Potato Crop Germplasm Committee
Vulnerability Statement 2014

Bullet potato crop and germplasm points

1. Top US vegetable at ~$4B/y production value
2. High but declining US consumption of ~110 lb/y/cap
3. Extremely productive crop, at up to 25T 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 60% processed (fries and chips) : 40% 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 (fed, state, private) and much knowledge base
15. Material resource: broad germplasm base in genebanks, but much more potential in wild
16. Germplasm well backed up at USPG and in international genebanks and 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.
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) needing efficiency gains
23. Among first in *in vitro* tech, but major molecular breeding resources recently developing
24. GMO-prohibited in US, except possible recent "intragenic" breakthrough approach
25. Low food-borne illness potential since always cooked and often fried dry.
26. Improvements should provide advantages for producers *and* consumers.
27. Opportunities may exist in consumer preferences for diversity, less prep time, nutrition.
28. Advances that benefit Latin American crop serve as value exchanged for germplasm
29. Website of US Potato Genebank/NRSP6 links to much germplasm and research info

Summary

Potato is the third most important food crop worldwide and the most important vegetable crop in the US Production has remained steady in recent years, with yields per acre increasing but production area decreasing in order to match demand. 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. The development of potato varieties with greater resistance to pests and pathogens is necessary for the potato industry and for rural America. In addition, research efforts in the near should focus on abiotic stress resistance. Global climate change models predict a decrease in potato yields throughout much of the US mainly due to warmer temperature throughout the growing season. The development of heat tolerant varieties is expected to increase yields by 5% in most regions. Consequently, potato farmers will likely benefit if breeders add heat tolerance to their selection criteria. If irrigation water becomes less available and rainfall becomes more sporadic, it will also be important to improve water use efficiency in potato. Finally, potato breeders will need to develop cultivars with higher nitrogen use efficiency in order to offset the increasing cost of nitrogen fertilizer and minimize the contamination of 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 can be used by breeders to improve heat tolerance, drought tolerance, and nitrogen use efficiency (Reynolds and Ewing, 1989; Errebhi et al., 1999; Cabello et al., 2012). In addition, the tightening of environmental regulations and emergence of new pests and pathogens will likely increase the value of resistance to the potato industry. Systematic efforts are needed survey genetic diversity in potato relatives and efficiently identify sources of valuable traits.

The sequencing of the potato genome in 2011 opened new opportunities to utilize genomics for potato improvement (Xu et al., 2011). The USDA-funded SolCAP project has provided abundant genomics resources to potato breeders. It is leading 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 conclusions of higher level of homozygosity than expected (Massa et al., 2013). These need confirmation. It is imperative to continue genomics analyses that will reveal underlying genetic diversity in wild species and 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 providing germplasm resources, but also a research center to advance understanding of genetic diversity, when USPG and other NPGS genebanks have been very active in such research for many years.

All potential benefits that are, at least initially, producer-oriented, will be moot if *consumers* do not continue to appreciate potato as a food in rich societies like the US where they have a choice. Thus a key to maintaining demand will be to use germplasm to improve potatoes in a way that is obvious to the end user. Price and availability are not a big issues for US consumers, but

negative and positive nutritional factors are. More sustainably-grown and low pesticide potatoes would be more attractive to some consumers, perhaps an increasing number. Variety in taste and appearance may be, as society becomes more "foodie" and finesse cooking oriented. There is likely an untapped niche market for ethnic potatoes to satisfy the particular tastes of (for example) Latin American 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 (we would not want an already overweight population to do 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 bluntly mentioned, perhaps because government also vigorously promotes our cereal competitors. Thus, the question: How much should public potato market promoters advertise reports of the negatives of competitors-- for example, reports claiming widespread and significant negative health impact from eating gluten?

