Potato Crop Germplasm Committee
Vulnerability Statement 2020

Bullet potato crop and germplasm points

1. Top US vegetable at ~$4 B/y production value
2. High but declining US consumption of ~111 lb/y/cap
3. Extremely productive crop, at up to 40T per acre state average yields
4. Top producer = China, top consumers = eastern Europeans
5. Starchy energy food, but with high flavor, comfort, satiety
6. High current dietary and economic impact and future potential
7. Extreme versatility in eating and growing (but primarily fall temperate US production)
8. Native to the Americas, primarily the mountains of Mexico through Chile
9. Genus *Solanum*, tuber (stem) crop in contrast to root crop "sweet potato"
10. Tetrasomic tetraploid clonal crop (thus 5% of potato "crop" is for seed)
11. About 70% processed (fries and chips): 30% fresh consumption in US
12. Susceptible to many diseases, pests and stresses
13. Very high quality requirements for 30+ traits in US breeding
14. Intellectual resource: Many professionals (federal, state, private) and extensive knowledge base
15. Material resource: broad germplasm base in genebanks, but much greater potential in the wild (~100 wild related species.)
16. Germplasm well backed up at US potato genebank (USPG) and in international genebanks and at Ft. Collins repository
17. Vulnerability: Catastrophe at USPG, requiring diversion of efforts to recovery
18. Vulnerability: Extinction of wild populations and useful genes
19. Vulnerability: Opportunity cost of not mining traits because of insufficient funding
20. Vulnerability: Crop production vulnerable to loss of available water and pesticides, diseases & pests
21. Vulnerability: Greatest threat to crop is loss of food reputation and market share
22. Cultivar selection and seed ramp-up a slow process (10+ years) requiring efficiency gains and industry acceptance
23. Among first in *in vitro* tech, but major molecular breeding resources recently developing
24. GMO generally not accepted in US, but "intragenic" modifications are finding small market share
25. Low food-borne illness potential since always cooked and often fried dry
26. Improvements should provide advantages for producers and consumers
27. Opportunities exist in consumer preferences for diversity, less preparation time, greater nutritional value, novel outlets like pet food, beer, extracts
28. Advances that benefit Latin American crop serve as value exchanged for germplasm
29. See website of US Potato Genebank/NRSP6 links to greater germplasm and research information:

https://www.ars.usda.gov/midwest-area/madison-wi/vegetable-crops-research/people/john-bamberg/bamberg-lab/

Summary:

Potato is the third most important food crop worldwide and the most important vegetable crop. In the US, potato production has remained steady in recent years, with yields per acre increasing but production area decreasing slightly. Potato is an intensively managed crop that requires substantial inputs of nutrients, pesticides, fungicides, and water to maintain tuber yield and quality. Fumigation and fungicide application practices are not compatible with long-term sustainability goals but are very essential to profitable crop especially in the high yielding potato production regions like the Columbia basin of Washington and Oregon. The development of potato varieties with greater resistance to pests and pathogens is necessary for the sustainability of the potato industry and for rural America. In addition, research efforts should also focus on abiotic stress resistance. Global climate change models predict a decrease in potato yields throughout much of the US, largely due to warmer temperatures throughout the growing season. The development of heat and drought tolerant varieties is expected to increase yields by 5% in most production regions. Consequently, potato farmers will likely benefit if breeders add heat and drought tolerance to their selection criteria. Finally, potato breeders must develop cultivars with higher nitrogen use efficiency to offset the increasing cost of nitrogen fertilizer and minimize groundwater contamination by nitrates.

The potato crop is well-positioned to utilize its diverse and readily available germplasm resources to meet future production demands (Jansky et al., 2013). The US potato genebank (USPG) contains accessions that breeders can use to improve disease and pest tolerance, heat tolerance, drought tolerance, and nitrogen efficiency (Reynolds and Ewing, 1989; Errebhi et al., 1999; Cabello et al., 2012; Graebner et al., 2018, Cooper and Bamberg, 2016). In addition, the tightening of environmental regulations and emergence of new pests and pathogens will likely increase the value of resistance to these production challenges to the potato industry. Systematic efforts to survey genetic diversity in potato relatives and identify sources of valuable traits will increase breeding effort efficiencies.

The sequencing of the potato genome in 2011 opened new opportunities for use of genomics in potato improvement (Xu et al., 2011). The USDA-funded SolCAP project has provided abundant genomics resources to potato breeders. The genomic resources have led to the development of mapping resources for marker development (Hirsch et al., 2013). Inclusion of wild species clones in the SNP array has led to some surprising preliminary findings of higher levels of homozygosity than expected (Massa et al., 2013). It is imperative to continue genomics analyses to reveal underlying genetic diversity in wild species and elucidate the significance of this diversity in cultivar improvement. It is ironic that recent publications (Tanksley and McCouch, 1997; McCouch et al., 2012) suggest that genebanks should take on a new role, not just being a repository to provide germplasm resources, but also a research center to advance the understanding of genetic diversity, when the USPG and other NPGS genebanks have been very active in such research for many years. The potato genome sequence resources led to development of modern genetic and genomic tools that are being effectively used in the breeding programs and national coordinated breeding trials (Schmitz Carley et al., 2018; Bali et al., 2018; Endelman et al., 2018)

All potential benefits that are at least initially producer-oriented, will be moot if consumers do not continue to appreciate the nutritional value of potato in wealthy societies like the US where consumers have wider food choices. Thus, a key to maintaining demand will be to use germplasm to improve potatoes in ways that obviously benefit the end user. Price and

availability are not significant issues for US consumers, but negative and positive nutritional factors are. More sustainably-grown and low pesticide potatoes will likely increase potato attractiveness to US consumers. Variety in taste and appearance may, increase the appeal of potatoes as consumers become more oriented toward reduced synthetic inputs and gourmet preparation. There is likely an untapped niche market for ethnic potatoes to satisfy the particular tastes of Latin American and other immigrants (see NRSP-6 annual report 2012 on USPG website). On the other hand, potato industry representatives have told us for over a decade that the future of food market success is in convenience and speed of preparation. Since people will not significantly increase their total food intake, nor would there be value in an already overweight population doing so, the practical challenge for use of germplasm to sustain the potato industry is to maintain choice and market share of energy foods, particularly in comparison to other savory carbohydrates like breads and pasta. This is not often directly mentioned, perhaps because the US government vigorously promotes cereal production. Thus, we ask: How much should public potato market promoters advertise reports of the negatives of competitors-- for example, reports claiming widespread and significant negative health impacts from gluten consumption?

This is a vulnerability statement, so the most basic threats related to germplasm availability, environmental degradation, genetic uniformity, and other threats to potato sustainability, are detailed in the main text following. However, some social/political changes could also be pertinent.

The most severe, acute threat to potato germplasm with impact on the industry would likely come from a precipitous loss from natural disaster or vandalism. Although genebank stocks are duplicated at the Ft. Collins, CO repository and in other world collections, restoring full genebank function would be slow and expensive, likely requiring temporarily abandonment of non-critical but important genebank functions and services. For the industry, the greatest acute threat is from precipitous loss of potato food reputation, perhaps by terrorist rumors. With the exception of "On Her Majesty's Secret Service" (Fleming 1963), the potential of agricultural terrorism does not have great popular recognition. Nevertheless, we have seen that the loss of reputation in foods like ground beef and sprouts can be an overnight disaster.

