Industrial Crops & Products 206 (2023) 117364

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Vulnerability of U.S. new and industrial crop genetic resources

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ARTICLE INFO

Keywords:
Castor
Grindelia
Guayule
Guar
Kenaf
Roselle
Safflower
Sesame
Sunn hemp
Russian dandelion
Vernonia
Vulnerability

ABSTRACT

New and industrial crops include castor bean (*Ricinus communis* L.), gumweed (*Grindelia* spp.), guar (*Cyamopsis tetragonoloba* (L.) Taub, guayule (*Parthenium argentatum* A. Gray), kenaf (*Hibiscus cannabinus* L.), roselle (*Hibiscus sabdariffa* L.), safflower (*Carthamus tinctorius* L.), sesame (*Sesamum indicum* L.), sunn hemp (*Crotalaria juncea* L.), rubber dandelion (*Taraxacum kok-saghyz* L.E. Rodin) and Vernonia [*Centrapalus pauciflorus* (Willd.) H. Rob.]. Relatively few cultivars for these species are used for production which increases their susceptibility to several pests and abiotic threats. Wild relatives for many of these species contain genes for resistance to biotic and abiotic problems. Acquiring wild relatives for these species worldwide is limited which may result in dramatic species losses due to expansion of human population growth and climate change. The USDA, ARS National Plant Germplasm System (NPGS) new and industrial crop collections include 1044 castor bean; 55 gumweed; 1300 guar; 121 guayule; 286 kenaf; 139 roselle; 2400 safflower; 1300 sesame; 22 sunn hemp; 37 rubber dandelion; and 61 *Centrapalus pauciflorus* accessions. Most of these new and industrial crops have some vulnerability in the U.S. because there are a few breeders developing or who have developed new cultivars. However, there have not been any breeding activities for gumweed, sunn hemp, and *Centrapalus pauciflorus*. New and current pests and climate change are some of the main threats to vulnerability and when incorporated with industry needs and consumer interests, additional cultivars will be required.

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, helps to prioritize traits for evaluation, and assists 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. The PGRCU has greenhouse

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https://doi.org/10.1016/j.indcrop.2023.117364
Received 7 June 2023; Received in revised form 17 August 2023; Accepted 19 August 2023

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 called the Western Regional Plant Introduction Station (WRPIS)) in Pullman, WA maintains the rubber dandelion, gumweed, and safflower collections in separate programs. Rubber dandelion and gumweed are under the curatorial management of the Horticulture Crops and *Beta* Program. Safflower is part of the Agronomy Program at the PGITRU. *Centrapalus* germplasm is maintained and curated at the North Central Regional Plant Introduction Station (NCRPIS) in Ames, IA. The National Arid Land Plant Genetic Resources Unit (NALPGRU) in Parlier, CA maintains the guayule collection 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 4 C and − 18 C.

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-Global 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 and if approved 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 vulnerability status of each crop in order to determine curatorial needs and projections for future action to preserve these crops and their relatives.

2. 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 are tall, woody, perennial, and have large leaves (Anjani, 2012). 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), however Bliss (2012) suggests that there are60 species which are herbaceous annuals, perennials, subshrubs and shrubs. Guar (*Cyamopsis tetragonoloba* (L.) Taub is a cultigen growing wild in India and Pakistan however, U.S. production is centered in Texas and Oklahoma. Guayule (*Parthenium argentatum* A. Gray) is a desert shrub native to the Chihuahuan desert of Northern Mexico and the Big Bend region of Texas. Southern Asia is the origin for kenaf, however India and Malaysia are considered the origins for roselle. Safflower (*Carthamus tinctorius* L.) is an ancient, yet under-utilized, crop with an origin of western Asia. The origins for sesame include India and Pakistan (Bedigian, 2010) while sunn hemp originates from India (Cook and White, 1996). Rubber dandelion is native to southeastern Kazakhstan with populations in the Tekes Kegen and Saryzhaz River valleys and around Tuzkol Lake (DRIVE4EU, 2019). *Centrapalus* is native to semi-arid tropical Africa including Ethiopia, Eritrea, Kenya, Malawi, Tanzania, Uganda and Zimbabwe with the greatest diversity in eastern Africa especially in Ethiopia.

