>). If available, passport data usually include collection site, general description of the site and the accessions, latitude, longitude, GPS coordinates, elevation, and habitat information. Other information recorded in GRIN include accession number (PI and/or local number), collector (if from an exploration), date when accession was received, backup status, accession name, availability, narrative (about the accession), source history (development or collection information), pedigree, and observation (phenotypic and genotypic data). Seed requests for all industrial crops are received through the GRIN-Global web platform from worldwide researchers. After receipt of each request, the curator determines its feasibility and approval. Then the request is prepared for distribution. See Table 1 for 5-year annual average distributions for new and industrial crops.

The curatorial goals for these collections are to continue providing seed to the research community, add accessions of elite lines or varieties when they are made available, identify and fill critical gaps in the collections, continually improve the quality of associated data including taxonomy, and provide new characterization data as available. In order to assist scientists in making informed decisions regarding new and industrial crop germplasm, NPGS curators collaborate with various external research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects are performed and, in both cases, all resulting data is published and linked to the collections via GRIN-Global.

The objective of this document is to provide background, benefits and the current status of each crop in order to determine curatorial needs and projections for future action to preserve these crops and their relatives. Not all crops from the New and Industrial Crop Germplasm Committee are treated in detail here, please see Quads for additional important new and industrial crops.

Table: Summary of main crops in New and Industrial Crops CGC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Crop Name** | **Scientific Name** | **Primary use(s)** | **NPGS site (curator)** | **NPGS accessions** | **NPGS annual distribution (5 year average)** |
| Castor | *Ricinus communis* | industrial oil, biodiesel, lubricant | Griffin, GA (Bradley Morris) | 1,004 | 246 |
| Gumweed | *Grindelia* | essential oils, industrial resin, ornamental | Pullman, WA (Barbara Hellier) | 55 | 1-2 |
| Guar | *Cyamopsis tetragonoloba* | food/beverage additive, industrial additive | Griffin, GA (Bradley Morris) | 1,300 | 299 |
| Guayule | *Parthenium* | rubber, resin, latex | Parlier, CA (Claire Heinitz) | 137 | 200 |
| Kenaf | *Hibiscus cannabinus* | fiber | Griffin, GA (Bradley Morris) | 286 | 205 |
| Roselle | *Hibiscus sabdariffa* | specialty foods, ornamental | Griffin, GA (Bradley Morris) | 139 | 73 |
| Safflower | *Carthamus tinctorius* | edible seed oil, florets for edible herb and dye, birdseed | Pullman, WA (Vicki Bradley – ret.) | 2396 | 900 |
| Sesame | *Sesamum indicum* | Edible oil and seeds | Griffin, GA (Bradley Morris) | 1,300 | 792 |
| Sunn Hemp | *Crotalaria juncea* | cover crop | Griffin, GA (Bradley Morris) | 22 | 34 |
| Rubber dandelion | *Taraxacum kok-saghyz* | rubber, inulin | Pullman, WA (Barbara Hellier) | 20 | 101 |
| Vernonia (previous name) | *Centrapalus pauciflorus* | industrial oil (vernolic acid) | Ames, IA (Laura Marek) | 64 (4 inactive) | 16 |

1. **Crops**
   1. ***Castor***

**2.1.1 Castor - Introduction**

**Origin**: Castor bean plants grow wild in Ethiopian desert areas; inner-Mongolian region in China; and in Indian forests, sand dunes, coastal areas, river beds, hill tops, valleys, roadsides, tropical, and wasteland (Anjani 2012). The wild types in Bihar, Uttar Pradesh, and Madhya Pradesh were tall, woody, perennial, and had large leaves (Anjani 2012).

**Primary Crop Products and Value:** Castor bean has several industrial uses including oil as biodiesel (Severino et al. 2012) or for human consumption as a laxative. Castor oil consists of the important fatty acid, ricinoleic acid which has use in lubricants (Severino et al. 2012). Castor oil value is not stable, since oil prices can be volatile (Roetheli et al. 1990).

**Breeding Programs in the U.S.:** A mutant line with high oleic acid and lower amounts of ricinoleic acid was selected from PI 179729 in the USDA, ARS, PGRCU germplasm collection for potential biodiesel uses (Auld et al. 2009). Ricin is a very toxic protein in the castor bean seed endosperm, which can be lethal if consumed (Khvostova 1986). Conventional plant breeding was used to develop the cultivar, Brigham with lower ricin levels using hybridization between a dwarf castor accession and two accession’s including PI 258368 and PI 257654 which produce reduced ricin content (Khvostova 1986).

**Domestic Production:** Castor bean (*Ricinus communis* L.) production in the United States is in Texas.

**International Production:** The primary countries involved in castor bean seed production include Brazil, China, Ethiopia, India, Paraguay, and Thailand with total seed production exceeding 1,300,000 metric tons (FAO 2008).

**2.1.2 Castor - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for castor bean (Severino et al. 2012). Even though the USDA, ARS, PGRCU collection in Griffin, GA maintains more than 1,000 castor bean accessions, nearly all of the castor oil used in the U.S. is imported. The PGRCU castor bean collection consists of about 63 cultivars worldwide. Eleven castor bean cultivars were developed in the U.S. Therefore, the reduction in genetic diversity within cultivars and the number of cultivars in the U.S. occurs because of emphasis on other oil producing crops resulting in the narrowing of the genetic base by breeding. Since castor programs in the U.S. have either reduced or stopped, older cultivars may be lost. Another factor playing a role in U.S. limited castor bean production is the presence of the toxic protein, ricin in the seed meal.

**Threats of Genetic Erosion *in situ***: People in India use castor plants for firewood, roofing, and building huts (Anjani 2012). Climate change, human intervention in castor bean (Anjani 2012) native habitats, and international treaty issues will have a negative impact on their wild relatives.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** The economically important diseases affecting castor are gray mold (*Botryotinia ricini* G.H. Godfrey or *Amphobotrys ricini* N.F. Buchw. Anamorphic), vascular wilt (*Fusarium oxysportum* f. sp. *ricini* Nanda and Prasad), and charcoal rot (*Macrophomina phaseolina* [Tassi] Goid) (Severino et al. 2012). Gray mold is the most infectious disease throughout the world. Moderate gray mold tolerance has been identified in some castor accessions (Anjani 2012) and further research is needed for chemical control of this disease (Severino et al. 2012). Vascular wilt is the most serious castor disease in India (Desai and Dange 2003) and several resistant hybrids and breeding lines have been developed (Anjani et al. 2004; Anjani 2005b, c; Patel and Pathak 2011; Anjani 2012). Charcoal rot is prevalent in those areas where castor is grown (Rajani and Parakhia 2009) and tolerant genotypes have been developed (Anjani et al. 2004; Anjani 2005a). Nematodes are reported on castor, however they are not usually economical (Kolte et al. 1995) with the exception of the reniform nematode (*Rotylenchulus reniformis* Linford and Oliveira) which can cause enough damage for vascular wilt infection (Dange et al. 2005). Rust (*Melampsora ricini* Pass ex E.A. Noronha), *Alternaria* leaf spot [*Alternaria ricini* (Yoshii) Hansf.], and bacterial leaf spot [*Xanthomonas axonopodis* pv. *ricini-cola* (Elliott) Dowson] are minor diseases (Anjani 2012) with no reports of resistance to any of these (Kishun et al. 1980; Chauhan and Swarup 1984). Important insect pests in India include the castor semilooper (*Achaea janata* L.), castor shoot borer (*Conogethes punctiferalis* Guen.), capsule borer (*Dichocrosis punctiferalis* Guen.), tobacco caterpillar (*Spodoptera litura* Fabr.), red hairy caterpillar (*Amsacta* spp.), and leafminer [*Liriomyza trifolii* (Burgess)] (Basappa 2007; Anjani et al. 2010). The main insect pests in Brazil are the stink bug (*Nezara viridula* L.), leafhopper (*Empoasca* spp.), armyworm (*Spodoptera frugiperda* J.E. Smith), semilooper, black cutworm (*Agrotis ipsilon* Hufnagel), two spotted spider mite (*Tetranychus urticae* Koch),and the bean spider mite (*T. ludeni* Zacher) (Ribeiro et al. 2008).Moderate resistance to the tobacco caterpillar is found in one cultivar (Thanki et al. 2001). Combinations of pesticide use, crop rotation, insect traps, and neem extract have resulted in higher yields in India (Basappa 2007). Castor cultivars with purple leaves showed tolerance to the leafminer (Severino et al. 2012) and epicuticular wax on leaves reduced damage by the semilooper and tobacco caterpillar (Sarma et al. 2006). Several castor bean sources of leafhopper resistance have been identified (Jayaraj 1966, 1967).

**Abiotic Stress:** Castor bean plants are very tolerant to drought (Severino et al. 2012), however they do not tolerate flooding very well (Severino et al. 2012). Soil acidity can reduce castor bean production also (Severino et al. 2012). Cold soil temperatures around 10°C reduced shoot and root biomass (Poire et al. 2010). Cultivar development is used to improve castor bean for abiotic stresses since, many accessions have been identified to tolerate salt, water use efficiency, and heat (Anjani 2012).

**Market and population growth demands:** In the U.S., the primary problem concerning castor bean production results from the toxic chemical, ricin in the seed meal of castor bean seeds. Producers are not willing to grow castor beansbecause of this toxic compound.

**2.1.3 Castor – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Castor bean accessions represented in the collection include cultivars with high oleic acid, reduced ricinoleic acid mutant, reduced ricin content, and dwarf internode growth habit. A draft genome sequence for castor has been developed (Chan et al. 2010). Molecular markers have been used to characterize large genetic variability in castor bean (Gajera et al. 2010; Zheng et al. 2010). However, only about 10% of the PGRCU castor collection is analyzed for genetic diversity.