The mid-level chronic threat to the industry would be growing consumer awareness of some specific negatives like acrylamide, greening (high glycoalkaloids) and resulting less-frequent choice of potato. However, nutritional information overload may provoke in many consumers a fatalistic, cynical attitude about their ability to avoid nutritional threats. Will bad press affect potato consumption rates?

A long-term threat to the industry and the supporting value of potato germplasm is a gradual loss of consumer preference for potato-based foods. As consumers become more health conscious they become increasingly concerned with lifestyle-based approaches to disease prevention. Most of the US population does not currently regard potato as a healthy food. We must vigorously generate and disseminate germplasm news and develop products that demonstrate the potato as a vegetable with nutritional benefits, athletic performance food and improve its reputation as a healthy choice for responsible eating.

1. Introduction to the Crop

1.1. Biological features and ecogeographical distribution

Potato, *Solanum tuberosum* L. (2n=4x=48), is grown as an autotetraploid crop in northern temperate regions of the world. Land races in South America range from diploid to pentaploid. Most tetraploid and diploid wild and cultivated relatives are either self-incompatible or suffer greatly from inbreeding depression. Thus, a uniform commercial crop is almost exclusively the result of clonal propagation, with tuber pieces serving as "seed." Breeders have long pursued botanical seed propagation to develop a propagule with much less disease transmission, perishability, and transport cost. Recently there has been new activity in reinventing potato as a diploid inbred crop (Jansky et al., 2016)

The tuber-bearing *Solanum* species are found in section Petota, which includes four cultivated (Spooner et al., 2007) and approximately 110 wild tuber-bearing Solanum species (Spooner, 2009). These species are distributed among 16 countries from the US through Central and South America to Chile and Argentina (Spooner and Salas, 2006). Wild potatoes grow from sea level to 4,300 m, but are most commonly found from 2,000 to 4,000 m. They are adapted to a much wider range of habitats than the cultivated potato including the cold high grasslands of the Andes, hot semi-desert and seasonally dry habitats, as can be found in Mexico, high deserts of south-western United States of America, humid subtropical to temperate mountain rain forests (Central America), and even as epiphytes in trees (Hawkes, 1990; Ochoa, 1990).

1.2. Genetic base of crop production

Wild relatives of potato are genetically rich and diverse in traits that are of economic value (Plaisted and Hoopes, 1989; Jansky, 2006; Bradshaw et al., 2006). Most of this germplasm is sexually compatible with the cultivated potato. Unlike many other crop plants, hybrids between wild and cultivated potato can look much like standard breeding selections (Hermundstad and Peloquin, 1985, 1986; Jansky et al., 1990; Peloquin et al., 1991). Consequently, extensive backcrossing (pseudo backcross) is not necessary to restore the commercially-acceptable phenotype. Populations generated from interspecific and interploidy crosses between wild and cultivated potato have been important for both crop improvement with many commercial varieties containing wild or cultivated potato in their pedigrees (e.g., Payette Russet and Castle Russet) and as the foundation for genetic studies (Hawkes, 1958; Ross, 1986; Bradshaw, 2009a).

Many wild potato relatives can be hybridized with the cultivated potato, either directly or by applying strategies that allow the circumvention of hybridization barriers (Hanneman Jr., 1989; Camadro, 2010). In fact, exotic potato germplasm has made important contributions to disease resistance, enhanced yield, and improved quality through plant breeding for over 150 years (Hawkes, 1945, 1958; Rieman et al., 1954; Rudorf, 1958; Ross, 1966, 1979; Plaisted and Hoopes, 1989; Bradshaw and Ramsay, 2005; Bamberg and del Rio 2005). Consequently, potato is acknowledged as a crop for which crop wild relatives (CWR) have been prominently used as a source of genetic improvement (Maxted et al., 2012). However, despite these apparent advantages, success is not so easy to accomplish in practice, as witnessed by the fact that a small proportion of the genetic diversity in genebanks has been incorporated into advanced breeding selections. Breeders' major focus is on inter cultivar cross selection, not experimental exotic hybrids. Progress is hindered by several generations of ploidy manipulation and evaluation, failed crosses, and limited by male fertility.

Crop Vulnerability Update for Potato

Vulnerabilities &Threats

- Susceptibility to many current, evolving and emerging pathogens and pests.
- Narrow US genetic base for commercial varieties.
- US production is input-intensive.
- Changing climates: hotter, drier—reducing yields.
- Some crop wild relatives (CWR) endangered in situ.
- Reduced budgetary support and operational capacity for breeding and plant genetic resource (PGR) management.

NPGS PGR Status & Impacts

- **Status:** Large collection (ca. 6000 accessions) with superior representation of CWR, managed as tubers and seeds in cold storage and greenhouses at Sturgeon Bay, WI. Accessions backed up at Ft. Collins and internationally.
- Rigorous disease and quarantine protocols in place, but add time and expense to germplasm import.
- **Impacts:** Protects and genetically improves top US vegetable with ca. $4 Billion/yr production value, and up to 25 tons/acre state average yields.
- NPGS source of base germplasm for most new US potato varieties; host-plant resistance to many diseases and pests; base genetics for specialty potato varieties.

Genetic research & breeding capacities

- ARS breeding and genetics programs at Beltsville, MD/Orono, ME & Madison, WI. Prosser, WA & Aberdeen, ID collaborative breeding with CO, MI, MN TX, WI state projects; OR, ID, and WA state projects as NW Variety Development Program.
- Very high quality requirements for 30+ traits.
- Cultivar selection lengthy (10+ yr); need rapid reliable disease-free propagation methods.
- Pepsico-Frito and Michigan State provide genetic marker and genotyping-by-sequencing (GBS) data.
- Germplasm evaluations by public & private sectors.

Priority Issues

- Additional budgetary support crucial for expanded NPGS potato PGR management capacity, handling high PGR demand (80% of collection distributed/yr.), and additional PGR evaluations and genomic characterizations.
- Additional budgetary support crucial for expanded potato breeding capacity, especially for host-plant resistance to biotic stresses, tolerance to abiotic stresses, and input use efficiencies.
- Additional CWR should be acquired.
- See https://www.ars-grin.gov/nr6/tac/CGC_PotatoVuln2014.pdf for more info.