3. 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).

Table 1
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)	1004	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)	1300	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)	1300	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

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. *Grindelia 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), and *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). 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; 2001b; 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, this species 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). *Grindelai squarrosa* 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.

Guar is used as a laxative, food additive, in gas and oil well drilling, in the mining industry, in pet foods, and in beverages (Whistler et al., 1979). Guar has recently been evaluated for use as a vegetable especially for those genotypes with longer pods. Morris and Wang (2016)found significantly greater concentrations of flavonoids including daidzein, genistein, and kaempferol in immature pods from several guar accessions.

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 andallowing regrowth from the roots so more than one growth cycle occurs from a single direct seeding. Rubber and resin are solvent extracted; 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 its 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.

Kenaf (*Hibiscus cannabinus* L.) is primarily used on a very limited scale for fiber production in automobile composites and for making rope and paper products (USDA, 2020a). However, roselle is used for paper pulp, edible calyces, leaves, seeds (Wilson and Menzel, 1964), Christmas drinks in Jamaica (Vaidya, 2000), salads, pie filling, sauce, juice, syrup, jam, relish, jelly (Morton, 1987), and used as tea and an ornamental.

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 inmonounsaturated 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. Sesame seed are used as food and the oil is used in cooking, however sunn hemp is primarily used as a cover crop.

The roots of rubber dandelion (*Taraxacum kok-saghyz,* 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, rubber dandelion 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). Rubber dandelion 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). Rubber dandelion is one of the more promising species identified for development.

Vernolic acid from *Centrapalus pauciflorus* is a naturally epoxidized oil used to replace volatile organic compounds in paints and coatings, and in production of oleochemical products, cosmetics, detergents and plastics.

4. Breeding programs in the U.S

A castor bean 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).

There are currently no gumweed, sunn hemp, *Centrapalus* breeding programs in the U.S. However, the University of Nevada, Reno initiated investigation's into *G. squarrosa* and there is interest in continuing the work.

Conventional plant breeding used in the U.S. to develop high seed producing guar varieties including Mesa (Staten and Brooks, 1960), Texsel (Brooks and Harvey, 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 and Ray, 1985). The variety, Matador was 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 was developed for uniformity, early maturity, high seed yield, resistant to virus, and tolerant to bacterial diseases (Texas Tech University and Halliburton Services, 2010).

An active guayule 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.

The kenaf cultivars that are used primarily in the U.S. include Everglades 41 and Everglades 71 which were developed by the USDA, ARS in Florida (LeMahieu et al., 1991). They are both resistant to anthracnose. 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. Three winter-hardy safflower accessions were developed by R.C. Johnson, PGITRU Agronomy Research Scientist (retired). 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).

Current breeding efforts for Russian dandelion 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.

5. Domestic production

There is no U.S. production for castor bean, gumweed, sunn hemp, Russian dandelion, *Centrapalus pauciflorus*, and *Vernonia*. However, a small farm operation in Georgia produces very limited roselle. Guar production occurs in Texas. Guayule production is at pilot (Dave Dierig, personal communication) scale. Very little kenaf and roselle production has been reported. 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 tons per hectare. Sesame production in the U.S. is primarily in Texas and Oklahoma, however some occurs in Kansas and Arkansas (Ag Marketing Resource Center, 2018).