**Acquisitions:** All of the castor bean cultivars were donated by U.S. and foreign breeders (USDA 2020a). Castor bean wild relatives needed for the U.S. collection include *Mallotus apelta* (Lour.) Mull. Arg. previously known as *Ricinus apelta* Lour., *Macaranga mappa* (L.) Mull. Arg. previously known as *R. mappa* L., *M. tanarius* (L.) Mull. Arg. previously *R. tanarius* L., and *M. triloba* (Thunb.) Mull. Arg. previously *R. trilobus* Thunb. Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The castor bean collection maintained consists of 1,044 accessions at PGRCU and NLGRP combined. 377 accessions are backed-up at NLGRP and 378 accessions are stored in –18°C freezers at PGRCU. Only 115 accessions in the PGRCU gene bank are available for distribution. This is due to inadequate seed production under normal field conditions or low viable seed. Currently, 357 (94%) accessions are tested for germination at PGRCU. Thus far, 19 accessions have also been backed up at the Svalbard, Norway facility. New methods to optimize seed production for many accessions is required and this may include growing hundreds of plants in the field to maximize better seed production.

**Regeneration:** Castor bean plants are self-pollinated, but they can naturally cross-pollinate with estimates averaging 80% (Brigham 1967). However, outcrossing is eliminated by regenerating the plants in isolation (Severino et al. 2012), bagging the inflorescences prior to flowering (Auld et al. 2009), or using border crops such as sudan grass. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a border crop using sudan grass and other species for castor bean at PGRCU. Seed capsules are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table

**Genotypic characterization data:** Approximately half of the diploid castor bean collection has been genotyped based on oil content, fatty acid composition, and origin using microsatellite markers. Datasets for 118 EST-SSR markers are used to assess genetic diversity based on these traits for 574 castor bean accessions (Wang et al. 2017). The results from cluster analysis, population structure, and principal component analysis were consistent, and partitioned accessions into four sub-populations. There were some admixtures among groups, but these clusters and sub-populations aligned with geographic origins. Both divergent and redundant accessions were identified.

**Phenotypic evaluation data:** The NPGS castor bean collection has been characterized for growth, morphological, and phenological descriptors. Castor bean phenotypic traits are related to: growth including plant height and vigor; morphology including raceme height, raceme length, seed color, seed size, and stem color; and phenology including maturity. Most of the collection has been phenotyped using these descriptor sets. All passport and phenotypic (descriptor) data are stored in GRIN-Global (USDA 2020a).

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the industrial crop germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing seed oil content. Currently, PGRCU in-house research efforts focus on the development of a castor bean core collection based on chemical, yield, and descriptor traits using SSR markers and principal component analysis.

**Significant accomplishments:** Even though the NPGS castor bean collection is diverse, there is a need for additional accessions to optimize genetic diversity. A natural castor mutant was isolated from PI 179729 in the NPGS collection with high oleic acid concentration and lower levels of ricinoleic acid (Rojas-Barros et al. 2005). The castor cultivar, Brigham is developed with lower levels of the toxin, ricin (Auld et al. 2009). The entire NPGS castor collection was evaluated for oil content with some accessions reaching 60% (Wang et al. 2010). Using molecular markers to partition castor bean accessions into four subpopulations, alignment into geographical origins, and identified divergent and redundant accessions was helpful (Morris and Wang 2017).

**2.1.4 Castor - Other genetic resource capacities**

Countries with castor bean collections include Brazil (1,287), China (3,341), Ethiopia (232), India (290), Kenya (173), Romania (66), Russia (423), Serbia (112), Ukraine (255), and the U.S. (1,056).

**2.1.5 Castor - Prospects and future developments**

The U.S. castor bean collection is vulnerable due to the low number of cultivars that are in production and the limited number of U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs have reduced due to retirements and the use of more popular oil, gum, and fiber producing crops. Reduced budgets for castor bean genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS castor bean collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized genetically and phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS industrial crop collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important *ex situ* populations that must be collected before important sources of diversity are lost. Castor bean will remain an important oil crop. Traditional breeding techniques have successfully incorporated desirable alleles into castor bean, improving resistance, and lowering toxic components. With a diverse germplasm base secured, the future for castor bean production looks positive.

* 1. ***Grindelia***

**2.2.1 Grindelia - Introduction**

**Origin:** The species in the genus Grindelia or gumweed are native to North and South America. Grindelia is a member of the Asteraceae family with 27 recognized species (USDA 2020b) which are herbaceous annuals, perennials, subshrubs and shrubs.

**Primary Crop Products and Value:** The North American Grindelia species have been used as medicinal herbs by Native Americans for bronchial and skin problems (Train et al. 1941; Canavan and Yarnell 2005) and are being used in current herbal preparations for respiratory support (Gaia Herbs 2018). Because of the high content of resin in the plants, this genus is being explored for industrial use. *G. camporum, G. squarrosa,* and *G. chiloensis* are the primary species of interest but resins and/or essential oils have been found in *G. nana* (Mahmoud et al. 2000), *G. integrifolia* (Ahmed et al. 2001), *G. scorzonerifolia* (Ybarra et al. 2005), *G. acutifolia* (Timmermann et al. 1987), *G. robusta* (Fraternale et al. 2007), *G. discoidea* (Timmermann et al. 1986).

In the 1980’s in response to a decline in petroleum supplies, extensive surveys were done on arid land plants to determine their potential as feed stocks for biofuels or as commodity crops (McLaughlin and Hoffmann 1982; McLaughlin et al. 1983). *G. camporum* was identified as one of the more promising species in these studies. The major components isolated from this species are diterpene acids which are similar to wood rosin used in the naval stores industry (Hoffmann and Mclaughlin 1986). *G. camporum* is native to California and Nevada (USDA-NRCS Plants 9/19/18). It is used as an ornamental in wildflower and butterfly gardens, in wetland restoration, as a pollinator and beneficial insect host and as a medicinal (Bliss 2012) along with being investigated as an industrial crop. In the 1980’s and 90’s agronomic and yield studies (Hoffmann and Mclaughlin 1986; McLaughlin and Linker 1987; Zafar et al. 1994; Ravetta et al. 1996) and initial breeding (McLaughlin 1986) was conducted but the crop was not developed. In the mid-2000’s, researchers reexamined this species and also explored *G. chiloensis*, a native shrub of Chile, for biofuels and resins production (Wassner and Ravetta 2000, 2005; Mahmoud 2001; Zavala and Ravetta 2001a, b; Pandey et al. 2009). There is currently no domestic production of *G. camporum* in the US or internationally.

Another *Grindelia* species evaluated in the 1980’s was *G. squarrosa*. It was found to have high grindelic acid content (McLaughlin and Hoffmann 1982). More recently, it is being investigated as a feed stock for jet fuel because of its high yield of biocrude extract (Neupane et al. 2017) and the nature of grindelic acid, a tricyclic diterpenoid with 20 carbon atoms and 3 oxygen atoms (Yang et al. 2018). *G. squarrosa* is native to all of the continental US and Canada except the southeastern states and Alaska. (USDA-NRCS Plants 9/19/18). It has been used as a medicinal by Native Americans and is highly attractive to native bees. Its late season blooming makes it a good pollen source for pollinators building winter reserves (Dalby 1999). It is also a food source for sage grouse juveniles (Peterson 1970), a species of concern in the western US.

**Breeding Programs in the U.S.:** There are currently no breeding programs in the U.S. University of Nevada, Reno initiated investigations into G. squarrosa and there is interest in continuing the work.

**Domestic Production:** No current production.

**International Production:** No current production

**2.2.2 *Grindelia -* Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** *G. camporum* is a herbaceous perennial that is an obligate outcrosser (Mclaughlin and Linker 1987). It can hybridize with other *Grindelia* species growing in its range (Dunford 1964). There are currently no cultivars of *G. camporum* (Bliss 2012) but seed is readily available on the internet. Dunford (1964) found both diploid (*G. camporum*) and tetraploid (*G. camporum* var. *camporum*) samples in the material he studied. In their agronomic studies, McLaughlin and Linker (1987) identified more potential for agronomic improvement in the tetraploid material trialed. *G. squarrosa* is an herbaceous short-lived perennial or biennial. Flowering occurs in mid to late summer into August and September (Tilley and Pickett 2016). There are currently no cultivars available but seed is available for sale on the internet.

**Threats of Genetic Erosion *in situ*:** *G. camporum* is currently listed as “apparently secure” by Nature Serve (<http://www.natureserve.org/> 9/19/18). *G. squarrosa* is not considered threated *in situ*. In some states it is considered weedy (Tilley and Pickett 2016).

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases and pests:** No diseases or pests were noted in the evaluation trials by McLaughlin and Neupane. Seed predations by beetles has been observed in regeneration plots at the PGITRU Central Ferry farm.

**Abiotic Stress:** *Grindelia* species are generally adapted to low moisture areas and poor soils.

**Market and population growth demands:** none.

**2.2.3 *Grindelia -* Status of the plant genetic resources in the NPGS**

**Genetic coverage and gaps:** The majority of *G. camporum* accessions were collected by the US Interior Dept. Bureau of Land Management (BLM), Seeds of Success(SOS) project. One accessions, W6-6564 (A-173) was donated by Dr. McLaughlin from his program at the University of Arizona. With only 14 accessions in the collection there are many gaps in the geographic coverage for this species. All accessions of *G. squarrosa* were collected by the BLM SOS project. Even though the collection locations for this species are widespread with accessions from Nevada, Utah, Wyoming and Colorado there still are many gaps. All *Grindelia* accessions have complete associated passport data.

**Acquisitions:** Additional collections of both *G. camporum* and *G. squarrosa* are needed to fully evaluate the crop potential of these species.

**Holdings and Maintenance:** The *Grindelia* collection currently has 55 accessions in 9 taxa. There are 12 accessions of *G. camporum* and 2 accessions of *G. camporum* var. *camporum.* The *G. squarrosa* collection currently consists of 26 accession: 19 *G. squarrosa*, 2 accessions of *G. squarrosa* var. *nuda*, 1 accession of *G. squarrosa* var. *quasiperennis*, 3 accessions of *G. squarrosa* var. *serrulata* and 1 accession of *G. squarrosa* var. *squarrosa*. The remaining 15 accession are of eight additional US native *Grindelia* species. Forty-five of the 55 *Grindelia* accessions are backed-up at NLGRP. None have been sent to Svalbard.

**Regeneration:** *Grindelia* accessions are selected for regeneration when seed quantities or quality declines and are grown in open-pollinated spatially-isolated field plots utilizing native pollinators at the WRPIS Central Ferry, WA farm. Each plot is hand harvested and cleaned. After regeneration, if needed, a back-up sample is sent to NLGRP. At the PGITRU, seed is stored at 4℃.