Imapact statement of exotic germplam use from the Sturgeon Bay genebank:

In recent years breeders have engaged in the revolutionary remaking of potato as a diploid inbred crop. This is only possible because haploidizing technology and selfing mutants were both discovered in NRSP6 germplasm-- *by NRSP6 staff*. And NRSP6 further supported the effort in the current project term by importing valuable new stocks and testing techniques. The ploidy manipulation technique that resulted in Yukon Gold was also developed with NRSP stocks--*by NRSP6 staff*. Wisconsin cooperators isolated and incorporated the gene providing durable resistance to late blight from a wild species that had been collected in Mexico and preserved and studied in the genebank long before its potential was recognized. Washington state collaborators incorporated potent nematode resistance. In 2017, Idaho collaborators reported incorporation of resistance to greening (responsible for 10-15% waste)-- *discovered by NRSP6 staff*. Cooperators used NRSP6 stocks to develop breeding stocks resistant to verticillium and scab, and donated those back to the genebank. NRSP6 staff helped Oregon State researchers identify germplasm with high folate and resistance to nematodes. We produced custom hybrids and propagules to help Industry partners breed lines with much greater levels of an anti-appetite compound aimed at reducing obesity. At least 70% of named US cultivars have our exotic germplasm in their pedigrees. For example, in Wisconsin, of the past 8 cultivar releases from the breeding program, 6 have wild species germplasm as parents obtained directly from NRSP6 (see detail below). NRSP6 staff bred cold tolerant families from which a new cultivar, Wiñay, was released in 2018 in Peru. Sequencing the potato genome depended on the use of genetic stocks from NRSP6 developed by cooperators at Virginia Tech. The revolutionary intragenic Innate potato lines from Simplot in Idaho were developed through the use of exotic germplasm from NRSP6. Two new potato pests—Zebra chip and *Dickeya*-- have become very serious in recent years. In the current NRSP6 project, we are cooperating with state and federal scientists in Colorado, Texas, New York, and Washington state, screening for and finding potent resistance in exotic germplasm from NRSP6. Folate deficiency causes severe birth defects. With help of NRSP6 staff, state scientists from Oregon identified wild species selections and custom hybrids available only from NRSP6 with high folate and a way to make screening for folate much easier. All these advances would not have been possible using germplasm in the common breeding pool. They needed to be accessed from exotic germplasm. And that exotic germplasm is *only* available in the USA from NRSP6. The use of NRSP6 germplasm by stakeholders has been very robust in the past, increasing knowledge and breeding products that have had a great positive impact on the crop-- and this process is increasing in the current project term.

US cultivars with US Potato Genebank species in their pedigrees

Excerpts from NRSP6 Annual Reports (see https://www.ars.usda.gov/midwest-area/madison-wi/vegetable-crops-research/people/john-bamberg/bamberg-lab/)

Recent cultivar releases: Yukon Gem (2010) Classic Russet (2010), Clearwater Russet (2010), Alta Crown (2011), Cooperation-88 (2011), Alpine Russet (2011), Sentinel (2013), Huckleberry Gold (2014), Teton Russet (2014), Elkton (2014), M7 Germplasm Release (2014), AmaRosa (2012), Purple Pelisse (2012), Owyhee Russet (2012), Palisade Russet (2012), Saikai 35 (2012). They all have NRSP6 exotic germplasm in their pedigrees, including species *S. andigena, acaule, chacoense, demissum, infundibuliforme, phureja,* and *vernei*. Clearwater Russet released by Tri-state program as recently been accepted by McDonalds and the acreage has been increasing. NRSP6 played a significant role in development of this variety.

New cultivars and releases published this year: Germplasm releases for Early blight resistance, Sierra Rose (2015), and Peter Wilcox (2015). They all have NRSP6 exotic germplasm in their pedigrees, including species *S. andigena, phureja, stenotomum, palustre, bulbocastanum, stoloniferum, edinense.*

The cultivars published this year (2016) in *American Journal of Potato Research* are Targhee Russet, Igorata, Yukon Nugget. They all have exotic germplasm from NRSP6 in their pedigrees: *S. phureja, stenotomum, speggazzinnii, raphanifolium, demissum, vernei*

From the 2018 Annual Report: At least 70% of named US cultivars have our exotic germplasm in their pedigrees. For example, in Wisconsin, of the past 8 cultivar releases from the breeding program, 6 have wild species germplasm as parents obtained directly from NRSP6. Each of the three US cultivars published in 2017 in *American Journal of Potato Research*, Lamoka, Sage Russet, and Payette Russet have exotics *S. chacoense, demissum*, and *andigena* in their pedigrees.

Reveille Russet (2018) has wild species *S. acaule* from NRSP6 in its pedigree.

Castle Russet (pending) has germplasm introgressed from *Solanum vernei*, *S. chacoense* and *S. stoloniferum*, is resistant to PVY, CRS, PMTV, coldsweetening and is one of the six clones (one of the two from U.S. the other being Atlantic) selected for PanGenome sequencing.

1.3 Primary products and their value (farmgate)

Cultivar development in potato focuses on market classes, each with different target characteristics. Russet potatoes are used for both the fresh market and for French fry processing. Round white potatoes are consumed fresh or processed into chips. Round reds are sold in the fresh market and are typically in the early maturity class. Specialty potato varieties, including baby potatoes, fingerlings and colored flesh potatoes attract a small but growing market share. Until the explosive increase in out-of-home meals, especially in "fast food" restaurants, most potatoes were grown for fresh consumption. A shift was noted in 1989, though, when the use of the crop for processing surpassed its use for the fresh market for the first time (Johnson et al., 2010). Since then, the majority of the US potato crop has been used for processing, primarily frozen, chip, and dehydrated products. Processors pay a premium for high specific gravity (dry matter content) potatoes (Johnson et al., 2010). Other important factors are tuber size, shape and size distribution, a lack of bruising and internal defects, and low reducing sugar levels, both at harvest and after storage. High levels of the reducing sugars glucose and fructose result in dark colored products when fried, resulting in increased acrylamide concentration (Malone et al., 2006). Production value in US in 2017 was about $4.5 billion.

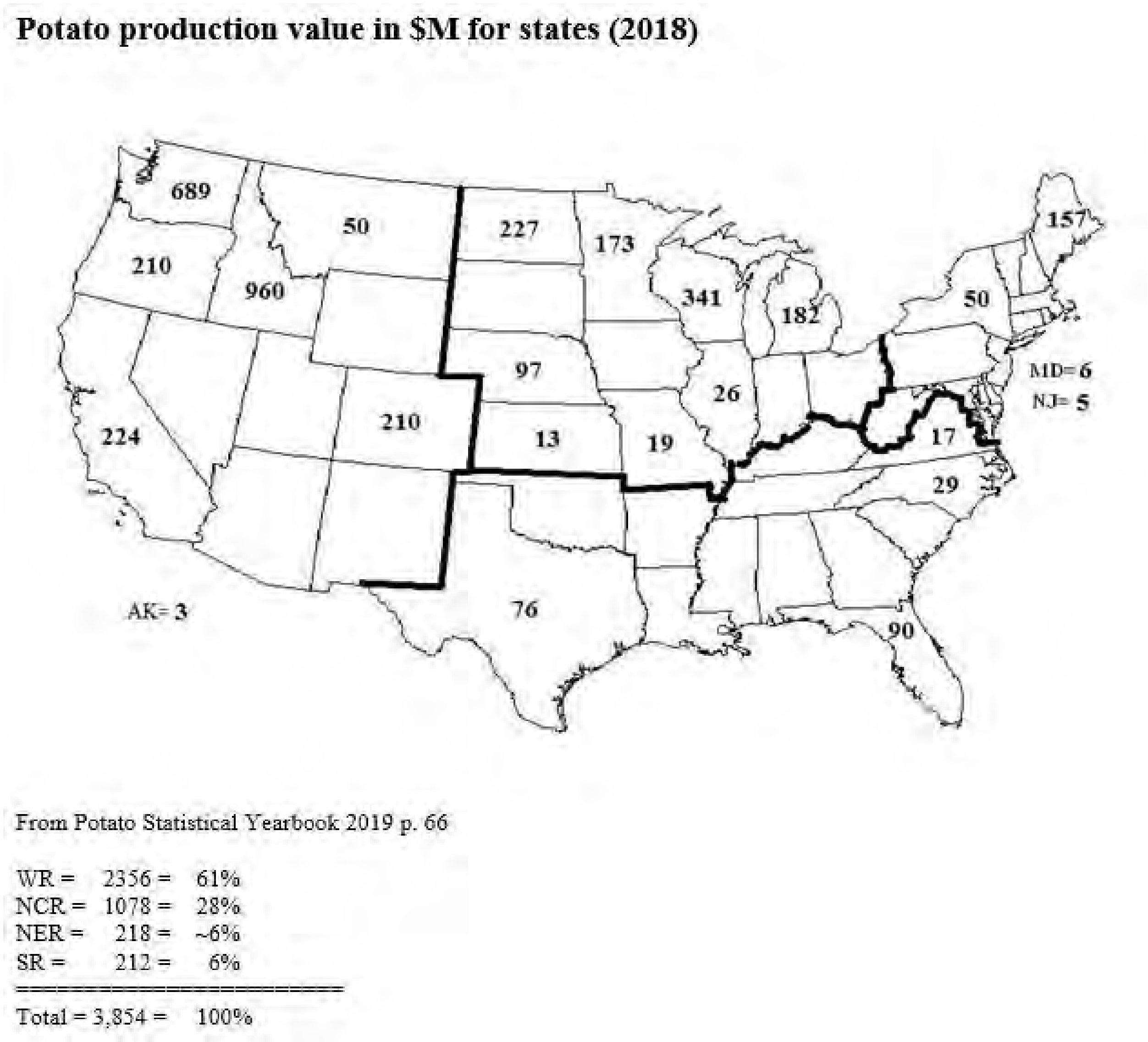
1.4. Domestic and international crop production