6. International production

The primary countries involved in castor bean seed production include Brazil, China, Ethiopia, India, Paraguay, and Thailand with total seed production exceeding 1300,000 metric tons (FAO, 2008). Currently, gumweed and *Centrapalus* are not produced internationally. The only countries producing guar are India and Pakistan (Morris, 2010). Guayule is produced at pilot scale (Dave Dierig, personal communication). Both China and India produce kenaf (University of Kentucky, 2014) however, roselle is primarily produced in China, Egypt, Jamaica, Mali,Mexico, Senegal, Sudan, Tanzania, and Thailand (FAO, 2004). Safflower is cultivated in many regions around the world and used for many purposes. International safflower production was 954, 127 ha harvested (FAO, 2018).

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). Sunn hemp is primarily produced in Brazil and Colombia (Cook and White, 1996). There have been small acreage experimental plantings to test elite lines but no large-scale production for Russian dandelion (DRIVE4EU 2019).

7. Genetic uniformity

Global uniform characterizations for phenotypic and genotypic traits are needed for all of the industrial crops mentioned in this paper. Even though the USDA, ARS, PGRCU collection in Griffin, GA maintains more than 1000 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.

About 286 and 139 kenaf accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO, respectively. The PGRCU kenaf and roselle collection's consists of about 17 and 6 cultivars, respectively, worldwide. Two kenaf cultivars were developed in the U.S. Similarly, uniform characterizations would help in the estimation of genetic variability in individual collections. The reduction of roselle breeding and research programs in the U.S. may result in inadvertent cultivar losses.

Gumweed 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. *Grindelia 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.

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 1300 guar accessions are in the PGRCU and NLGRP collections at Griffin, GA and Ft. Collins, CO combined (USDA, 2020a). The PGRCU guar collection consists of about 63 cultivars worldwide and Twelve of these were developed in the U.S.

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.

Johnson et al. (2007) characterized 96 NPGS safflower accessions from seven world regions with AFLP molecular markers and showed that safflower from different regions differed in genetic structure. Although this work indicated the presence of genetic diversity in the collection, obtaining CWRs remains a priority to enhance disease and insect resistance. Priority species for collection are C. *oxyacantha*, C. *palaestinis*, and C. *persicus*, which cross readily with C. *tinctorius* (safflower manual, personal communication from the Safflower Working Group at the 8th International Safflower Conference, 2012). Other species are also of interest for potential use in transgenic and basic research (Johnson et al., 2008).

Evaluations for phenotypic and genotypic traits are needed for sesame in gene bank's. About 1300 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.

Characterizations are also needed for sunn hemp accessions as well 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 and one sunn hemp cultivar was developed in the U.S.

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

8. 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. Gumweed 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 cases it is considered weedy (Tilley and Pickett, 2016).

Three additional guar 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 and Hymowitz, 1979). Many populations of these wild guar species may be susceptible to decline due to human encroachment and drought.

Guayule 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 guayule and *G. camporum* germplasm in Texas in 2005 and 2008 found that plants no longer existed at many historic collection sites.

Climate change, human intervention, native habitats, and international treaty issues will have a negative impact on kenaf, roselle, safflower, sesame, and sunn hemp. *In situ*, Russian dandelion populations are common with abundant plants per population (van Dijk et al., 2010; DRIVE4EU 2019). There have been no assessments for *Centrapalus*.

9. Current and emerging biotic, abiotic, and production threats

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, 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, 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).

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).

No diseases or pests were noted in the evaluation trials by McLaughlin and Neupane for gumweed. Seed predations by beetles has been observed in regeneration plots at the PGITRU Central Ferry farm, WA. Stem galls and the root parasite, *Orobanche* are common in Patagonia (Damian Ravetta communication). *Grindelia* species are generally adapted to low moisture areas and poor soils.

The guar disease, 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 and Hymowitz, 1979). There are no known resistant guar varieties (Whistler and Hymowitz, 1979). The Rhizoctonia rot (*Rhizoctonia solani* Kuhn) disease is another soil-borne fungus (Whistler and Hymowitz, 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 and Hymowitz, 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 and Hymowitz, 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 and Hymowitz, 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 and Hymowitz, 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 and Hymowitz, 1979). 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 and Hymowitz, 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 and Hymowitz, 1979). Climate change resulting in flooding and droughts will impact guar production worldwide.