This is a *vulnerability* statement, so the most basic threats related to germplasm availability, habitat destruction, genetic uniformity, etc., 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 (backed up) at the Ft. Collins, CO repository and in other world collections, restoring full genebank function would involve a slow and expensive recovery, probably requiring temporarily abandoning non-critical (but important) genebank services. For the industry, the biggest acute threat is from precipitous loss of potato food reputation, perhaps by terrorist rumors. But excepting "On Her Majesty's Secret Service" (Fleming 1963), the potential of agricultural terrorism does not seem to have much popular recognition. Never the less, we do see that the loss of reputation in things like ground beef and sprouts can be a virtual overnight disaster for these products.

The mid-level chronic treat to the industry would be growing consumer awareness of some specific negatives like acrylamide that could subconsciously make potato chosen less often. However, many consumers may be suffering from nutritional information overload, such that they adopt a fatalistic, cynical attitude about the ability to avoid nutritional threats. *The Week* newsmagazine, for example, carries a feature entitled "Health Scare of the Week" which seems to imply that the observant consumer is jaded by alarms on a regular basis. Will this effect protect potato from bad press?

The long term threat to the industry and the supporting value of potato germplasm is a gradual loss of consumer preference for potato foods. As healthcare becomes limiting, it seems likely that more consumers will become increasingly concerned with lifestyle-based approaches to disease prevention. Potato currently does not have a reputation as a health food for most people. We will want to be vigorously generating germplasm news and products that demonstrate that potato is a progressive vegetable, enhancing its nutritional strengths and minimizing its nutritional weaknesses, improving its reputation as a choice in harmony with 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 north temperate regions of the world. Land races in South America range in ploidy from diploid to pentaploid. Most tetraploid and diploid wild and cultivated relatives are either self-incompatible or suffer greatly from inbreeding depression, so a uniform commercial crop is almost exclusively accomplised by clonal propagation, with tuber pieces serving as "seed". Botanical seed propagation has been pursued for a long time for the benefit of a propagule with much less disease transmission, perishability, and transport cost.

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 at altitudes of 2,000 to 4,000 m. They are adapted to a much wider range of habitats than the cultivated potato and are found in a diverse array of environments, including the cold high grasslands of the Andes, hot semi-desert and seasonally dry habitats, humid subtropical to temperate mountain rain forests, cultivated fields, 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 lines (Hermundstad and Peloquin, 1985, 1986; Jansky et al., 1990; Peloquin et al., 1991). Consequently, extensive backcrossing 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 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 CWR have been prominently used (Maxted et al., 2012). However, despite all these apparent advantages, success is really 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 lines. Breeders' major focus is on intercultivar cross selection, not experimental exotic hybrids. Progress is encumbered by several generations of ploidy manipulation and evaluation, failed crosses, and limited by male fertility.

1.3 Primary products and their value (farmgate)

Cultivar development in potato focuses on market classes, each with different target properties. 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 used in the fresh market and are typically in the early maturity class. Specialty potato varieties, including fingerlings and colored flesh potatoes, are found in a small but growing market share.
Until the explosive increase in out-of-home meals, especially in the "fast food" restaurant, 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 potato crop has been used for processing, mainly frozen, chip, and dehydrated products. Processors pay a premium for high specific gravity (dry matter content) (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 (Malone et al., 2006). Production value is about $4 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 2012 was 21,182,800 t, grown on 516,357 ha.

Most potatoes are produced in the western states and harvested in the fall. The highest production is in Idaho, Washington, Wisconsin, North Dakota, Oregon, and Colorado (listed in order of total production, based on 2012 data). The fall crop in these six states accounted for 73% of the total US production in 2012. 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 is available from the National Potato Council: http://www.nationalpotatocouncil.org/potato-facts/

1.4.2 International

China is the world's largest producer of potatoes and production is expanding in order to enhance food stability (Jansky et al., 2009; Scott and Suarez, 2012). Other major potato producing countries include India, Russia, Ukraine, and the US Colorado (listed in order of total production, based on 2010 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 with 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 did 30 years ago.
Most yield improvement has resulted from 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 in terms of increased marketable yield and improved tuber quality. In the future, it seems likely that genetic improvement will make a greater contribution to productivity increases, but only if growers, processors, and consumers adopt new varieties.