1.4.1 US (regional geography)

Potato is the most important vegetable crop in the US. It is produced throughout the country and across all seasons. Total production in 2017 was 22,419,430 T grown on 415,005 ha.

Most potatoes are produced in the western states and harvested in the fall. The greatest production in order of total production for western states is in Idaho, Washington, Colorado, Oregon, and California (2017 data). The fall crop in these five states accounted for 63% of the total US production in 2017. Yield per hectare varies widely among production regions, states, and growing seasons, with the highest yields in the fall crop in Washington, Oregon and Idaho.

Details of US production, consumption, nutrition and other statistics are available from the National Potato Council: http://www.nationalpotatocouncil.org/potato-facts/.



Potato production value in $M for states (2018)

From Potato Statistical Yearbook 2019 p. 66

WR = 2356 = 61%
NCR = 1078 = 28%
NER = 218 = ~6%
SR = 212 = 6%

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Total = 3,854 = 100%

Fig 1. Snapshot of US National potato production

1.4.2. International

China is the world's largest producer of potatoes; production is expanding to enhance food stability (Jansky et al., 2009; Scott and Suarez, 2012). Other major potato producing countries listed in order of total production, include India, Russian Federation, Ukraine, and the US (2016 FAOstat data).

2. Urgency and extent of crop vulnerabilities and threats to food security

2.1 Genetic uniformity in the “standing crops” and varietal life spans

It is generally agreed that the cultivated potato in North America and Europe has a narrow genetic base (Mendoza and Haynes, 1974; Plaisted and Hoopes, 1989). A study comparing modern and historical cultivars was not able to detect genetic improvements in yield or specific gravity during the twentieth century (Douches et al., 1996). The authors concluded that a century of potato breeding had not resulted in genetic advances for these traits. However, current potato production in the US has a much more diverse cultivar base than it had 30 years ago. Most yield improvement is the result of better management practices and a shift to production in geographic regions with higher yield potential. Genetic gains for yield have been negligible in comparison, although newer potato varieties have produced significant economic benefits for increased marketable yield and improved tuber quality. In the future, it seems likely that genetic improvement will contribute to productivity increases, but only if growers, processors, and especially consumers adopt new varieties.

2.2 Threats of genetic erosion in situ

The ecosystems in which potato CWR grow are becoming less stable due to climate change, poor land management practices, urbanization, and infrastructure expansion such as road development (Maxted et al., 2012). Geographic information systems technologies have enabled a better understanding of potato species distributions based on passport data from genebank collections (Hijmans and Spooner, 2001; Hijmans et al., 2002). However, in recent decades no field-level research has been conducted on habitat shifts and conservation status in situ. Our understanding of the population ecology and dynamics of potato wild relatives is limited. Biases in genebank collections have been documented with recommendations for filling gaps, (Hijmans et al., 2012), but these may be logistically impractical (for example, a recommendation to search likely habitats in extremely remote areas far from roads).

Among priority taxa, those with the most urgent need for conservation typically have a limited geographic range (Maxted et al., 2012). However, this standard also may lead to impractical goals assuming that the rarest and unsampled taxa are those less related to *S. tuberosum* and thus with reduced potential for use, and posing greater problems to all aspects of genebank preservation. While collecting expeditions should focus on adding to the genetic diversity found in current germplasm collections, re-collection of populations held in genebanks would provide an opportunity to assess genetic erosion in the field and genetic drift in genebank collections (Del Rio et al., 1997). In addition, recent investigation into accessions from a wild *Solanum* species indicates a high level of heterozygosity (Haynes et al., 2017). Despite a longstanding and vigorous program of genetic diversity and collecting research at USPG (see Appendix for publications), more research in this area is needed.

A considerable challenge to the collection of potato wild relatives is that they often are found in sympatric associations where they hybridize readily and blur species boundaries (Masuelli et al., 2009; Camadro et al., 2012). Transgressive segregation in these hybrid populations may allow them to survive in habitats that are more extreme than those of either of their parents. It is important then to include naturally occurring hybrids when collecting, but to keep them separate and, when possible, clearly label them as such. Descriptive information on habitat, spatial distribution, ecology, geography and surroundings, such as threats and conservation efforts, is also critical. Ongoing evolution, mediated by gene flow between cultivated and wild species, occurs in the Andean center of potato origin and should be more thoroughly documented (Celis et al., 2004; Scurrah et al., 2008). Little is known about what happens after gene flow has occurred between wild and cultivated relatives in agricultural settings. Offspring must pass a series of critical natural and human selection steps to become viable new landrace varieties. We can learn much from the study of successful cases of spontaneous farmer-mediated “pre-breeding” by selection resulting in the influx of wild species genes into the cultivated gene pool (Brush et al., 1981).

2.3. Current and emerging threats and needs

2.3.1 Biotic (diseases and pests)

Potato is an intensively managed crop that requires substantial inputs of nutrients, pesticides, fungicides, and water to maintain tuber yield and quality. Fumigation and fungicide application practices are not compatible with long-term sustainability goals. Strategies to rapidly and efficiently create potato varieties with greater resistance to pests, pathogens, environmental stress and tuber quality defects are important to the potato industry and to rural America.