**Distributions:** see Table

**Genotypic characterization data:** This collection is fairly new and has not yet been genotyped.

**Phenotypic evaluation data:** No phenotypic data has been collected other than images during regeneration.

**Plant genetic resource research associated with the NPGS**:

**Goals and emphasis:** There are currently no NPGS research projects associated with G. camporum but Dr. Miller, University of Nevada, Reno was awarded 2020 funds to collect G. squarrosa from selected habitats for future agronomic and biofuel yield evaluation. We will collaborate on these projects.

**2.2.4 *Grindelia -* Prospects and future developments**

Because *Grindelia* species can be grown on marginal land and need limited water and other agricultural inputs, *G. squarrosa* is a promising bioenergy plant (Neupane et al. 2017).

* 1. ***Guar***

**2.3.1 Guar - Introduction**

**Origin:** Guar (*Cyamopsis tetragonoloba* (L.) Taub is a cultigen growing wild in India and Pakistan. U.S. production is centered in Texas and Oklahoma.

**Primary Crop Products and Value:** Guaris used as a laxative, food additive, in gas and oil well drilling, in the mining industry, pet foods, and beverages (Whistler et al. 1979).

**Breeding Programs in the U.S.:** Conventional plant breeding used in the U.S. to develop high seed producing varieties including Mesa (Staten and Brooks 1960), Texsel (Brooks et al. 1950), Groehler (Matlock et al. 1960), Brooks (Anon 1964), Mills (Anon 1966), Hall (Anon 1966), Esser (Anon 1975), Kinman (Anon 1975), Santa Cruz (Ray and Stafford 1985), and Lewis (Stafford et al. 1985). Esser is also tolerant to bacterial blight and Kinman is resistant to bacterial blight and alternaria leaf spot (Anon, 1975). Lewis is also resistant to bacterial blight (Stafford et al. 1985). The variety, Matador developed for uniformity, later maturing, high seed yield, and tolerant to bacterial and virus disesases, and high gum content (Texas Tech University and Halliburton Services 2004). The variety, Monument developed for uniformity, early maturity, high seed yield, resistant to virus, and tolerant to bacterial diseases (Texas Tech University and Halliburton Services 2010).

**Domestic Production:** More than 100,000 acres of guar are produced in the U.S.

**International Production:** The only countries producing guar are India and Pakistan (Morris 2010)

**2.3.2 Guar - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for guar accessions in the world wide gene banks which would be beneficial for estimating genetic variability in individual collections. About 1,300 guar accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO combined. The PGRCU guar collection consists of about 63 cultivars worldwide. Twelve guar cultivars were developed in the U.S.

**Threats of Genetic Erosion *in situ:*** Three additional wild relatives including *C. senegalensis* Guill. and Perr., *C. serrata* Schinz, and *C. dentata* (N.E. Br.) Torre are known. *Cyamopsis senegalensis* grows wild in Saudi Arabia, Ethiopia, Sudan, Mali, Senegal, and Tanzania. *Cyamopsis serrata* grows wild in southwestern Africa, Botswana, and S. Africa while *C. dentata* grows wild in Rhodesia, Angola, southwestern Africa, and S. Africa (Whistler et al. 1979).

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** Phymatotrichum root rot (*Phymatotrichum omnivorum* (Shear) Dug is a soil-borne fungus and is usually found in the southwestern U.S. (Whistler et al. 1979). The Mesa cultivar is resistant to Phymatotrichum root rot (Streets 1948a). Sclerotium or southern blight (*Sclerotium rolfsii* Sacc.) attack guar plants in the southwestern U.S. (Whistler et al. 1979). There are no known resistant guar varieties (Whistler et al. 1979). The Rhizoctonia rot (*Rhizoctonia solani* Kuhn) disease is another soil-borne fungus (Whistler et al. 1979) in the U.S. and India (Streets 1948b). Charcoal rot is very pathogenic to guar plants in east Texas and Pakistan (Prasad 1944). Two types of Fusarium root rot and wilt infecting guar plants include *Fusarium moniliforme* (Sheld.) emend. Snyder et Hansen and *F. coeruleum* (Lib) Sacc. (Whistler et al. 1979). Alternaria blight is another fungus caused by *Alternaria brassica* (Berk.) Sacc. (Streets 1948b) and *A. cucumerina* var. *cyamopsidis* (Rangaswami & V. Rao) E.G. Simmons (Orellana and Simmons 1966). The cultivars, Brooks, Mills, Hall, Esser, and Kinman are moderately resistant to *A. cucumerina* var. *cyamopsidis* (Whistler et al. 1979). Another seed-borne fungus, anthracnose caused by *Colletotrichum capsici* (Syd.) Butl.and Bisby results in black spots on the stems, petioles and leaves in India and Georgia (Rao and Rao 1956). Purple stain fungus [*Cercospora kikuchii* (T. Matsu and Tomoyasu) Chupp.] causes purple stains on leaves, dark lesions on stems, and leaf spotting (Johnson and Jones 1962). Powdery mildew [*Leveillula taurica* (Lev.)] produces a grey colored powder on leaves and young pods in India and Pakistan (Butler 1918). Bacterial blight [*Xanthomonas campestris* Pv. *cyamopsidis* (Patel, Dhande and Kulkarni)] infects guar in India, Texas, Oklahoma, and Maryland causing leaf spots, stem curvature and breakage (Whistler et al. 1979). Glabrous cultivars are tolerant to bacterial blight. Another bacterial leaf spot (*Pseudomonas syringae* van Hall) causes leaf lesions similar to bacterial blight. It infects guar in Australia, Texas and Oklahoma (Whistler et al. 1979). Top necrosis, caused by tobacco ring spot virus causes young leaf abscission, terminal necrosis, stem lesions, stunting, and death and has been reported in Oklahoma and Texas (Whistler et al. 1979).

**Insects:** The most destructive insect pests of guar include the gall midge (*Asphondylia* spp.) and the guar midge [*Contarinia texana* (Felt)] in India and Texas (Whistler et al. 1979). The gall midge maggots feed on the ovules resulting in the ovary developing into a gall while the guar midge attacks buds and prevents seed development (Whistler et al. 1979).

**Abiotic Stress**: See quads.

**Market and population growth demands:** Guar production in the U.S. is low because currently most of the guar used is imported from India or Pakistan.

**2.3.3 Guar – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Guar accessions in the collection includes cultivars with high seed yield, bacterial blight tolerance, and leaf spot resistance (Whistler et al. 1979). Molecular markers have been developed for guar (Kuravadi et al. 2014). Seventy-three accessions have been characterized for genetic diversity (Morris 2010). However, the vast majority of the collection remain in need for genetic diversity characterizations.

**Acquisitions:** Guar wild relatives needed include *C. dentata* (N.E.Br.) Torre, *C. senegalensis* Guill. & Perr., and *C. serrata* Schinz. Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The guar collection consists of 1,300 accessions at PGRCU and NLGRP combined. A total of 413 accessions are backed up at NLGRP and stored at -18°C at PGRCU. Four hundred and twelve accessions have been tested for germination at PGRCU. Four hundred and eleven accessions are available, and 74 accessions have been backed-up at Svalbard. The guar cultivars were donated by U.S. and foreign breeders (USDA 2020a).

**Regeneration:** Guar is self-pollinated. However, it is grown in the field using buffer crops to prevent potential outcrossing. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a buffer crops using other species at PGRCU. Pods are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table

**Genotypic characterization data:** Descriptor data from 73 guar accessions were subjected to a principal component and cluster analysis for characterization (Morris 2010).

**Phenotypic evaluation data:** Guar phenotypic traits related to disease includes leaf spot; growth includes plant height; morphology includes plant surface, pod length, stem type; phenology including maturity; production includes both seed production and seed weight; and quality includes ash, dry matter, fat, protein, and total dietary fiber. Most of the collection has been phenotyped for growth, morphology and phenology. However less than half of the guar collection has been phenotyped for leaf spot and less than 10% has been phenotyped for quality.

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the guar germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing seed gum content and flavonoid concentrations.

**Significant accomplishments:** Even though the NPGS guar collection is diverse, there is a need for additional accessions to optimize genetic diversity. Nineteen guar genotypes were evaluated over two years for flavonoid concentrations in immature pods with several showing significantly greater concentrations of daidzein, genistein, and kaempferol (Morris and Wang 2017). Seventy-three guar accessions evaluated for morphology and reproduction resulted in the identification of variability among accessions (Morris 2010).

**2.3.4 Guar - Other genetic resource capacities**

An addition guar gene bank is located in India (4,312 accessions) (Rana et al. 2016).

**2.3.5 Guar - Prospects and future developments**

The U.S. guar collection is vulnerable due to the low number of cultivars that are in production and the limited number of U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs have reduced due to retirements and the use of more popular gum and fiber producing crops. Reduced budgets for guar genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS guar collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized genetically and phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS guar collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important ex situ populations that must be collected before important sources of diversity are lost. Guar will remain important

gum, functional food, and fiber crop. Traditional breeding techniques have successfully incorporated desirable alleles into guar and resulted in high seed and gum yield, disease resistant and widely adapted cultivars.

**2.4 *Guayule***

**2.4.1 Guayule - Introduction**

**Origin**: Guayule (*Parthenium argentatum* A. Gray) is a desert shrub native to the Chihuahuan desert of Northern Mexico and the Big Bend region of Texas.

**Primary Crop Products and Value:** Natural rubber, resin, latex. Natural rubber (NR) is considered a critical agricultural material for U.S industry, medicine, and defense, yet the current world’s supply is derived from one plant species, *Hevea brasiliensis* (rubber tree) grown almost exclusively in SE Asia.Guayule uses less water than many crops grown in the US southwest such as alfalfa or cotton. In times of irrigation water shortages, it can tolerate missed or delayed irrigation cycles without serious detriment to rubber yield. The plant is destructively harvested to obtain the rubber as latex or as solid rubber for tires. The plant also contains a valuable resin in equal or higher quantities. Guayule rubber is primarily contained in the bark tissue of the shrub stems and roots. The common practice is to harvest the shrub by cutting at ground level after two years of growth and allowing regrowth from the roots so more than 1 growth cycle occurs from a single direct seeding. Rubber and resin are solvent extracted or latex can be water extracted. High value products such as adhesives or natural pesticides made from the resin are being investigated. The dried cut biomass referred to as bagasse, can be made into a fuel due to the high btu value. Guayule is currently being developed by tire companies such as Bridgestone as a domestic supplement to the natural rubber currently obtained from SE Asia.