2.2 Threats of genetic erosion *in situ*

[See also treatment of this topic in section 3.1]

The ecosystems in which potato wild relatives grow are becoming unstable 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 if one makes the reasonable assumption that the most rare and unsampled taxa tend to be those less related to *tuberosum* and thus with less potential for use, and more problematic in all aspects of genebank preservation. While collecting expeditions should focus on adding to the genetic diversity that is already 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). Despite a longstanding vigorous program of genetic diversity and collecting research at USPG (see Appendix for publications) more research in this area is needed.

A considerable challenge with the collection of potato wild relatives is that they are often 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 in order to become viable new land race varieties. We can learn 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, 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 a number of 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 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 disease 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.).

2.3.2 Abiotic (environmental extremes, climate change)

Water problems are the most prevalent environmental production constraint for potato 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. Drought obviously 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 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 because 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 sufficiently cooled 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 large losses due to both disease and physiological stresses. Losses in marketable yield as a result 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 data available from 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 both 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 habitat loss in general. The regions under greatest threat to crops and their wild relatives overall 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, considering that most consumers are not even aware of the major new late blight problem that hit about 15 years ago. To make potato profitable for farmers and sustained as a vehicle for nutrient delivery to the US and world consumers, we need to 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, the industry most understands and appreciates the value of germplasm, so is a focused advocate for public support of germplasm. This line of thought leads one to the conclusion that consumer education will be increasingly important.

2.3.4 Dietary

<u>Plus</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 yield will have to double by 2050 to meet demand and provide global food security. Importantly, potatoes are affordable, putting them within reach of the economically disadvantaged. A recent study reported that potatoes and beans provide the most nutrients per dollar out of 98 vegetables studied. Potatoes are versatile, store better than many fresh vegetables and have a universally desirable flavor. The potato is the most popular vegetable in the US with an annual per capita consumption of 110 lb. Since consumers eat potatoes more frequently and in larger quantities than other vegetables, improvements in nutritional composition can have a particularly large impact on the American

public's diet. Consequently, there is considerable potential to develop the potato as a functional food with health-promoting or disease-preventing properties beyond the basic function of supplying nutrients. 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). Potato is a major source of vitamin C and potassium, and other essential nutrients in the US diet. Very importantly, potato has a very high satiety index per calorie (see Appendix).

<u>Minus</u>: 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 often regarded as an icon of "junk food" due to 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 make news of research findings that make potato sound like an unhealthy food. A major question will be how potato supporters respond to reports that carb 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 carbohdrates, which are the type found in potatoes. A strong case can be made for the nutritional importance of potatoes with numerous scientific papers in support. On the other hand, as with most foods, potatoes can be cooked in manners that mitigate their nutritional value. French fries and potato chips can be much harder to defend nutritionally and constitute a large percentage of consumed potatoes. Consequently, an increased emphasis on low-calorie potato dishes may be important for sustainability of the industry and there is risk in having too large a percentage of sales in the forms of 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 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 necessarily conclusive or applicable to every situation. But we do recognize that such reports exist, which pointedly claim potatoes as having serious dietary effects in the context of positive effects observed from other vegetables (e.g., Skuladottir et al. 2006).

Potato has a historic reputation as a starchy energy food, and there is little doubt that the dietary needs of the 2/3 of US individuals who are overweight or obese do not include getting more energy-- i.e., more calories. If we count potato as belonging in a list of 28 common "vegetables" it falls in the top four (sweet corn, sweet potato, peas, potatoes) 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 which bring together asparagine and sugars at high temperature and pH (Behke and Bussan 2013; Felton and Knize 2006).

Carbs are reputed to be addictive, impeding weight loss (Spring et al. 2008).