Reports of disease resistance in wild and cultivated relatives of potato are abundant. Based on published screening data, it is apparent that some species are especially potent sources of resistance to several diseases and pests. Resistance to ring rot, potato cyst nematode, root knot nematode, *Potato virus Y* and *Potato virus X* has been reported in *S. acaule*; resistance to Colorado potato beetle, green peach aphid, potato tuberworm, late blight, and Verticillium wilt has been reported in *S. berthaultii*; resistance to silver scurf, Colorado potato beetle, four species of root knot nematode, late blight, potato leaf roll virus, *Potato virus Y*, thrips, and both Verticillium wilt species has been reported in *S. chacoense*; resistance to root knot nematode, late blight, *Potato virus X, Tobacco rattle virus*, and Verticillium wilt has been reported in *S. commersonii*; resistance to potato cyst nematode, late blight, potato leaf roll virus, Verticillium wilt and potato viruses M, X, and Y has been reported in *S. sparsipilum*; resistance to soft rot, silver scurf, late blight, cucumber mosaic virus, henbane mosaic virus, and potato virus Y has been reported in *S. stoloniferum*; and resistance to soft rot, Colorado potato beetle, root knot nematode and Verticillium wilt has been reported in *S. tarijense*. The non-tuber bearing species *S. palustre* seems to be an especially rich source of virus resistance genes. It is reported to be resistant to eight different viruses. From a breeding standpoint, it is encouraging to note that several of the wild species that are rich in disease resistance genes (*S. berthaultii, S. chacoense, S. sparsipilum,* and *S. tarijense*) are also easily accessible through simple ploidy manipulations.

One of the most significant emerging potato diseases in the US is zebra chip. It is caused by the phytoplasma pathogen *Candidatus Liberibacter solanacearum* and vectored by the psyllid *Bactericera cockerelli* (Munyaneza et al., 2007). Resistance to the vector and the pathogen has been identified in wild relatives of potato and is being introgressed into advanced breeding lines (Novy, pers. comm.). Other emerging potato diseases include *Potato mop-top virus* (PMTV) vectored by *Spongospora subterranea*, the powdery scab organism, a protist and corky ring spot (CRS) disease caused by *Tobacco rattle virus* and vectored by stubby root nematode. Difficulties of PMTV are that powdery scab appears to be widespread and that PMTV can be symptomless in many varieties. Breeding for resistance to CRS and PMTV are of prime importance to the Tri-State Potato Breeding and Variety Development Program which encompasses the U.S. states of Idaho, Washington, and Oregon.

2.3.2 Abiotic (environmental extremes, climate change)

Water problems are the most prevalent environmental production constraint for potato production in the US. Yield reductions of 20% or more were common due to drought in the late 1980's and flooding in the 1990's and 2000's. Clearly, drought affects dryland production, for example in the Red River Valley of North Dakota and Minnesota. However, a lack of irrigation water in some regions also impacts production. For example, drought in the West at the turn of the 21st century led to a shortage of irrigation water. In 2001, this lack of water for irrigated production reduced potato yields in California by 70% and in Oregon by 32%. The past two decades have been marked by a significant number of serious floods in the Midwest. Flooded fields are often abandoned; when tubers are harvested from flooded fields, disease pressure in storage increases and storage quality suffers. In 1993, 50,000 acres of potatoes in the Red River Valley were abandoned due to flooding.

Temperature is the second most significant environmental production constraint. Spring frost damage in the West in 1985 led to the loss of 10,000 acres. Excessive heat during the production season impacts both yield and quality. Heat at harvest is a problem because tubers cannot be cooled immediately in storage facilities. In 1992, warm fall temperatures resulted in large reductions in marketable yield in Maine due to storage losses. Finally, severe disease causes large yield reductions, as seen by tuber breakdown in the East in 1994, late blight in the West in 1995, and PVY in the West in 2007.

As a tuber crop, potato is vulnerable to losses due to disease and physiological stresses alike. Losses in marketable yield because of dehydration and respiration in storage are commonly 5% or more. In addition, potatoes that do not meet market standards due to bruising, greening, sprouting, and tuber disease are counted as losses. Average harvest loss, based on 2008-2012, ranged from 32.6% in North Dakota to 10.8% in Wisconsin.

Climate change predictions indicate that increasing temperatures and decreasing water availability will result in a substantial worldwide potato yield reduction of up to 32% by 2050 (Schafleitner et al., 2011). Severe threats in the Andes and Mexico, where most of the wild potato species are found, include mining, overgrazing, expansion of exogenous livestock (such as pigs and goats), deforestation, expanding agriculture, and general habitat loss. The regions under greatest threat to cultivated potato and their wild relatives include the tropical highlands of South America, Asia and Africa, and parts of southern Africa.

2.3.3. Production/demand (inability to meet market and population growth demands)

The average US consumer has little concern about the price and quality, or availability of potatoes; most consumers are unaware of the major new late blight problem that emerged in 2000. To make potato profitable for farmers and a sustained vehicle for nutrient delivery to US and world consumers, we must maintain and expand demand. This can be done by shifting some of the historic emphasis on industry/production-oriented interests to consumer-oriented interests. However, it is industry that most understands and appreciates the value of germplasm and is a focused advocate for public support of germplasm. This emphasizes the increasing importance of consumer education.

2.3.4 Dietary

<u>Positive attributes:</u> The potato produces more food energy and food value per unit of land area than any other major crop. This is particularly notable, given some estimate that crop yields must double by 2050 to meet demand and provide global food security. Importantly, potatoes are

affordable and within reach of the economically disadvantaged. A recent study reported that of 98 vegetables studied, potatoes and beans provide the most nutrients per dollar. Potatoes are versatile, store better than many fresh vegetables and have a universally acceptable flavor. The potato is the most popular vegetable in the US with an annual per capita consumption of 111 lb. Since consumers eat potatoes more frequently and in greater quantities than other vegetables, improvements in nutritional composition can have a particularly large impact on the American public's nutritional status. Consequently, there is considerable potential to develop the potato as a functional food with health-promoting or disease-preventing properties beyond its basic food energy value. Cultivated and wild relatives have been reported to be good sources of variability for starch properties, antioxidants, anti-cancer compounds (Jansen et al., 2001; Reyes et al., 2005; Brown et al., 2007; Reddivari et al., 2007; Rosenthal and Jansky, 2008; Nzaramba et al., 2009; Fajardo and Jansky, 2012; Robinson et al., 2018). Potato is a major source in the US diet of vitamin C and potassium, and other essential nutrients. Very importantly, potato has a very high satiety index per calorie (see Appendix). With potatoes being a rich source of potassium, potatoes are being promoted as a good choice to fuel the demands of athletes (www.potatogoodness.com/performance).

Negative attributes: Potato researchers tend to emphasize the potential benefits of potato nutritional improvement, but a balanced assessment must also recognize the need to work on problems, real or perceived. While there is little argument that fries and chips are attractive as comfort foods, they are also regarded as iconic junk foods due to their fat and salt content. The low-carb fad of the mid-2000s has subsided, but research continues to recommend carb limitation for weight loss and other aspects of improved health. Public media outlets continue to report research findings that cast potato in the role of an unhealthy food. A major question will be how potato supporters respond to reports that carbohydrate-rich foods cause or exacerbate health problems. A negative perception of complex carbohydrates is not shared by all researchers, and this is a contentious issue in the health field. Notably, the WHO and FAO recommend 55-75% of daily calories come from complex carbohydrates, the type found in potatoes. Papers extant in the scientific literature support a strong case for the nutritional importance of potatoes. A recent issue of the American Journal of Potato Research contains 16 articles on 'The Contribution of Potatoes to Human Nutrition' (vol. 96, number 2).