**Breeding Programs in the U.S.:** An active breeding program by Bridgestone America in Arizona is focused on improving rubber content and yield, and expanding the growing region to colder, lower cost areas. Public programs by USDA, ARS in Albany, CA and Maricopa, AZ also have work in progress. The University of Arizona has maintained a long-term guayule breeding program, and now is part of a USDA, National Institute for Food and Agriculture (NIFA) five-year grant to help commercialize guayule.

**Domestic Production:** Pilot-scale

**International Production:** Pilot-scale

**2.4.2 Guayule - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** The USDA, ARS, NPGS guayule collection is the source of germplasm for guayule breeding worldwide. Accessions of guayule vary in genetic uniformity; some represent bulk collections, and a few are publicly released varieties.

**Threats of Genetic Erosion *in situ:*** *Parthenium argentatum* is native to a relatively narrow niche in the Chihuahuan Desert. While not designated as endangered, guayule is not protected, and stands are vulnerable to land use change and development on unprotected land. Most wild stands are in inaccessible regions in northern Mexico. Populations in the US are restricted to the Big Bend region in southern Texas. Big Bend National Park and Big Bend Ranch State Park both contain guayule populations. Attempts to re-collect germplasm in Texas in 2005 and 2008 found that plants no longer existed at many historic collection sites.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** The NPGS collection has not been characterized for phenotypic traits. In order to reduce production costs, direct-seeded guayule is preferred to seedling transplant. However, successful seed germination requires shallow sowing of seed on fine-textured, firm beds with the maintenance of high soil-surface moisture until emergence. One unintended consequence of high moisture levels is damping-off diseases, which were found to be responsible for poor survival of these young stands and high seedling mortality. For example, seedling mortality was observed in field planting on both sandy and clay soils. Seedling mortality due to possible seedling disease could be as high as 28%. Several fungal pathogens including *Rhizoctonia* sp., *Fusarium* sp., *Pythium* sp., *Phytophthora* sp. have been added to the list of guayule seedling pathogens in the United States (Norton, 1954, Beaupre and Cheo 1983). Preliminary results from studies at the University of Arizona indicate that resistance to *Verticillium* is present within available *Parthenium* germplasm.

**Insects:** Insect damage occurs in field-emerging guayule especially by the pale-striped flea beetle, *Systena blanda*. It is so severe to small seedlings that it becomes a major barrier for direct-seeded guayule. An entire new field can be destroyed within a day or two by this insect. Furthermore, the resulting losses due to weed competition and subsequent herbicide injury to guayule greatly increase the costs of this initial stand loss. We do not know of other insect pressures at this stage of research and development.

**Abiotic Stress**: Increased tolerance of low temperatures and saline irrigation water are desired characteristics to expand the potential growing region of this new crop. Variability in cold tolerance among plants of the same accession (PI 478640) has been reported, indicating that there is room for selection for this trait within the current collection (Foster et al. 2011). Expanded collections of related species (*P. incanum*) from higher elevations could help introduce additional sources of cold tolerance. Researchers at USDA-ARS and California State University, Fresno are currently evaluating a subset of the collection for salinity and boron tolerance, and initial results indicate that some accessions can tolerate high abiotic stress and marginal soil conditions (Zhu and Bañuelos 2016).

**Market and population growth demands:** Commercialization of guayule will require a large increase in planting area to supply the required feedstock to support industrial processes. Demand for an alternative domestic source of natural rubber will increase in the future as climate change threatens the tropical *Hevea* production. Guayule production will likely take place in the southwestern US and Mexico, which will also be subjected to a continued decline in high quality irrigation water. Therefore, development of guayule needs to focus on production on marginal lands with little available water.

**2.4.3 Guayule – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Much of the NPGS *Parthenium* collection was recently genotyped using SNP markers (Ilut et al. 2017). They found that while the guayule accessions generally lacked broad diversity, recent collections from the Big Bend region in southern Texas are distinct from the historic Mexican collections and may represent an opportunity to bring in more diversity. The most obvious gap in the collection is a lack of sexually reproducing diploid accessions. Polyploid *P. argentatum* largely reproduces by apomyxis, making controlled crossing difficult. Diploids reproduce sexually and are self-incompatible. The current NPGS collection contains 2 diploid accessions which are genetically indistinct (Ilut et al. 2017). Expanding the diversity of related *Parthenium* species could aid future breeding efforts once the underlying molecular control of rubber and resin synthesis is better understood.

**Acquisitions:** Most of the NPGS guayule collection is the historic remnant of the Emergency Rubber Project conducted by the US government in the 1940’s, as well as a second round of research in the 1970’s. At this time material was exchanged with and collected in the native range in Mexico. After both of these eras much of the germplasm was lost, and the surviving collection likely represents a fraction of the original diversity. Acquiring new guayule germplasm from the wild today is difficult to impossible as much of the native range is either in Mexico or on National Park land in the United States, both of which do not permit the collection of material for the NPGS. Recent exploration trips to southern Texas in 2005, 2008, and 2019 have resulted in several new accessions.

**Maintenance:** All perennial species in the *Parthenium* collection are maintained as semi-permanent field plots, and seed is stored under conventional cold conditions.

**Regeneration:** New seed is produced by caging the field plot and introducing pollinators. Guayule presents some challenges to curation because it has facultative apomictic reproduction for polypoid accessions representing most of the entire germplasm collection. The rate of recombination within these accessions is about 5%. Therefore, the plots must be caged with isolation screens to prevent crossing between accessions. Currently only two collections are diploids, which are sexually reproducing and self-incompatible.

**Distributions:** see Table for average number of seed packets distributed annually

**Genotypic characterization data:** Much of the collection was genotyped in Ilut et al. 2017, but currently the data is not available directly in GRIN-Global.

**Phenotypic evaluation data:** GRIN-Global does not contain phenotypic data based on a common set of descriptors. Large-scale phenotypic measurements on replicated field trials in Arizona are currently being conducted as part of the SBAR project.

**2.4.4 Guayule - Prospects and future developments**

Guayule currently has momentum for commercialization, building on previous attempts over the last century. There is the most investment by private industry (Bridgestone Americas and others) than any other time in its history of establishing a domestic source of natural rubber. Public funding has also been a driver. Multi-million-dollar grants from USDA-NIFA, (BRDI grant from 2011 to 2016 with Cooper Tires and public researchers) and AFRI grant “Sustainable Bioeconomy for Arid Regions” (SBAR) 2018-2022 with Bridgestone and other public institutions. Efforts are underway to expand and better characterize the NPGS collection to support breeding and development.

* 1. ***Kenaf***

**2.5.1 Kenaf - Introduction**

**Origin**: Southern Asia.

**Primary Crop Products and Value:** Kenaf (*Hibiscus cannabinus* L.) is primarily used on a very limited scale for fiber production in automobile composites.

**Breeding Programs in the U.S.:** The kenaf cultivars that are used primarily in the U.S. include Everglades 41 and Everglades 71 and were developed by the USDA, ARS in Florida (LeMahieu et al. 1991). They are both resistant to anthracnose.

**Domestic Production:** Very little acreage.

**International Production:** Kenaf is produced in China and India (University of Kentucky 2014).

**2.5.2 Kenaf - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for kenaf accessions in the world wide gene banks which would be beneficial for estimating genetic variability in individual collections. About 286 kenaf accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO, respectively. The PGRCU kenaf collection consists of about 17cultivars worldwide. Two kenaf cultivars were developed in the U.S. Therefore, the reduction in genetic diversity within cultivars and the number of cultivars in the U.S. occurs because of emphasis on other oil and fiber producing crops resulting in the narrowing of the genetic base by breeding. Since kenaf breeding and research programs in the U.S. have either reduced or stopped, older cultivars may be lost.

**Threats of Genetic Erosion *in situ:*** Climate change, human intervention, native habitats, and international treaty issues will have a negative impact on kenaf’s wild relatives.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** Kenaf is resistant to most plant diseases, however anthracnose (*Colletotrichum hibisci* Poll) is the economic disease effecting this species (LeMahieu et al. 1991). Resistant lines have been developed by USDA, ARS (LeMahieu et al. 1991). The root knot nematode (*Meloidogyne* spp.) is also known to infect kenaf (LeMahieu et al. 1991) with crop rotation as a possible control mechanism.

**Insects:** No serious insect threats (LeMahieu et al. 1991).

**Abiotic Stress:** See quads.

**Market and population growth demands:** Since kenaf is a minor crop, very little production progress has been made.

**2.5.3 Kenaf – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Kenaf accessions include cultivars with disease resistance (LeMahieu et al. 1991), and high yielding calyces (Morton 1987).

**Acquisitions:** Currently the kenaf collection consists of 31 wild relatives, however several hundred are still needed. Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The kenaf collection consists of 286 accessions at PGRCU and NLGRP combined. There are 131 accessions are available for distribution. Currently 151 accessions are stored at -18°C at PGRCU and backed-up at NLGRP with 146 accessions tested for germination and 10 accessions have been backed-up at Svalbard. The kenaf cultivars were donated by U.S. and foreign breeders (USDA 2020a).

**Regeneration:** Kenaf is self-pollinated. However, these species are grown in the field using buffer crops to prevent potential outcrossing. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a buffer crop using other species at PGRCU. Seed capsules are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table

**Genotypic characterization data:** None.

**Phenotypic evaluation data:** The kenaf phenotypic traits related to growth includes plant height and width; morphology includes branching; phenology including maturity; and production includes foliage and seed production. Most of the collection has been phenotyped for these descriptors.

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the kenaf germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing seed oil content concentrations.

**Significant accomplishments:** Even though the NPGS kenaf collection is diverse, there is a need for additional accessions to optimize genetic diversity. The kenaf collection was evaluated for oil content and fatty acid composition (Wang et al. 2012). Significant variability in oil content and major fatty acids were detected.

**2.5.4 Kenaf - Other genetic resource capacities**

An additional gene bank includes Bangladesh (698 accessions) (Razzaque and Hossain 2007).