Potatoes have been associated with Advanced Glycation Endproducts (AGEs) from processed carbs (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 outweigh the risks by doing these things:

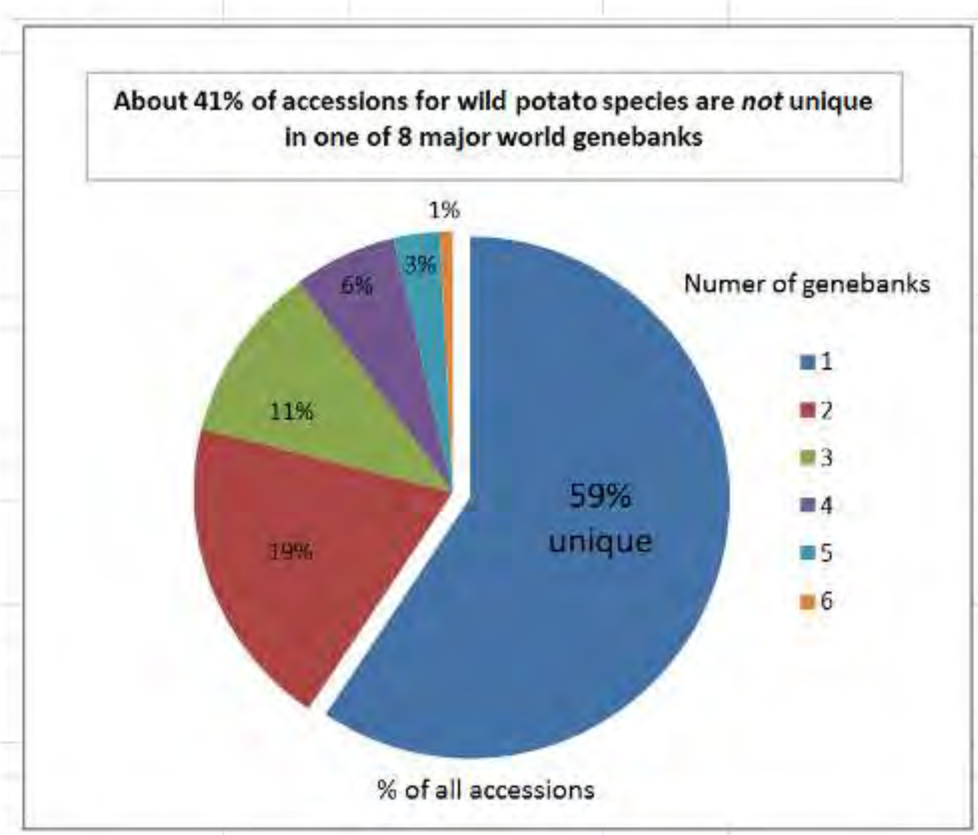
a. remove undesirable the anti-nutritionals and pesticide residues
b. announce and enhance current positive components
c. discover and enhance new positive components

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, readily available, much more diverse material than researchers and breeders currently have time, money and expertise to test and deploy. Bringing the status of information and technology to the point where the USPG germplasm is fully staged for use is a daunting job. So <u>one envisions the prospect for rapid progress depending on new, more powerful tools (DNA-based and otherwise) for evaluation and techniques for breeding</u>.

It is true that all potatoes are listed as import prohibited, meaning that special permits and careful testing by federal quarantine in Beltsville is required. <u>Under the efficient management by Dr. Jorge Abad, however, import bottlenecks have not been a major limitation in recent years. Another reason for the adequacy of import throughput in the past decade is the block of collecting expedition imports from Latin America</u>.

Accessibility and preservation of exotic potato germplasm is secured by about 41% overlap of holding of the 8 major world collections:



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 trips by renowned potato germplasm explorers like Hawkes, Ochoa, Okada, Tarn, Hoopes. Since 1987 USDA has provided USPG with a staff scientist responsible for taxonomy and collecting. Dr. David Spooner conducted extensive collecting in Latin America resulting in germplasm additions to the genebank and numerous publication on their taxonomy and germplasm value (see http://horticulture.wisc.edu/faculty-profiles/spooner_publications/).

We assume that most of the major species have been collected. However, assessment of the representativeness of the diversity captured is relative and subjective. It is also guesswork, since potatoes often grow wild in remote areas, and in regions where there are a multitude of tiny niches where potatoes may grow in small colonies which surely have not all been discovered. Little is know about relative diversity richness in locations. Little is known about the representativeness of a single sampling of a population in one point in time. How much diversity is uncollectable as seeds or tubers in the soil, for example? A summary of research and insights on these topics using USA collecting as a model is provided in the Appendix.