Potatoes can be cooked in ways that mitigate their nutritional value. French fries and potato chips, which constitute a large percentage of consumed potatoes, are hard to defend on a nutritional basis. An increased emphasis on low-calorie potato dishes may sustain the industry; there is risk in having too large a percentage of sales as fries and chips. In the midst of the global obesity epidemic, the potential for major paradigm shifts exist. If sales of French fries and chips decline, grower's risk is magnified by the lack of potato germplasm diversity. This is one rationale for increasing development of fresh market potatoes.

Nutritional ideas are often refined or even reversed, so research reports that cast potato in a negative light are not conclusive or applicable to every situation. We do recognize that such reports which pointedly claim potatoes as having serious dietary effects as opposed to the positive effects observed from other vegetables (e.g., Skuladottir et al. 2006), do exist.

Potato is a starchy energy food. There is little doubt that the dietary needs of the 2/3 of the US population who are overweight or obese do not include accessing more caloric energy. If we count potato as belonging in a list of 28 common vegetables, it is in the company of sweet corn, sweet potato, and peas that have at least twice the calories per 100 grams (raw) as most other common vegetables (see Appendix).

Potatoes are infamously listed as one of the "dirty dozen" fruits and vegetables for pesticide contamination (Environmental Working Group 2010), but less known are scholarly publications that quantify actual pesticide exposure from potatoes and find it to be negligible (Winter and Katz, 2011).

Browning is an important part of the popular taste of processed potato products, but also the source of the toxin/carcinogen acrylamide, which forms in toasted foods when asparagine and sugars come together at high temperature and pH (Bethke and Bussan 2013; Felton and Knize 2006).

Carbohydrates are reputed to be addictive, impeding weight loss (Spring et al. 2008). They also have been associated with advanced glycation endproducts (AGEs) from processed carbohydrates (Negrean et al. 2007; Elliot 2006), diabetes (Nettleton 2009, Cordain 2005), inflammation, weight gain (Mozaffarian et al. 2011), neurological and cognitive degeneration (Perlmutter 2013), and premature death (Gonzalez et al. 2008; Menotti et al. 1999).

The challenge will be to use germplasm for breeding and research to prove that the benefits of potato consumption outweigh the risks. These research outputs will support that goal:

a. remove undesirable anti-nutrients and pesticide residues

b. enhance current positive components

c. discover and enhance new positive components

d. develop healthy, palatable, easy to prepare potato products

e. educate consumers on potato as a part of a well-balanced diet

f. improve and increase public awareness of the health benefits of potato consumption

2.3.5. Accessibility (inability to gain access to needed plant genetic resources because of phytosanitary/quarantine issues, inadequate budgets, management capacities or legal restrictions)

The CGC does not see germplasm access as a major limitation. The genebank already has easily available diverse material, far more diverse than researchers and breeders currently have time, money and expertise to test and deploy. The challenge of fully staging USPG germplasm for evaluation and pre-breeding is a daunting job. Success will come from rapid progress dependent on new, more powerful tools and techniques, DNA-based and otherwise, to evaluate these diverse materials and incorporate them into market-acceptable selections. New concepts in genomic techniques are being evaluated at this time by various breeding programs across the U.S. to improve breeding efficiency and to track gene introgressions. Reinventing potato as a diploid crop can promote increased use of available germplasm at the genebank.

Special permits and careful testing by federal quarantine facilities in Beltsville MD are required to bring new potato acquisitions into the US. From the perspective of USPG and total allelic diversity, the importing of new accessions has not been limiting due to the wealth of diversity already maintained, the efficient management of Dr. Ronald French of the importing and quarantine process, and the blocking of collecting expedition imports from Latin America.

Accessibility and preservation of exotic potato germplasm is secured by a 41% overlap of the holdings of the 8 major world collections, as shown in Figure 2, below:

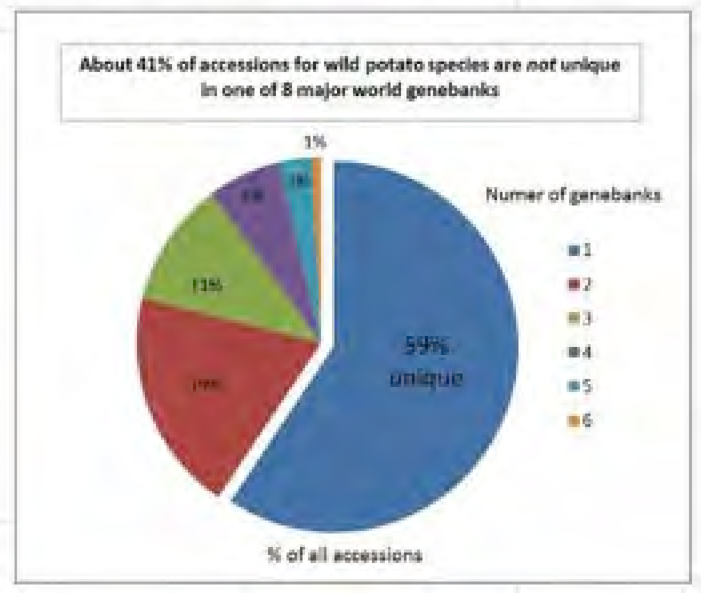

Figure 2. Percent of unique accession holdings by eight major international genebanks. Source: Intergenebank Potato Database (see USPG website)

3. Status of plant genetic resources in the NPGS available for reducing genetic vulnerabilities

3.1 Germplasm collections and in situ reserves

USPG has been the beneficiary of donations from collection expeditions by such well-known potato germplasm explorers as Hawkes, Ochoa, Okada, Tarn, Hoopes. Since 1987, the USDA has provided the USPG with a staff scientist responsible for taxonomy and collections. Dr. David Spooner collected potato germplasm extensively in Latin America resulting in additions to the genebank and numerous publications on the taxonomy and germplasm value of these findings (see http://horticulture.wisc.edu/faculty-profiles/spooner_publications/).

We assume that most major species have been collected. However, assessment of the representativeness of the diversity captured is relative and subjective. However, potatoes often grow wild in remote areas, and in regions where a multitude of tiny niches could permit potatoes to grow in small colonies; all of which have surely not been discovered. Little is known about the relative diversity richness by location. The representativeness of a single sampling of a population in one point in time has not yet been verified. For example, diversity held in soils as as seeds or tubers is difficult to collect efficiently See the Appendix for a summary of research and insights on these topics, based on US collection activities.

We assume that climate change, non-native grazing animals, competition from introduced plants and other human pressure have a negative impact on exotic populations. Thus, we assume that efforts to capture diversity *ex situ* before it is lost forever is a high priority. New geospatial analysis tools and climate change models now available can assist in identifying sites most at risk for prioritization; USPG staff are pursuing this work.