**2.5.5 Kenaf - Prospects and future developments**

The U.S. kenaf collection is vulnerable due to the low number of cultivars that are in production, the limited number of U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs have reduced due to retirements and the use of more popular oil and fiber producing crops. Reduced budgets for kenaf genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS kenaf collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized genetically and phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS industrial crop collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important ex situ populations that must be collected before important sources of diversity are lost. Kenaf will remain an important fiber crop. With a diverse germplasm base secured, the future for kenaf production looks positive.

***2.6 Roselle***

**2.6.1 Roselle - Introduction**

**Origin**: India and Malaysia.

**Primary Crop Products and Value:** Roselle is used in the ornamental industry, tea, and confectionary industries.

**Breeding Programs in the U.S.** Roselle cultivars include Rico, Victor, and Archer (Morton 1987). Rico produces high red calyx yield, while Victor produces red calyces earlier than Rico. Archer is also known as white sorrel because it produces high yielding green calyces.

**Domestic Production:** Very little acreage.

**International Production:** Roselle is primarily produced in China, Egypt, Jamaica, Mali, Mexico, Senegal, Sudan, Tanzania, and Thailand (FAO 2004).

**2.6.2 Roselle - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for roselle in the worldwide gene banks which would be beneficial for estimating genetic variability in individual collections. About 139 roselle accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO combined. The PGRCU roselle consists of about 6 cultivars worldwide. Therefore, the reduction in genetic diversity within cultivars and the number of cultivars in the U.S. occurs because of emphasis on other medicinal, oil, fiber, and functional food producing crops resulting in the narrowing of the genetic base by breeding. Since castor roselle breeding and research programs in the U.S. have either reduced or stopped, older cultivars may be lost.

**Threats of Genetic Erosion *in situ:*** Climate change, human intervention in roselle’s native habitats, and international treaty issues will have a negative impact on their wild relatives.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** Root knot nematode [*Heterodera radicicola* (Greef) Muller is the primary disease infecting roselle plants (Morton 1987). Powdery mildew (*Podosphaera* spp.) infects roselle plants in Florida (Morton 1987) and Georgia (Brad Morris, personal observations). Plants grown in the Philippines have shown susceptibility to *Phoma sabdariffae* Sacc. Sulfur compounds can be used to control powdery mildew on roselle plants (Brad Morris, personal observations).

**Insects:** Aphid species observed on roselle plants under greenhouse conditions can be controlled with Marathon (Brad Morris personal observations). Minor species including *Niotra breweri, Lagris cyanea*, and *Rhyparida discopunctulata* beetles in Australia attack leaves (Morton 1987). The cocoa beetle (*Steirastoma breve*) attacks plants in Trinidad (Morton, 1987). Additonal minor insect pests include scales (*Coccus hesperidum* and *Hemichionaspis aspidistrae*), yellow aphids (*Aphis gossypii*) and the cotton stainer (*Dysdercus suturellus*) (Morton 1987).

**Abiotic Stress:** See quad.

**Market and population growth demands:** Since roselle is a minor crop very little production progress has been made.

**2.6.3 Roselle – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Roselle accessions include cultivars with high yielding calyces.

**Acquisitions:** Currently the roselle collection consists of 31 wild relatives, however several hundred are still needed. Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The roselle collection consists of 139 accessions at PGRCU and NLGRP combined with 46 roselle accessions available. Currently 85 accessions are stored at –18°C and 87 accessions backed-up at NLGRP with 75 roselle accessions tested for germination and 23 accessions are backed-up at Svalbard. The roselle cultivars were donated by U.S. and foreign breeders (USDA 2020a).

**Regeneration:** Roselle is self-pollinated. However, it is grown in the field using buffer crops to prevent potential outcrossing. Since it is photo-period sensitive, roselle can be successfully increased in a greenhouse. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a buffer crop using other species. Photo-period sensitive accessions are regenerated in gallon size plastic pots containing potting soil in a greenhouse. Seed capsules and pods are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table.

**Genotypic characterization data:** None.

**Phenotypic evaluation data:** The NPGS roselle collection has been characterized for growth, morphological, and phenological descriptors.

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the industrial crop germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing seed oil content, fatty acid, and flavonoid concentrations. Roselle accessions are evaluated for seed production capacity, flavonoids, and calyx production.

**Significant accomplishments:** Even though the NPGS roselle collection is diverse, there is a need for additional accessions to optimize genetic diversity. The roselle collection was evaluated for oil content and fatty acid composition (Wang et al. 2012). Significant variability in oil content and major fatty acids were detected. Calyces with high concentrations of the flavonols, quercetin, myricetin, and kaempferol were identified among six roselle accessions (Morris et al. 2012). Currently up to 10 roselle accessions which were previously considered to be photo-period sensitive and could not be successfully regenerated in Georgia are showing positive results in quality seed production by harvesting calyces when they are fully red or green. Evaluating these roselle accessions for seed and calyx production to produce chutney, jam, tea, and other edible products with a start-up company, Pride Road.

**2.6.4 Roselle - Other genetic resource capacities**

An additional gene bank includes Bangladesh (453 accessions) (Razzaque and Hossain 2007).

**2.6.5 Roselle - Prospects and future developments**

The U.S. roselle collection is vulnerable due to the low number of cultivars that are in production and the limited number of U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs have reduced due to retirements and the use of more popular oil, medicinal, functional food, and fiber producing crops. Reduced budgets for roselle genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS roselle collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS industrial crop collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important ex situ populations that must be collected before important sources of diversity are lost. Roselle will remain an important medicinal, fiber, and functional food crop. With a diverse roselle germplasm base secured, the future for crop production looks positive.

***2.7 Safflower***

**2.7.1 Safflower - Introduction**

**Origin:** Safflower (*Carthamus tinctorius* L.) is an ancient, yet under-utilized, crop. A member of the Asteraceae family, it is an annual plant that usually has spines on the leaves, giving it a thistle-like quality. Safflower has a strong taproot to reach deep soil moisture and is usually grown in dry climates. The taproot also improves soil structure by breaking up hard pan and compaction layers (Gilbert 2008). GRIN-Global, which may be found at: <https://npgsweb.ars->grin.gov/gringlobal/search.aspx, lists the probable origin of safflower as Western Asia. Areas from which crop wild relatives (CWRs) are native are also found in GRIN-Global.

**Primary Crop Products and Value:** Safflower florets are used for dyeing fabric, as tea, and as a substitute for saffron. It is purported to have medicinal qualities as well. Safflower is grown for seed utilized for the birdseed industry and for edible oil. According to the USDA National Agricultural Statistics Service (2018), the U.S. safflower crop was valued at nearly $33.5 million in 2017, with a yearly average 2012 through 2016 of $51.5 million. The main product from safflower, oil, is mostly used for cooking and is a very healthful oil. It has a higher smoke point than corn, canola, olive, or sesame oil and is suitable for high heat cooking. Safflower oil with polyunsaturated fats (high-linoleic acid) is used in making soft margarines and salad oils. Safflower oil high in monounsaturated fats (high-oleic acid) is more heat stable than high- linoleic and desirable for frying food. Recently, breeders have become interested in producing safflower with few spines and high oil content. Varieties with these combined traits could be important for both oil production and for production of florets for tea and food dye, as florets are typically harvested by hand and the spininess of most high oil producing varieties makes hand harvest difficult at best.

**Breeding Programs in the U.S.**

**Domestic Production:** The FAOSTAT (2018) yearly average (2012-2016) for safflower seed production in the US was 65,954 ha harvested. The U.S. ranked fifth in the world production of total tonnes of safflower seed 2012-2016. However, a comparison of the hectares planted and the total tonnes produced from 2012 through 2016, indicated that the U.S. and Mexico lead the five countries with the highest production in tonnes per hectare

**International Production:** Safflower is cultivated in many regions around the world and used for many purposes. International production, not including the US, was 954,127 ha harvested (FAO 2018).

**2.7.2 Safflower - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Disease:** Although safflower is susceptible to a number of diseases and pests, the diseases of most concern worldwide are Sclerotinia head rot (*Sclerotinia sclerotiorum*), Alternaria blight (*Alternaria carthami* and *Alternaria alternata*), Rust (*Puccinia carthami*) (Dajue and Mündel 1996; Mündel et.al. 2004) *Phytophthora* and *Pythium* root rots, and bacterial blight (*Pseudomonas syringae*) (Oelke et al. 1992). Leaf spot (*Ramularia carthami*), has caused major damage to safflower crops in Mexico and India (Lope Montoya Coronado 2008; Prasad and Suresh 2012).

**Insects:** Insects rarely cause problems in North America except in extreme cases: Grasshoppers have devastated crops in Canada and research plots in Central Ferry, Washington (unpublished data 1994; Mündel et al. 2004). However, in Africa, Asia, and Europe the safflower fly (*Acanthiophilus helianthi*) can be detrimental to safflower crops and aphids have injured crops in India and Spain (Dajue and Mündel 1996; Nimbkar 2008).

**Abiotic Stress:** Common abiotic stresses are drought, salinity, and alkalinity for

safflower (Dajue and Mündel 1996).

**2.7.3 Safflower – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Some of the *Catharanthus* accessions in the collection have specific qualities of interest. Oil percent is usually low in seeds with the thick white pericarp, or hull, of “normal” safflower. Accessions with four other types of hulls, reduced (4 accessions), thin (9 accessions), partial (10 accessions), and either brown, grey, or purple striped (86 accessions), have been identified and the accessions are reported to have higher oil content (Dajue and Mündel 1996; Bergman and Kandel 2013). Dave Rubis, University of Arizona, contributed two “Arizona wild composite” accessions to the collection that are very diverse combinations of wild and C. *tinctorius* species crosses, as well as 137 other accessions. Three winter-hardy safflower accessions were developed by R.C. Johnson, PGITRU Agronomy Research Scientist (retired), and are available to requestors. Dr. Paulden Knowles, UC-Davis, who contributed more than 1,200 accessions to the collection, submitted accessions with variations in many traits such as disease resistance, seed color and hull type, flower color, spininess, plant type (spring or winter), plant height and maturity. Dr. Li Dajue, Beijing Botanical Garden, (332 accessions) and Lee Urie, USDA ARS, (71 accessions) are also noted contributors to the collection. This collection is often referred to as the “World collection” and is widely used in safflower research and education globally (Mukta 2012).