We assume that climate change, non-native grazing animals, foreign plants and other human pressure are having a negative impact on exotic populations. Thus, we assume that efforts to capture diversity *ex situ* deserves high priority. New geospatial analysis tools and climate change models are now available to help us identify which particular sites are most at risk for prioritization, and are being used by USPG staff.

3.1.1 Holdings

Details of the USPG holdings are fully documented and open for public view and ordering in GRIN. The broad-brush picture 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: http://www.ars-grin.gov/cgi-bin/npgs/html/site_holding.pl?NR6.

The NRSP6 Technical Advisory Committee has long held the conviction that it is most often 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 collections domestic and foreign. However, our sister genebank, the International Potato Center, CIP, in Lima Peru has also 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 >1000 populations of botanical seeds representing the genetics.

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. This analysis compares the natural range of wild relatives with that documented in genebank inventories. Results of the gap analysis provide direction for efforts to expand collections that are under-represented in *ex situ* genebanks (Maxted et al., 2008; Ramírez-Villegas et al., 2010). A team at CIAT is working on a gap analysis on potato wild relative, in coordination with CIP and the Global Crop Diversity Trust. Additional collection priority criteria, such as threats to wild populations (for example, mining, urbanization, overgrazing, climate change), and degree of relatedness of taxa to cultivated species, may also be included in the analysis when data are available. In order to include a more complete picture, the method should ideally 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 the natural range, the five SW states in which potato originates in the USA (see Appendix). Even with this concentrated attention to a small area, new diversity and new information about collecting strategies and population dynamics continue to emerge. This makes us conclude that our knowledge about where potato exists, how much genetic value it has, and how vulnerable it is in the much broader expanse of *ex situ* Latin America is probably weak.

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

Facilities, staff and funding are currently able to support a program of maintenance at USPG that will 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 a goal to fill orders within one week of receipt. All orders cannot be delivered that rapidly, since, for example, in vitro orders in long term storage need to be subcultured and grow out on rapid-grow media for distribution. Non-professional distributions are naturally limited due to the fact that 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 requester, since there is value in encouraging appreciation of genetic resources among the general (gardening) public and educators.

Another "distribution" is germplasm technical advice. Staff have some involvement in a broad array of germplasm research topics (see CVs of staff at professional links at USPG website), participate in local, national and international potato research conferences, know the researchers, and participate in potato research publication. The aim of this is to be able to give germplasm-selection and technique advice to requesters. The result of this is that many times when we do not have precisely the germplasm requested, we can recommend an alternate just as useful or even better.

USPG "distributes" custom service to research collaborators and others as resources permit. Extended services are summarized below...

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 (http://www.ars-grin.gov/nr6). USPG website also has 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

Fingerprinting or barcoding has not been done for USPG holdings. Species taxonomy has resulted from extensive DNA-based testing (for numerous detail examples, see staff publications at USPG website, especially those of Spooner).

3.2.4 Phenotypic evaluation data

As suggested above, potato is a major, high-value US crop with many specialist researchers. Thus, since it's beginning in 1948, the USPG has been gathering data from formal and informal research originating in-house, with specialist cooperators, or from the applicable published potato research literature. Traits cover 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

Major goals of NPGS research on exotic potato:

Species boundaries
Detecting and managing within-species diversity and core collections
Evaluation for common economic traits
Exploration and preliminary characterization of new traits, especially nutritional
Technologies to enhance germplasm management efficiency and promote its use
Detection and management of potential threats to loss of diversity in the genebank
Benefit sharing through cooperative work with Latin American germplasm donor countries

3.3.2 Significant accomplishments

The most efficient way to access this information is to follow the "Administrative Reports" link of the USPG website. There the reader will find Annual Reports from 1997 to present, which summarize distributions, research publications, and impact in terms of germplasm use in released cultivars. This link also provides the past three project renewal/report documents, each summarizing accomplishments in 5-year intervals. The one-page "Executive Summary" of the current project term FY11-15 provides a comprehensive general sketch. Here are selected examples:

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. Numerous associates in the form of students and specialist collaborators from Wisconsin, other states, federal, and international also contribute.