The guayule 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.

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.

Increased tolerance to low temperatures and saline irrigation water are desired characteristics to expand the potential growing region of this new crop, guayule. 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 NPGS 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).

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. No serious insect threats are known (LeMahieu et al., 1991). Kenaf will suffer from climate change. 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). 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* (Blackburn) beetles in Australia attack leaves (Morton, 1987). The cocoa beetle (*Steirastoma breve* Sulzer, 1776) attacks plants in Trinidad (Morton, 1987). Additonal minor insect pests include scales (*Coccus hesperidum* Linnaeus) and *Hemichionaspis aspidistrae* Signoret), yellow aphids (*Aphis gossypii* Glover) and the cotton stainer (*Dysdercus suturellus* Herrich-Schaeffer) (Morton, 1987). Changing weather patterns will impact roselle production.

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 Mundel, 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 rarely cause problems in North American safflower 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 helianthin*) can be detrimental to safflower crops and aphids have injured crops in India and Spain (Dajue and Mundel, 1996; Nimbkar, 2008). Common abiotic stresses are drought, salinity, and alkalinity for safflower (Dajue and Mundel, 1996).

A major disease infecting sesame is phyllody (*Phytoplasma*) which causes their floral parts to revert to a vegetative state (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 and Wiemers, 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).

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, 2007). Climate change will impact sesame production.

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).

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. Climate change will impact sunn hemp production.

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.

During the studies in the 1940′s, rubber dandelion 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 aphids on flowering plants in the greenhouse. Whaley and Bowen (1947) point out that sufficient pollinators are needed for seed production in rubber dandelion. With declining populations of native pollinators, having sufficient pollinators for successful seed production might be an issue for rubber dandelion cultivation. Disease, insect, and abiotic issues are unknown for *Centrapalus*.

10. Market and population growth demands

In the U.S., the primary problem concerning castor bean production results from the toxic chem.

ical, ricin in the seed meal of castor bean seeds. Producers are not willing to grow castor beans because of this toxic compound. Guar production in the U.S. is low because currently most of the guar used is imported from India or Pakistan.

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 Heveaproduction. 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. Since kenaf and roselle are minor crops, very little production progress has been made. Sesame is grown on a very limited scale in Texas, however, progress for production is increasing in the southern U.S. 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. There are no market and population growth demand's for gumweed, safflower, Russiandandelion, and *Centrapalus.*

11. 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.

The majority of *G. camporum* accessions were collected by the US Interior Dept. Bureauof 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. There are no active collections of South American *Grindelia* specieswhich may provide high resin and grindelic acid content (Damian Ravetta communication).

Guar accessions in the collection includes cultivars with high seed yield, bacterial blighttolerance, and leaf spot resistance (Whistler and Hymowitz, 1979). Molecular markers have been developed for guar (Kuravadi et al., 2014). Seventy-three accessions have been characterized for genetic diversity (Morris, 2010). However, most of the collection needs genetic diversity characterizations.

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.

Kenaf accessions include cultivars with disease resistance (LeMahieu et al., 1991), and high yielding calyces (Morton, 1987). Roselle accessions include cultivars with high yielding calyces. However, since roselle is used in various food products including tea, additional accessions are required to fill gaps in the collection.

Some of the *Carthamus* 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 Mundel, 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 1200 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).

Sesame cultivars include those with disease resistance and indehiscent capsules. Accessions and cultivars showing tolerance to drought and flooding stress are needed, since the production area is extending into the southeastern U.S. Three cultivars are on the market and one of these was developed in the U.S. for production and yield. Russian dandelion accessions were collected across the species range in Kazakhstan. There are no accessions from populations in China. There is no information for *Centrapalus.*

12. 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.