**Acquisitions:** Priority species for collection are C. *oxyacantha*, C. *palaestinis*, and C. *persicus*, which cross readily with C. *tinctorius* (Dajue and Mündel 1996; personal communication, Safflower Working Group-8th International Safflower Conference 2012). Other species are also of interest for potential use in transgenic and basic research (Johnson et al. 2008). Crop wild relatives of safflower are not native to the US. International access is limited due to the political climate of the countries from which many of the *Carthamus* taxa of interest are native. Safflower is not listed on the Annex I list of crops covered under the Multilateral System of the International Treaty on Genetic Resources for Food and Agriculture, making species related to safflower more difficult to acquire even if political issues were not of concern.

**Maintenance:** The safflower seed is stored in a cold storage vault at 4⁰C and 28% relative humidity. In addition, a -20⁰C walk-in freezer is used for longer term storage of old or low quality seed for at-risk accessions. Back-up samples are sent to the National Laboratory for Genetic Resources Preservation (NLGRP). At present, 97% of the collection has been backed-up at the NLGRP. Accessions that are not backed-up are those that have not germinated in past attempts to regenerate them, accessions for which the proper growing environment is not available, or accessions that are listed on the federal noxious weed list and that we are not authorized to grow.

**Regeneration:** Safflower accessions selected for regeneration by considering seed quality, quantity, and back-up status are grown at the Central Ferry, Washington research farm. Prior to planting, the seed are treated with a liquid fungicide, dried, and two row plots are directly-seeded. The plots are approximately six meters long with 0.5 meters between the two rows within the plot of 100 -150 plants. Plots are thinned to approximately 10 cm between plants, when necessary. The plants are irrigated with a single buried drip line that runs down the middle of the plot. A 15-15-15 fertilizer is applied through the drip line in early spring. The plots are caged as soon as flowering begins. Flowers appearing before the plot is caged are cut off prior to caging. An entire regeneration plot covered with a single tent-like screen cage, 7.5 meters long and 3.5 meters wide, and supported by two strands of heavy wire attached to metal fence posts. The bottom of the cage is buried and both ends are closed with clothes pins. The irrigation water is turned off after flowering is completed and seeds are filled. Rust ratings are recorded when plots are mature. The cages are removed just prior to harvest. Harvest begins when the plants are brown and dry. The plants cut off at the base are put through a rubber drum thresher. After going through the thresher, the seed is pre-cleaned in the field with a 26/64 mesh seed cleaning screen. The seed is fine cleaned by seed cleaning staff then processed by seed storage personnel for storage and distribution. *Carthamus tinctorius* accessions are not difficult to regenerate with current resources. However, regenerating other *Carthamus* species is difficult and requires specialized facilities, not readily available, to contain very weedy accessions. *Catharanthus oxyacantha*, a primary CWR, is a federal noxious weed and a containment facility to regenerate these accessions is not available. In addition, the cost of such would not be warranted for the number of accessions in the collection (52). A past collaboration with scientists in Spain resulted in regeneration of a number of *C. oxyacantha*. However, the collaborators are no longer working with *Carthamus*. Another concern for proper management of this collection is that viability of *C. oxyacantha* accessions cannot be assessed at our facility due to federal regulations.

**Distributions:** see Table. Five hundred and seventeen orders for *Carthamus* seed were submitted between January 1, 2013 and April 30, 2018, and more than 4,500 packets of seed were sent to stakeholders in 64 countries. Fifty percent of the orders were from requestors in the United States. Seed orders are typically received through GRIN-Global. The curator reviews and approves all orders and determines the requirements for international shipments. If the US noxious weed, C. *oxyacantha* is ordered, the noxious weed permit holder reviews the order, contacts the requestor for appropriate documents, and fills the order. Approval from APHIS to ship the seed is also obtained.

**Genotypic characterization data:** Safflower was included in the Compositae Genome Project (<http://compgenomics.ucdavis.edu/compositae_data.php?name=Carthamus+tinctorius>) and genomic resources may be found on the website. The Safflower Genetic resources website (<http://safflower.wsu.edu/>) maintained and edited by the PGITRU staff, is a source for general information, links of interest, International Safflower Conference proceedings, and other hard-to-find documents and resources.

**Phenotypic evaluation data:** Geographical, source, and collection information, as well as phenotypic evaluation data for *Carthamus* accessions are available on GRIN-Global. Seventy-one *Carthamus* descriptors are listed in GRIN-Global under the categories: Chemical composition, Growth, Physiology, Production, Subset (Core), Disease, Phenological, and Uncategorized (Image).

**Plant Genetic Resource Research Associated with the NPGS:**

**Significant accomplishments:** Based on country of origin and morphological data, a core collection of 210 *Carthamus* *tinctorius* accessions was developed from the USDA collection (Johnson et al. 1993) and was later found to represent a large portion of the collection diversity for oil and meal characteristics when compared to nearly 800 non-core accessions (Johnson et al. 1999). By characterizing 96 USDA *C*. *tinctorius* accessions from seven world regions with AFLP molecular markers, Johnson et al. (2007) showed that safflower from different regions differed in genetic structure.

Although this work indicated the presence of genetic diversity in the C. *tinctorius* collection,

obtaining CWRs remains a priority to enhance disease and insect resistance.

**2.7.4 Safflower - Other genetic resource capacities**

The FAO WIEWS database lists an additional 10,166 *Catharanthus* accessions in world genebanks, totaling 12,609 in collections worldwide. Of these, the largest number, 6,987 accessions, are maintained in India.

**2.7.5 Safflower - Prospects and future developments**

The primary goal for the PGITRU *Carthamus* program is to provide high quality seed as well as information to help stakeholders better utilize the collection. An evaluation nursery is planted each year to collect phenotypic data. Traits typically evaluated include plant height, plant habit, head diameter, head shape, fresh corolla color, dry corolla color, spininess of leaves, and branching. Completing analysis of percent oil and fatty acid content on approximately 400 distributable accessions for which this information is not available in GRIN-Global is planned. Recently, breeders have shown interest in developing high oil spineless varieties and GRIN-Global descriptor data for both oil and spininess will be useful to these stakeholders. Individual seeds with higher oleic or linoleic acids have been identified during fatty acid analysis and have been stored for use in crosses with winter-hardy lines as the accessions that are currently available are relatively low in oil content. Future collection of safflower CWRs will be important to researchers. However, prior to incorporating CWR seeds into the PGITRU *Carthamus* collection, proper facilities for regeneration must be available.

***2.8 Sesame***

**2.8.1 Sesame - Introduction**

**Origin:** India, Pakistan (Bedigian 2010).

**Primary Crop Products and Value:** Sesame seed are used as ingredients on foods and the oil is edible.

**Breeding Programs in the U.S.:** Sesaco Co. developed 76 sesame cultivars in the U.S. Twenty of these cultivars are indehiscent and 25 cultivars are resistant to race 2 of Pseudomonas sesami Malkoff. Six cultivars have bacterial leaf spot resistance (P. sesami Malkoff.) (USDA 2020a).

**Domestic Production:** Sesame production in the U.S. is primarily in Texas and Oklahoma, however some occurs in Kansas and Arkansas (Ag Marketing Resource Center 2018).

**International Production:** Sesame is produced in Afghanistan, Angola, Bangladesh, Benin, Bolivia, Brazil, Bulgaria, Burkina Faso, Cambodia, Cameroon, Central African Rep., Chad, China, Taiwan, Colombia, Congo, Costa Rica, Cote d’Ivoire, Cyprus, Dominican Rep., Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Gambia, Greece, Guatemala, Guinea, Haiti, Honduras, India, Indonesia, Iran, Iraq, Israel, Italy, Japan, Jordan, Kenya, Lebanon, Mali, Mexico, Morocco, Mozambique, Myanmar, Nicaragua, Niger, Nigeria, Pakistan, Panama, Paraguay, Peru, Rep. of Korea, Saudi Arabia, Senegal, Sierra Leone, Somalia, Sudan, Sri Lanka, Syria, Tajikistan, Thailand, Macedonia, Togo, Turkey, Uganda, Tanzania, Russia, Uzbekistan, Venezuela, Viet Nam, Yemen, and Yugoslavia (FAO 2017).

**2.8.2 Sesame - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for sesame in the worldwide gene banks which would be beneficial for estimating genetic variability in individual collections. About 1,300 sesame accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO combined. The PGRCU sesame collection consists of more than 276 cultivars worldwide. Seventy-six sesame cultivars were developed in the U.S. Therefore, the reduction in genetic diversity within cultivars and the number of cultivars in the U.S. occurs because of emphasis on other oil functional food producing crops resulting in the narrowing of the genetic base by breeding.

**Threats of Genetic Erosion *in situ*:** Climate change, human intervention native habitats, and international treaty issues will have a negative impact on wild relatives.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:**A major disease infecting sesame is phyllody (*Phytoplasma*) which causes their floral parts to become green leafy structures (Gupta et al. 2018). Additional major diseases include charcoal rot [*Macrophomina phaseolina* (Tassi) Goid] (Mihail and Taylor 1995), cercospora leafspot [*Cercospora sesame* Zimm] (Gupta et al. 2018), powdery mildew [*Erysiphae orantii* Cast] (Rajpurohit 1993), phytophthora blight [*Phytophthora parasitica* (Dastur) var. *sesame* Prasad] (Gupta et al. 2018), alternaria leaf spot [*Alternaria sesame* (Kawamura)] (Gupta et al. 2018), bacterial blight [*Xanthomonas camprestris* (Pamel) Dowson pv. *sesami* (Sabet & Dowson) Dye] and bacterial leaf blight [*Pseudomonas syringae* Van Hall pv. *sesame* (Malkoff) Young. Dye & Wilkie] (Gupta et al. 2018).

Sesame genotypes have shown tolerance to extreme susceptibility to fusarium [*Fusarium* oxysporum (Schelt.) f. *sesami* Jacz,] phytophthora blight, charcoal rot, and bacterial leaf blight in Texas (Langham 2002). Sesame varieties with tolerance to most of these diseases have been developed (Gupta et al. 2018). Cultural practices, hot water treatments, biological control, and fungicides have been useful in controlling or minimizing these diseases also (Gupta et al. 2018).