3.4.2 Facilities and equipment

The home genebank site is located close to the city of Sturgeon Bay, WI, as a longstanding guest project on the University of Wisconsin Peninsular Agricultural Research Station (PARS). The state owns all facilities and provides structures, utilities and general farming support. USPG occupies 10 greenhouse compartments, four large screenhouses, a seed extraction and order processing lab, a tissue culture and disease testing lab, administrative office, 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, UW Hort Department 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. 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)

Information on these topics is provided in the foregoing text.

5. Prospects and future developments

Germplasm is expected to increase in use and value:

Society, economy, health, international relations. The future impact of health on the national economy and human wellbeing can hardly be overstated. Potato is a powerful delivery system for nutrition, a key component of health, and germplasm will have much to contribute. Advances in medical knowledge will point the way to potato germplasm-use opportunities by showing more clearly what is needed in food. Potato germplasm could provide powerful benefits to the USA in international relations. USA germplasm workers are addressing problems most pertinent in developing countries-- like micronutrient and vitamin deficiencies, and frost tolerance. These outreach and sharing functions promote general improved international relations, are a specific argument for free international exchange of germplasm.

Data storage and software continues to improve. 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.

Technology for germplasm evaluation is racing forward. This will make it more practical for researchers to order and successfully survey large blocks of USPG germplasm which have not yet been evaluated. Note that extreme expression of traits in exotics, even if not used in cultivars per se, can have value as tools to discover the genetic and physiological bases of those traits.

Technology for breeding is rapidly advancing. New molecular tools like the SolCap SNPs, developed by D. Douches at Michigan State and associates, will make selection of improved cultivars faster, cheaper and better. These molecular tools will also be useful for a better understanding of the partitioning of general genetic diversity in the genebank, and revealing which techniques are best to counter vulnerabilities to maximize germplasm preservation.

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

Positive consumer interest and education in any form helps, and is especially powerful when tied to current hot-button issues. Thus, appreciation of food with greater variety and quality, grown by more sustainable means, safe, organic, eco-friendly, family farmer & fairtrade -friendly, reduced CO_2 emission, are potential selling points to be promoted through genetic improvements leveraged by genebank germplasm. The example of the ubiquitous ornamental sweet potato developed by C. Yencho and associates at NC State suggests that ideas for creative innovations like ornamental potato should not be quickly dismissed as trivial.

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 resulted in 2012 sales of over 1M units *per day*, and requiring 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)-- why no potato products?

Rapid, reliable disease-free propagule generation is one current industry limitation, needed for converting suspected elite clones to adequate numbers of plants for proving 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

Contents of *Bamberg, JB and A del Rio. 2005. Conservation of Genetic Resources. In: Maharaj K Razdan and Autar K Mattoo (Eds.), 2005. Genetic Improvement of Solanaceous Crops Vol.1: Potato. Science Publishers, Inc., Enfield, USA, 451 pp.*

1. Conservation of Potato Genetic Resources 1

J. Bamberg and A. del Rio

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Status and dynamics of genetic diversity as related to collecting and sampling

Bamberg & del Rio, updated April 23, 2013

<u>Are populations re-collected many years equivalent to those already in the genebank? No.</u>

A. H. Del Rio, J. B. Bamberg, Z. Huaman, A. Salas, S. E. Vega. 1997 Assessing Changes In The Genetic Diversity Of Potato Genebanks 2. *In Situ* Vs *Ex Situ.* Theor. Appl. Genet. 95(1/2):199-204.

<u>Are eco-geo parameters associated with patterns of genetic diversity? Not for US sp.</u>

AH del Rio, JB Bamberg, Z Huaman, A Salas, SE Vega. 2001. Association of eco-geographical variables and genetic variation in native wild US potato populations determined by RAPD markers. Crop Science 41:870-878.