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

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. Currently the kenaf and roselle collection's consists of 31 wild relatives, however several hundred are still needed. Many of the accessions were donated or obtained by plant exploration trips.

Priority species for the safflower collection are *C. oxyacantha*, *C. palaestinis*, and *C. persicus*, which cross readily with C. tinctorius (Dajue and Mundel, 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. Sesame wild relatives includes about 20–40 species and all are needed in the NPGS germplasm system. Many of the accessions were donated or obtained by plant exploration trips.

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

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. The majority of the NPGS *Centrapalus* collection originated from five explorations in the 1980 s, 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 the 1990′s resulted in the development of three day-neutral flowering lines which are in the NPGS collection (Thompson et al., 1994).

13. Maintenance

The castor bean collection consists of 1044 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 seed production.

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.

The guar collection consists of 1300 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).

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

The safflower seed is stored in a cold storage vault at 4ºC and 28% relative humidity. In addition, a − 20ºC 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.

The sesame collection consists of 1300 accessions at PGRCU and NLGRP combined. This includes 1161 available accessions, 1212 accessions stored at − 18 °C at PGRCU and 1214 accessions backed-up at NLGRP with 1205 accessions tested for germination, and 87 accessions backed-up at Svalbard. The sesame cultivars were donated by U.S. and foreign breeders (USDA, 2020a). 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).

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.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. Most 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.

14. 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.

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 ℃.

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.

Guar, kenaf, roselle, and sesame are 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. Since roselle is photo-period sensitive, roselle can be successfully increased in a greenhouse. Guar, kenaf, roselle, and sesame seeds are regenerated when the germination percentages are lower than 70% or when quantities drop to around 250 total seed. Photo-period sensitive kenaf and roselle accessions can be regenerated in gallon size plastic pots containing potting soil in a greenhouse. Seed capsules and pods are hand harvested at maturity and dried similar to field grown accessions. Cages placed over sesame plants are utilized to prevent outcrossing from pollinating bees and insects.

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 m 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. The entire regeneration plot is covered with a single tent-like screen cage, 7.5 m long and 3.5 m 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 threshing, 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. *Carthamus 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.

Sunn hemp requires pollinators such as the giant resin bee [*Megachile sculpturalis* (Smith)] 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 one week. Rubber dandelion 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.

Centrapalus 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.

15. Distributions

See Table 1.

16. 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.

Gumweed is a fairly new collection and has not yet been genotyped. Descriptor data from 73 guar accessions were subjected to a principal component and cluster analysis for characterization (Morris, 2010). Much of the guayule collection was genotyped by Ilut et al. (2017), but currently the data are not available directly in GRIN-Global. Kenaf, roselle, and sunn hemp have not been characterized genotypically. 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.

Several genotypic characterization evaluations have been conducted on sesame (Ali et al., 2007; Sharma et al., 2009; Kumar and Sharma, 2011; Ibrahim and Khidir, 2012) for origin, yield, and diversity and the TKS collection has been explored with molecular markers by outside research groups (McAssey et al., 2016; Nowicki et al., 2019). *Centrapalus pauciflorus*, (PI 312852, Harar area, Ethiopia), was sequenced in 2019 in Dr. Jennifer Mandel's Laboratory, University of Memphis, TN.

17. 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). No phenotypic data has been collected other than images during regeneration for gumweed. Guar phenotypic traits related to disease includes leaf spot; growth traits includes plant height; morphology traits includes plant surface, pod length, stem type; phenology traits include maturity; and production traits include 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.

GRIN-Global does not contain phenotypic data based on a common set of descriptors for guayule. However, large-scale phenotypic measurements on replicated field trials in Arizona are currently being conducted as part of the SBAR project. The kenaf phenotypic traits related to growth includes plant height and width; morphology includes branching; phenology includes maturity; and production includes foliage and seed production. Most of the collection has been phenotyped for these descriptors. The NPGS roselle collection has been characterized for growth, morphological, and phenological descriptors.