**Insects:** The primary sesame insect pests in India are the leaf roller and capsule borer (*Antigastra catalaunalis* Dup.), jassid (*Orosius albicinctus* Distant), mirid bug (*Nesidiocoris tenuis* Rent.), and white fly [*Bemisia tabaci* Gennadius] (Mishra et al. 2015). Resistance varieties needed worldwide for the sphingid moth (*Acherontia styx* Westwood), leaf roller and capsule borer, and white fly (Ashri 2006).

**Abiotic Stress:** See quad.

**Market and population growth demands:** Sesame is grown on a very limited scale in Texas, however, progress for production is increasing in the southern U.S.

**2.8.3 Sesame – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Sesame cultivars include those with disease resistance and indehiscent capsules.

**Acquisitions:** Sesame wild relatives includes about 20 to 40 species and all are needed in the NPGS germplasm system. Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The sesame collection consists of 1,300 accessions at PGRCU and NLGRP combined. This includes 1,161 available accessions, 1,212 accessions stored at -18°C at PGRCU and 1,214 accessions backed-up at NLGRP with 1,205 accessions tested for germination, and 87 accessions backed-up at Svalbard. The sesame cultivars were donated by U.S. and foreign breeders (USDA 2020a).

**Regeneration: S**esame is self-pollinated. However, it is grown in the field using buffer crops to prevent potential outcrossing. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a buffer crop using other species. Seed capsules are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table

**Genotypic characterization data:** Several characterization evaluations have been conducted on sesame (Ali et al. 2007; Sharma et al. 2009; Kumar and Sharma 2011; Ibrahim et al. 2012) for origin, yield, and diversity.

**Phenotypic evaluation data:** Sesame phenotypic traits related to growth include plant height; morphology includes capsule length, plant color, seed color, stalk strength, stem type, capsules per axil, locules, and seed size, and phenology including maturity. Most of the sesame collection has been phenotyped for these traits.

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the sesame germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing seed oil content, fatty acid, lignan, tocopherol, and protein concentrations. Currently, PGRCU in-house research focuses on evaluating sesame accessions for protein and lignan content, fatty acid concentrations, and oil percent.

**Significant accomplishments:** Nucleotide polymorphisms have been identified in the *FAD2* gene-coding region between wild and cultivated sesame species (Chen et al. 2014). Chen et al., 2014 found that some of the nucleotide polymorphisms resulted in amino acid changes with one at the enzyme active site and may have been responsible for the altered fatty acid composition. Seeds from 11 sesame accessions were found to vary significantly for α, δ, γ-tocopherols, and sesamin composition (Williamson et al. 2008).

**2.8.4 Sesame - Other genetic resource capacities**

Additional countries with sesame collections include India (>10,000), South Korea (>7,698), China (>7,000) (Dossa et al. 2017), and Pakistan (73) (Zahoor 2007).

**2.8.5 Sesame - Prospects and future developments**

The U.S. sesame collection is vulnerable due to the low number of cultivars that are in production and the limited number of U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs have reduced due to retirements and the use of more popular oil and functional food producing crops. Reduced budgets for sesame genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS sesame collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized genetically and phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS sesame collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important ex situ populations that must be collected before important sources of diversity are lost. Sesame will remain an important oil and functional food crop. Sesame cultivars have been developed with high oil content and indehiscent capsules. With a diverse germplasm base secured, the future for sesame crop production looks positive.

***2.9 Sunn hemp (Crotalaria juncea L.)***

**2.9.1 Sunn Hemp - Introduction**

**Primary Crop Products and Value:** Sunn hemp is primarily used as a cover crop.

**Breeding Programs in the U.S.**: There are no breeding programs in the U.S..

**Domestic Production:** No production in the U.S.

**International Production:** Sunn hemp is primarily produced in Brazil and Colombia (Cook and White 1996).

**2.9.2 Sunn Hemp - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** Global uniform characterizations for phenotypic and genotypic traits are needed for sunn hemp accessions in the worldwide gene banks which would be beneficial for estimating genetic variability in individual collections. Twenty-two sunn hemp accessions, are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO, respectively. The PGRCU sunn hemp collection consists of 2 cultivars worldwide. One sunn hemp cultivar was developed in the U.S. Therefore, the reduction in genetic diversity within cultivars and the number of cultivars in the U.S. occurs because of emphasis on other cover and fiber producing crops resulting in the narrowing of the genetic base by breeding.

**Threats of Genetic Erosion *in situ*:** Climate change, human intervention in sunn hemp native habitats, and international treaty issues will have a negative impact on their wild relatives.

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** Sunn hemp is susceptible to Phymatotrichum root rot (*Phymatotrichum omnivorum* Duggar) in the United States (Cook and Hickman 1990), however it can be controlled using cultural practices and crop rotations (Streets and Bloss 1973). Anthracnose (*Colletotrichum curvatum* Briant and Martyn (Whiteside 1955) and wilt (*Fusarium udam* E.J. Butler f. sp. *Crotalariae* (G.S. Kulkarni) Subramanian (Purseglove 1968) are the most important diseases infecting sunn hemp in India. Anthracnose resistant germplasm is identified (Dey et al. 1990). A wilt disease (*Ceratocystis fimbriata* Ellis & Halst) infects sunn hemp plants in South America (Barros Selgado et al., 1972). Crop rotations and some resistant germplasm are recommended for controlling this wilt disease (Ribeiro et al. 1977).

**Insects:** Sunn hemp is very susceptible to the lima bean pod borer (*Etiella zinckenella* Treit.), bella moth (*Utetheisa bella* L.), and sunn hemp moth (*Utethesia pulchella* L.) in Florida (Seale et al. 1957) which feed on leaves and pods. Additional insect pests include the top shoot borer (*Laspeyresia pseudonectis* Meyr), *Argina cribraria* Clerck, *A. syringe* Cramer species cause leaf damage (Cook and White 1996). Other stem and shoot boring insects include *L. tricenta* Meyr., *Cymotricha tetraschema* Meyr., and *Selinas monotropa* Gaert. The sunn hemp mirid (*Ragmus* *importunitas* Distant), flea beetle (*Longitarsus belgaumensis* Jac.), and stink bug (*Nezara viridula* L.) will damage sunn hemp. The silverleaf whitefly (*Bemisia argentifolii* Bellows & Perring) consumes lower surfaces of sunn hemp leaves; however minimal damage occurred except for premature leaf loss.

**Abiotic Stress:** See quads.

**Market and population growth demands:** Sunn hemp is a minor crop with very little production progress. However, sunn hemp research has increased due to the crop’s capacity to use in cover cropping systems.

**2.9.3 Sunn Hemp – Status of Plant Genetic Resources in the NPGS**

**Genetic coverage and gaps:** Three cultivars are on the market and one of these was developed in the U.S. for production and yield.

**Acquisitions:** Five hundred wild relatives exist worldwide, however the collection consists of only 39 spp.Many of the accessions were donated or obtained by plant exploration trips.

**Maintenance:** The sunn hemp collections consists of 22 accessions at PGRCU and NLGRP combined and 12 accessions are available. Currently 21 accessions are stored at -18°C and backed-up at NLGRP with 18 accessions tested for germination and 12 accessions backed-up at Svalbard. The sunn hemp cultivars were donated by U.S. and foreign breeders (USDA 2020a).

**Regeneration:** Sunn hemp requires pollinators such as the giant resin bee (*Megachile sculpturalis*) because few seeds are naturally produced from self-pollinating plants. Therefore, sunn hemp can regenerate seeds if adequate buffering is used with multiple species and the giant resin bee is found in the area. Seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Fifty plants per accession are planted in 6 m rows with a border crop using other species at PGRCU. Seed pods are hand harvested at maturity and dried at 21°C with 25% relative humidity for 1 week.

**Distributions:** see Table

**Genotypic characterization data:** No data.

**Phenotypic evaluation data:** Sunn hemp phenotypic traits related to chemical composition includes Ca, Cu, Fe, K, Mg, Mn, Na, P, Zn, and tannins; growth includes plant height and width; morphology includes branching and foliage; phenology including maturity; production includes seed production; and environmental stress includes hardiness. Most of the sunn hemp collection has been phenotyped for all of these traits except chemical compositions.

**Plant genetic resource research associated with the NPGS:**

**Goals and emphasis:** In order to assist scientists in making informed decisions of the sunn germplasm, PGRCU collaborates with various research programs to develop genetic knowledge about the collections and important traits. When resources permit, in-house research projects focus on characterizing cover crop capacity.

**Significant accomplishments:** There is a need for additional accessions to optimize genetic diversity. Sunn hemp cutting date and planting density reduced grass weed populations in a Georgia study (Morris et al. 2015). Sunn hemp seeding rate suppressed weed biomass in a Florida study (Cho et al. 2015). Another Florida study showed that 7 sunn hemp accessions had higher biomass production for cover cropping uses, and produced few to no seeds (Cho et al. 2016). However, they also found 9 other sunn hemp accessions which produced smaller plants and more seeds.

**2.9.4 Sunn Hemp - Prospects and future developments**

The U.S. sunn hemp collection is vulnerable due to the low number of cultivars that are in production and the zero U.S. breeding programs. Increased production expenses, pathogens and pests, water and high temperature stresses are driving the need for the development of improved cultivars with improved resistance to biotic and abiotic stresses. Traditional breeding programs don’t exist due to the use of more popular cover and fiber producing crops. Reduced budgets for sunn hemp genetic resource management is a reality, given the current federal and state funding levels. Advances in genomic technologies, powerful bioinformatic tools, elucidated marker-trait relationships, and rapid, affordable screening tests should improve the efficiency, creativity, and productivity of breeding programs. Future breeding programs will rely on ready access to diverse genetic resources, and international quarantine programs are important to ensure that pathogen-free germplasm is imported into the U.S. from other countries. The USDA-ARS NPGS industrial crop collection provides an important repository of cultivars and accessions. This collection is accessible and is being characterized genetically and phenotypically. Data are publicly available through the GRIN database. Breeders and researchers use the NPGS industrial crop collection as germplasm for breeding and as genetic material for fundamental scientific discovery purposes. PGRCU scientists are limited by the type of evaluations that can be performed with the current budget. Since it is expensive to maintain large collections, consideration should be given to which new accessions will be accepted into the collection, and which priority traits should be evaluated. Molecular analyses of the existing diversity will assist in the identification of gaps. An understanding of the diversity held in gene banks worldwide will help to strategically determine important ex situ populations that must be collected before important sources of diversity are lost. Sunn hemp will remain an important fiber and cover crop. With a diverse germplasm base secured, the future for sunn hemp production looks positive.