3.1.1 Holdings

Details of the USPG holdings are fully documented and open for public view and purchase in GRIN. The collection includes about 5,000 botanical seed populations of wild and cultivated species, and about 900 clonal stocks kept and distributed *in vitro*. The number of populations per species varies widely and is listed here: https://www.ars.usda.gov/midwest-area/madison-wi/vegetable-crops-research/people/john-bamberg/bamberg-lab/.

The NRSP6 Technical Advisory Committee has long believed that it is most practical for a potato genebank to preserve genes rather than genotypes. This is true to the extent that the stocks we have will not be used as the intact genotype, but rather in crosses. Moreover, if the genotype has current value for cultivation, we may rely on its secure preservation and availability in several state seed certification organizations or other public domestic and foreign collections. However, our sister genebank, the International Potato Center, CIP, in Lima Peru also has emphasized maintaining the intact genotypes of primitive Andean cultivars. The global value those clones have is being preserved by CIP, and need not be duplicated at USPG, which has >1,000 populations of botanical seeds representing the genetics of the clones held by CIP.

3.1.2 Genetic coverage and gaps

A gap analysis in potato would help to determine the extent to which germplasm resources are assembled and conserved in major genebanks. Such an analysis would compare the natural range of wild relatives with that documented in genebank inventories. Results of an analysis would direct efforts to expand collections that are under-represented in *ex situ* genebanks (Maxted et al., 2008; Ramírez-Villegas et al., 2010). A team at the International Center for Tropical Agriculture (CIAT) is working on a gap analysis on potato wild relative, in coordination with International Potato Center (CIP) and the Global Crop Diversity Trust. Additional collection priority criteria, such as threats to wild populations for example from, mining, urbanization, overgrazing, or climate change, and degree of relatedness of taxa to cultivated species, could be included in the analysis when data are available. To develop a more complete picture, the analysis would be coupled with an assessment of perceived *in situ* conservation status, for example, in parks and other protected areas.

Some empirical evidence is available from activities of USPG staff who have explored, collected, and studied potato extensively for over 20 years in a small part of its natural range, the five southwestern US states in which potato is native (see Appendix). Despite the small size of this area, new diversity and new information about collecting strategies and population dynamics continue to emerge. Our knowledge about where potato exists, how much genetic value it has, and how vulnerable it is in Latin America is very likely incomplete.

3.1.3 Acquisitions

The US genebank acquires stocks by donation from collectors, exchange with other genebanks, collections by genebank staff, and subsets of germplasm already extant in the USPG identified or developed by genebank staff and research cooperators.

3.1.5 Maintenance

At this time, facilities, staff and funding are sufficient to support a maintenance program at USPG to ensure the preservation of secure, viable, disease-free, accurately-documented botanical seed populations and *in vitro* clones.

3.1.5 Distributions and outreach

USPG has the goal to fill orders for breeding materials within one week of receipt. However, *in vitro* orders in long term storage must be subcultured and grown out on rapid-grow media prior to distribution. Requests for materials from non-professionals are limited, since wild and primitive cultivated potato is not very suitable for eating, and one or two plantlets *in vitro* are not an attractive form for the home gardener. However, we try to avoid saying "no" to any request, since there is value in encouraging appreciation of genetic resources among the general gardening public and educators.

Germplasm technical advice is another type of distribution. USPG staff are involved in a broad array of germplasm research topics, participate in local, national and international potato research conferences, interact with potato breeders and researchers, and participate in potato research publication. The USPG website posts CVs of its staff under “professional links,” for greater detail about these activities. These activities enable USPG staff to provide germplasm selection and technical advice to requesters. Through this activity, staff can recommend an alternate germplasm when the bank does not have precisely the germplasm requested.

USPG "distributes" custom service to research collaborators and others as resources permit. These extended services are summarized in Figure 3.

Genebank evaluation role:

Helping cooperators by designing & creating custom materials

- ✓ Representative pops within a core set of species
- ✓ Bulk pops within elite species
- ✓ Fine (genotype-level) screen within elite pops
- ✓ Discovery or synthesis of pops with highest, pure expression of trait
- ✓ Make wide F_2 for genetics, physiology, associated marker identification
- ✓ Cross into adapted background (pre-breed)

Figure 3. A summary of extended services offered by USPG staff to further potato breeding activities.

3.2 Associated information

3.2.1 Genebank and/or crop-specific web site(s)

All USPG passport and evaluation data is available on GRIN with convenient links from the genebank website (https://www.ars.usda.gov/midwest-area/madison-wi/vegetable-crops-research/people/john-bamberg/bamberg-lab/). The USPG website offers links to the websites of other world potato genebanks and other potato germplasm sites of interest.

An inter-genebank potato database for wild species contains records from seven potato genebanks (Huaman et al., 2000). The database is hosted by CIP and can be found online at http://germplasmdb.cip.cgiar.org.

3.2.2 Passport information

As for most crops, old passport data for potato often lacks detail and accuracy. But the completeness and accuracy of provenance data for USPG in GRIN is generally good.

3.2.3 Genotypic characterization data

USPG holdings are being fingerprinted or barcoded. Extensive DNA-based testing has resulted in species taxonomy.

3.2.4 Phenotypic evaluation data

As noted above, potato is a major, high-value US crop; many specialist researchers have devoted their careers to its improvement and value. Since its beginning in 1948, the USPG has gathered data from formal and informal research originating in-house, with specialist cooperators, or from the applicable published potato research literature. This data covers disease, pests, stresses, quality, mutants, crossing behavior and other basic biological features. A list of descriptors is available at GRIN as linked from the USPG website.

3.3 Plant genetic resource research associated with the NPGS

3.3.1 Goals and emphases

The major goals of NPGS research on exotic potato include species boundary detection and management, within-species diversity and core collection evaluation for common economic traits, exploration and preliminary characterization of new traits, with an emphasis on human nutrition, technologies to enhance germplasm management efficiency and promote its use, detection and management of potential threats to loss of diversity in the genebank, and benefit sharing through cooperative work with Latin American germplasm donor countries.

3.3.2 Significant accomplishments

At the "Administrative Reports" link of the USPG website, readers will find Annual Reports from 1997 to present, which summarize such accomplishments as distributions, research publications, and impact of germplasm use expressed as released cultivars. This link also provides project renewal/report documents, each summarizing accomplishments at 5-year intervals.

3.4. Curatorial, managerial and research capacities and tools

3.4.1 Staffing

The "STAFF" link on the USPG website lists and describes specialties of research personnel. In brief: Spooner is responsible for taxonomy, collecting and herbarium. Jansky is responsible for evaluation and enhancement. Bamberg is responsible for curator service, and, with Dr. A. del Rio, research on within-species diversity, USA collecting methods, genebank technology, DNA marker-based diversity management. Many student and specialist collaborators from Wisconsin, other states, federal, and international facilities also contribute.

3.4.2 Facilities and equipment

The home genebank site is near Sturgeon Bay, WI and is a longstanding guest project on the University of Wisconsin Peninsular Agricultural Research Station (PARS). The State of Wisconsin owns all facilities and provides structures, utilities and general farm support. USPG occupies 10 greenhouse compartments, four large screenhouses, a seed extraction and order processing laboratory, a tissue culture and disease testing laboratory, administrative offices, and accompanying sufficient storage, refrigerators, freezers and workspaces.