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). Sesamephenotypic traits related to growth include plant height; morphology traits includes capsule length, plant color, seed color, stalk strength, stem type, capsules per axil, locules, and seed size, and phenology includes maturity. Most of the sesame collection has been phenotyped for these traits.

Sunn hemp phenotypic traits related to chemical composition includes Ca, Cu, Fe, K, Mg, Mn, Na, P, Zn, and tannins; growth traits includes plant height and width; morphology includes branching and foliage; phenology traits include maturity; production traits include seed production; and environmental stress traits includes hardiness. Most of the sunn hemp collection has been phenotyped for all of these traits except chemical compositions. Phenotypic descriptors and rubber analysis were collected on rubber dandelion plants grown for seed increase in 2011 and 2012. *Centrapalus pauciflorus* accessions are evaluated for basic morphological descriptors during regenerations. Descriptors to allow loading of phenotypic data into GRIN Global are under development.

18. Goals and emphasis

In order to assist scientists in making informed decisions about 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 in castor bean. 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. There are currently no NPGS research projects associated with *G. camporum* but Dr. Miller, University of Nevada, Reno (retired) was awarded 2020 funds to collect *G. squarrosa* from selected habitats for future agronomic and biofuel yield evaluation. The PGITRU will collaborate on these projects. PGRCU collaborates with various research programs for seed gum content and flavonoid concentrations.

Seed oil characterization, seed production, flavonoid, and calyx production research projects are conducted in house or through collaborations for kenaf and roselle.

Currently, PGRCU in-house research focuses on evaluating sesame accessions for protein and lignan content, fatty acid concentrations, and oil percent. Sunn hemp research for cover cropping has been conducted in-house and in collaboration with other Universities.

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 lacking a species identification and to add additional *Taraxacum* species to the collection. There is currently no information for *Centrapalus*.

19. 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 (Wang et al., 2017). There is currently no information for gumweed, guayule, Russian dandelion, and *Centrapalus*.

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, 2016). Seventy-three guar accessions evaluated for morphology and reproduction resulted in the identification of variability among accessions(Morris, 2010). T.

he 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. 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). Labbe et al. (2009) showed that flavonols may have health implications. 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.

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.

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).

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.

20. Other genetic resource capacities

Countries with castor bean collections include Brazil (1287), China (3341), Ethiopia (232), India (290), Kenya (173), Romania (66), Russia (423), Serbia (112), Ukraine (255), and the U.S. (1056). An addition guar gene bank is located in India (4312 accessions) (Rana et al., 2016). A gene bank in Bangladesh has 698 kenaf and 453 roselle accessions (Razzaque and Hossain, 2007). 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, 6987 accessions, are maintained in India. Additional countries with sesame collections include India (>10,000), South Korea (>7698), China (>7000) (Dossa et al., 2017), and Pakistan (73) (Zahoor, 2007). Kenya Genetic Resources Institute is reported to have a *Centrapalus* germplasm collection. Agronomic (2018) and molecular diversity (SSR based) research at Addis Ababa University, Ethiopia on collections made by researchers in Ethiopia was described (Mideksa et al., 2019). It is unclear if this material is represented in a genebank. Basic agronomic research in Kenya and Eritrea was described as well. There is no information for gumweed, guayule, sunn hemp, and Russian dandelion.

21. 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. Since *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).

Guar will remain an 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.

Guayule currently has momentum for commercialization, building on previous attempts over the last century. This is the most investment by private industry (Bridgestone Americas and others) than at any other time in its history of establishing this crop as 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.

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 and roselle is a medicinal, fiber, and functional food crop. With a diverse germplasm base secured, the future for kenaf and roselle production looks positive.

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.

Sesame will remain an important oil and functional food crop. Sesame cultivars have been developed with high oil content and indehiscent capsules. Sunn hemp will remain an important fiber and cover crop. The prospects for rubber dandelion 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.

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.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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