***2.10 Taraxacum kok-saghyz (TKS)***

**2.10.1 TKS - Introduction**

**Origin**: *Taraxacum kok-saghyz* (TKS) (Russian dandelion, Kazak dandelion or rubber dandelion) is a diminutive perennial plant in the Asteraceae family. It produces seed by sexual recombination, is self-incompatible and requires pollinators for seed production. A native to southeastern Kazakhstan, its geographic distribution is fairly small with populations in the Tekes, Kegen, and Saryzhaz River valleys and around Tuzkol Lake (DRIVE4EU 2019).

**Primary Crop Products and Value:** The roots of TKS contain significant amounts of rubber on a dry weight basis and the rubber is high-quality (Buranov and Elmuradov 2010). In addition to rubber, TKS roots contain 15-36% dry weight inulin (Arias et al. 2016). Inulin is used as a food additive or can be used for biofuel production (Whaley and Bowen 1947; Ujor et al. 2015). TKS is being developed as a temperate region source of natural rubber and, as a value-added product, inulin.

According to the International Rubber Study Group, the 2017 worldwide natural rubber consumption was 13.2 million tones with a value of $23.7 billion (IRSG 2019). Natural rubber is used in over 40,000 products including tires, gloves, condoms, catheters and other medical devices (Cornish 2001). Currently, the majority of natural rubber comes from the Brazilian rubber tree, *Hevea brasiliensis,* which grows only in the tropics. Due to problems with disease in this crop, changing land use patterns in the countries where it grows and increasing demand for natural rubber, alternative sources of natural rubber are being developed in the U.S. and European Union (Cornish 2001). TKS is one of the more promising species identified for development.

**Breeding Programs in the U.S.:** Current breeding efforts for TKS are focused on increasing root rubber content and root weight, herbicide resistance, increased stand establishment, and germination (Arias et al. 2016; Moussavi et al. 2016; Cornish et al. 2017; Hodgson-Kratky et al. 2017; Keener et al. 2018; Luo et al. 2018). There are programs at The Ohio State University, University of Nebraska and Oregon State University.

**Domestic Production:** Currently, there is no commercial production of TKS in the U.S..

**International Production:** There have been small acreage experimental plantings to test elite lines but no large-scale production (DRIVE4EU 2019).

**2.10.2 TKS - Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity:** The NPGS collection of TKS consists of 20 accessions collected from the wild in Kazakhstan in 2008. The European Union also conducted collection missions for TKS in the same time period. The limited germplasm collection is a concern of the breeding community

**Threats of Genetic Erosion *in situ:*** *In situ*, TKS populations are common with abundant plants per population (van Dijk et al. 2010; DRIVE4EU 2019).

**Current and Emerging Biotic, Abiotic, and Production Threats:**

**Diseases:** There are many problems to overcome in domesticating TKS for use as a crop but currently, diseases and pests have not been among them. Several root diseases were isolated by Eggert et al., (2018) but none were severe problems. Weed pressure is a problem (Keener et al. 2018) as there are currently no registered herbicides for the crop.

**Insects:** During the studies in the 1940’s, root diseases from a previous crop of cabbage wiped-out one test planting and others were destroyed by leafhoppers, grasshoppers and cutworms (Whaley and Bowen 1947). At the Western Regional Plant Introduction Station in Pullman, WA we found populations of root aphid on some of our plants grown for seed increase and had problems with thrips and aphid on flowering plants in the greenhouse. Whaley and Bowen (1947) point out that sufficient pollinators are needed for seed production in TKS. With declining populations of native pollinators, having sufficient pollinators for successful seed production might be an issue for TKS cultivation.

**2.10.3 TKS - Status of the plant genetic resources in the NPGS**

**Genetic coverage and gaps:** The NPGS TKS accessions were collected across the species range in Kazakhstan. There are no accessions from populations in China.

**Acquisitions:** The genetic diversity among the TKS accessions as assessed with SSR markers is relatively low to moderate (McAssey et al. 2016; Nowicki et al. 2019). The majority of the diversity is partitioned to individuals, as would be expected of an out-crossing species. Because of this, it may be beneficial to recollect in Kazakhstan. There is also a need to expand the *Taraxacum* collection to include additional species.

**Holdings and Maintenance:** There are 37 accessions in the *Taraxacum* collection in 6 taxa. The majority are TKS. 33% of the collection is backed-up at NLGRP. *Taraxacum* seed is stored at 4℃ at the PGITRU.

**Regeneration:** TKS accessions are regenerated when seed supply is low or of low quality. Seed is started in the greenhouse and seedlings transplanted to field plots. Each plot is caged with insect proof netting and pollinators, either blue bottle flies or honeybees, are added to the cages during flowering. Seed is harvested daily due to the nature of the seed heads. Accessions of the other species of *Taraxacum* are regenerated in the greenhouse with individual accessions spatially isolated if more than one accession of *Taraxacum* is being grown.

**Distributions:** see Table

**Genotypic characterization data:** The TKS collection has been explored with molecular markers by outside research groups (McAssey et al. 2016; Nowicki et al. 2019)

**Phenotypic evaluation data:** Phenotypic descriptors and rubber analysis were collected on plants grown for seed increase in 2011 and 2012

**Plant genetic resource research associated with the NPGS**:

**Goals and emphasis:** The curatorial goals for the *Taraxacum* and TKS collection are to continue providing seed to the research community, add accessions of elite lines or varieties when they are made available, taxonomically identify the accessions ID’ed only to species and to add additional *Taraxacum* species to the collection.

**2.10.4 TKS - Prospects and future developments**

The prospects for TKS becoming a crop plant grown in the U.S., EU and Canada seem good. Investment by private companies like Continental Tire (Tire Review 2018), Keygene, Kultivat and government funded projects like the EU project DRIVE4EU and the U.S. project, The Program of Excellence in Natural Rubber Alternatives (PENRA) are moving the crop forward.

***2.11****. Vernonia (renamed Centrapalus pauciflorus)*

**2.11.1 Introductions** Current Origin: semi-arid tropical Africa including Ethiopia, Eritrea, Kenya, Malawi, Tanzania, Uganda and Zimbabwe with the greatest diversity in eastern Africa especially in Ethiopia.

**Primary Crop Products and Value**: vernolic acid, a naturally epoxidized oil used to replace volatile organic compounds in paints and coatings, and in production of oleochemical products, cosmetics, detergents and plastics.

Breeding Programs in the U.S.: currently none (May 2020)

Domestic Production: currently none (May 2020)

International Production: currently none (May 2020)

**2.11.2 Urgency and Extent of Crop Vulnerabilities and Threats to Food Security**

**Genetic Uniformity**: Significant variation was observed in morphological and chemical characteristics of *Centrapalus* accessions collected during plant explorations in the 1980s. Collections have been made by researchers in Africa; those materials are not a part of the NPGS collection.

**Threats of Genetic Erosion *in situ***: no assessment

**Current and Emerging Biotic, Abiotic, Production, Dietary and Accessibility Threats**

**Diseases:**

Insects:

Abiotic Stress:

Market and population growth demands:

**2.11.3 - Status of the plant genetic resources in the NPGS**

**Genetic coverage and gaps:**

**Acquisitions:** The majority of the NPGS collection originated from five explorations in the 1980s, two led by R. E. Perdue, one by G. Christenson, one by S. Saufferer and one by S. Muchai. A breeding program at the USDA Maricopa location during 1990’s resulted in the development of three day-neutral flowering lines which are in the NPGS collection (Thompson, et al., 1994).

**Maintenance**: There are 61 accessions of *Centrapalus pauciflorus* in the in the NPGS collection in Ames, 24 of which are backed up at NLGRP. Twenty-one accessions are available for distribution, four of which are original seed. The majority of the accessions have only original seed either because regenerations have not been attempted or because regenerations failed due to original seed not germinating or due to lack of flowering.

**Regeneration:** Regeneration efforts have been limited because most species have strong daylength control of flowering and do not flower in Ames nor at our alternate grow out location in Parlier, CA. In Ames, we have recently had successful seed production from plants started in the fall and growing over the winter in a greenhouse. Capacity for production in this manner in Ames is very limited.

**Distributions:** see Table

**Genotypic characterization data**: *Centrapalus pauciflorus*, (PI 312852, Harar area, Ethiopia), was sequenced in 2019 in Dr. Jennifer Mandel’s Laboratory, University of Memphis, TN.

**Phenotypic evaluation data**: Centrapalus pauciflorus accessions are evaluated for basic morphological descriptors during regenerations. Descriptors to allow loading of phenotypic data into GRIN Global are under development.

**2.11.4 Prospects and future developments**: Researchers have agreed that the seed oil from *Centrapalus* is useful and an excellent source of non-petroleum based naturally epoxidized oil; however, its agronomic development has not advanced much since initial efforts in the 60s and 70s. A USDA program based in Maricopa, AZ measured basic agronomic and oil analyses data for a subset of the NPGS collection. The group also developed three day-neutral lines but the AZ program ended in the early 2000’s. There is currently no breeding program for *Centrapalus* in North America. A program in Canada (Ontario Ministry of Agriculture) has looked at some agronomic characteristics of *Centrapalus* such as weediness and field germination as well as done some breeding; however, that program has also ended (Todd, et al., 2018). It is very difficult to make agronomic advances without ongoing breeding for improved germplasm. Molecular analysis of the genus, with an interest in identifying flowering time genes (earlier flowering being one necessary domestication trait), is underway at the University of Memphis, TN.

**Other genetic resource capacities:** Kenya Genetic Resources Institute is reported to have a *Centrapalus* germplasm collection. Agronomic (2018) and molecular diversity (SSR based) (submitted) research at Addis Ababa University, Ethiopia on collections made by researchers in Ethiopia (Mideksa et al., 2019). Unclear if this material is represented in a genebank. Basic agronomic research in Kenya and Eritrea as well.

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