3.5 Fiscal and operational resources

USPG is supported by a USDA/ARS federal CRIS project budget, the NRSP6 multistate project, University of Wisconsin Department of Horticulture and PARS infrastructure and utilities, industry gifts, and ad hoc grants. Full budget details are available on "Administrative Reports" link of the USPG website.

4. Information on other genetic resource capacities (germplasm collections, *in situ* reserves, specialized genetic/genomic stocks, associated information, research and managerial capacities and tools, and industry/technical specialists/organizations) is provided in the text.

5. Prospects and future developments

Germplasm is expected to increase in use and value.

<u>Society, economy, health, international relations</u>. The future impact of health on the national economy and human wellbeing cannot be overstated. Potato is a powerful delivery system for nutrition and a key component of health; germplasm has much to contribute. Advances in medical knowledge will point the way to potato germplasm-use opportunities by more clearly identifying gaps in human nutrition. Potato germplasm could provide powerful benefits to US international relations. US germplasm workers are addressing problems most pertinent in developing countries, including micronutrient and vitamin deficiencies, and frost tolerance. These outreach and sharing functions improve international relations, and are a specific argument for free international exchange of germplasm.

<u>Data storage and software continues to improve.</u> Thus, more logical and complete storage of USPG germplasm data will be facilitated, and easy, universal internet access will be expanded. This is expected to greatly advance potato science by helping specialists recognize the value and availability of USPG stocks that precisely fit their research objectives.

<u>Technology for germplasm evaluation is racing forward.</u> Improvements in data storage and software will make it more practical for researchers to order and successfully survey large blocks of USPG germplasm which have not yet been evaluated. Expression of traits in exotics, even if not used in cultivars, can have value as tools to discover the genetic and physiological bases of those traits.

<u>Technology for breeding is rapidly advancing.</u> New molecular tools like the SolCap SNPs, polyploid mapping tools, genomic selection tools developed by various researchers in the U.S. and other countries will make selection of improved cultivars faster, cheaper and better. These molecular and genomic tools will also improve understanding of the partitioning of general genetic diversity in the genebank and reveal which techniques best counter vulnerabilities to maximize germplasm preservation.

Genetic tools, like USPG collaborator Simplot's Innate technology promises consumer acceptance of a higher quality product grown with less inputs and pesticides. This technology will genetically improve the processed forms of existing popular cultivars without introducing foreign DNA. This is a step toward the goal of efficiently transferring useful genes from exotics into existing cultivars on a consumer-accepted platform. Biotechnology also has the potential to contribute to producer efficiency, particularly though increased resistance to disease and insect pests including late blight, potato virus Y and Verticillium wilt. Wild relatives of potato may provide functional genes incorporated into transgenic lines.

Positive consumer interest and education in any form is a powerful force for change when tied to current nutritional controversies. Foods with greater variety and quality, grown with safe, sustainable means, with positive social, economic and environmental impacts are potential selling points. These outcomes could promote genetic improvements leveraged by genebank germplasm. The example of the ubiquitous ornamental sweet potato developed by C. Yencho and associates at North Carolina State University suggests that ideas for creative innovations like ornamental potato should not be quickly dismissed as trivial. Wild potato germplasm is being evaluated for their ornamental value at the potato genebank.

New products and outlets for potato will develop, like that of USPG cooperator Kemin Industries, maker of an appetite-reducing potato protein extract which addresses the national obesity epidemic (at >$152B = >20% of annual healthcare). USPG supporter Frito-Lay put their Doritos shell on a Taco Bell taco, resulting in 2012 sales of over 1M units per day, and requiring the hire of >15,000 additional employees. Are there similar creative new outlets for potato products? For example, grain starches dominate the lucrative processed sweetened breakfast cereal market (>$11.5B), whereas potato products are not represented at this time.

Rapid, reliable, disease-free propagule generation currently limits the industry; are required to develop adequate numbers of potentially elite clones to prove in large-scale production-relevant tests. USPG cooperator Controlled Environment Technology Systems (CETS) promises to revolutionize potato propagation, facilitating the rapid deployment of enhanced lines bred using genebank stocks.

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Appendix:

USDA National Nutrient Database for Standard ReferenceRelease Legacy

Nutrients: Energy (kcal) ; Fiber, total dietary (g) ; Protein (g)

Food Groups: Vegetables and Vegetable Products
Food Subset: Abridged List
Ordered by: Nutrient Content
Measured by: 100 g
Report Run at: July 20, 2018 12:14 EDT

NDB_No	Description	Energy(kcal) Value Per	Fiber, total dietary(g) Value Per	Protein(g) Value Per
11378	Potatoes, mashed, dehydrated, flakes without milk, dry form	354.00	6.60	8.34
11284	Onions, dehydrated flakes	349.00	9.20	8.95
11982	Peppers, pasilla, dried	345.00	26.80	12.35
11237	Kanpyo, (dried gourd strips)	258.00	9.80	8.58
11364	Potatoes, baked, skin, without salt	198.00	7.90	4.29
11048	Beans, pinto, immature seeds, frozen, unprepared	170.00	5.70	9.80
11406	Potatoes, french fried, cottage-cut, salt not added in processing, frozen, as purchased	153.00	3.00	2.42
11215	Garlic, raw	149.00	2.10	6.36
11450	Soybeans, green, raw	147.00	4.20	12.95
11451	Soybeans, green, cooked, boiled, drained, without salt	141.00	4.20	12.35
11196	Cowpeas (blackeyes), immature seeds, frozen, cooked, boiled, drained, without salt	132.00	6.40	8.49
11039	Lima beans, immature seeds, frozen, baby, unprepared	132.00	6.00	7.59
11361	Potatoes, roasted, salt added in processing, frozen, unprepared	127.00	2.60	2.22
11316	Peas, mature seeds, sprouted, raw	124.00	--	8.80
11032	Lima beans, immature seeds, cooked, boiled, drained, without salt	123.00	5.40	6.81
11383	Potatoes, mashed, dehydrated, prepared from granules with milk, water and margarine added	116.00	1.30	2.13
11211	Edamame, frozen, unprepared	109.00	4.80	11.22
11647	Sweet potato, canned, syrup pack, drained solids	108.00	3.00	1.28
11381	Potatoes, mashed, dehydrated, prepared from granules without milk, whole milk and butter added	108.00	2.20	2.05
11037	Lima beans, immature seeds, frozen, fordhook, unprepared	106.00	5.50	6.40
11040	Lima beans, immature seeds, frozen, baby, cooked, boiled, drained, without salt	105.00	4.80	6.65
11379	Potatoes, mashed, dehydrated, prepared from flakes without milk, whole milk and butter added	97.00	0.80	1.77
11192	Cowpeas (blackeyes), immature seeds, cooked, boiled, drained, without salt	97.00	5.00	3.17
11356	Potatoes, Russet, flesh and skin, baked	95.00	2.30	2.63
11875	Sweet potato, cooked, baked in skin, flesh, with salt	90.00	3.30	2.01
11191	Cowpeas (blackeyes), immature seeds, raw	90.00	5.00	2.95
11178	Corn, sweet, yellow, frozen, kernels cut off cob, unprepared (Includes foods for USDA's Food Distribution Program)	88.00	2.10	3.02
11372	Potatoes, scalloped, home-prepared with butter	88.00	1.90	2.87