<u>Are eco-geo parameters associated with patterns of genetic diversity? Not for Bolivian *sucrense*.</u>

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<u>Are eco-geo parameters associated with patterns of genetic diversity? YES for Mexican *verrucosum*</u>.

del Rio, AH and JB Bamberg. 2004. Geographical parameters and proximity to related species predict genetic variation in the inbred potato species *Solanum verrucosum* Schlechtd. Crop Science 44:1170-1177.

<u>Are eco-geo parameters associated with patterns of genetic diversity? YES for cold hardiness.</u>

Hijmans, RJ, M Jacobs, JB Bamberg, and DM Spooner. 2003. Frost tolerance in wild potato species: Assessing the predictivity of taxonomic, geographic, and ecological factors. Euphytica 130:47-59.

<u>Do many rare and vulnerable alleles exist in heterogeneous potato populations? No.</u>

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<u>Could unintentional selection of seedlings for seed increase parents cause genetic drift? In some cases</u>.

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<u>Could unintentional selection of seedlings for seed increase parents cause genetic drift? Not for inbreds.</u>

Bamberg, JB and A del Rio. 2006. Seedling transplant selection does not cause genetic shifts in genebank populations of inbred potato species. Crop Science 46:424-427.

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Are certain insect resistant populations relatively homogeneous and therefore less subject to sampling error? Yes.

Bamberg, J., C. Singsit, A. H. del Rio and E. B. Radcliffe. 2000. RAPD Analysis of Genetic Diversity in *Solanum* Populations to Predict the Need for Fine Screening. Am. J. Potato Res. 77:275-278.

Does high replication of small, poor samples promote resolution of their true relationships? No.

del Rio, A. H. and J. B. Bamberg. 1998. Effects of sampling size and RAPD marker heterogeneity on the estimation of genetic relationships. Am J. Potato Res. 75:275. (Abstract).

Do potato species widely differ in their within-pop heterogeneity, and therefore their potential sampling error? Yes.

Bamberg, JB and AH del Rio. 2004. Genetic heterogeneity estimated by RAPD polymorphism of four tuber-bearing potato species differing by breeding system. Amer J Potato Res 81:377-383.

Can RAPDs efficiently determine the taxonomy and uniqueness of unlabeled accessions? Yes.

del Rio, A. H. and John B. Bamberg. 2000. RAPD markers efficiently distinguish heterogeneous populations of wild potato (*Solanum*). Genetic Resources and Crop Evolution. 47:115-121.

Do wild collections undergo a large genetic change upon its first seed multiplication in the genebank? No.

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Hijmans, R., T. Gavrilenko, S. Stephenson, JB Bamberg, A. Salas and D.M. Spooner. 2007. Geographic and environmental range expansion through polyploidy in wild potatoes (Solanum section Petota). Global Ecol. Biogeogr. 16: 485-495.

Does introgression of proximal species explain the distinction of northern ver in Mexico? No.

Bamberg, JB and A. del Rio. 2008. Proximity and introgression of other potato species does not explain genetic dissimilarity between *Solanum verrucosum* populations of northern and southern Mexico. Am. J. Pot. Res. 85:232–238.

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Bamberg, JB, AH del Rio, Z Huaman, S Vega, M Martin, A Salas, J Pavek, S Kiru, C Fernandez and DM Spooner. 2003. A decade of collecting and research on wild potatoes of the southwest USA. Amer J Potato Res 80:159-172.

Does unbalanced seed bulking of regenerations present a substantial risk of drift? No.

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Does clonal versus seed collecting net different genetics? Yes. Bamberg, J.B., A. H. del Rio and Rocio Moreyra. 2009. Genetic consequences of clonal versus seed sampling in model populations of two wild potato species indigenous to the USA. *American Journal of Potato Research* 86:367-372.

Do proximal "remote" and "easy" collection sites net different genetics? Yes. Bamberg, JB, AH del Rio, CF Fernandez, A Salas, S Vega, C Zorilla, W Roca and D Tay. 2010. Comparison of "remote" versus "easy" in situ collection locations for USA wild Solanum (potato) germplasm. *American Journal of Potato Research* 87:277-284.

Do different Sky Islands differ in their diversity density? Yes. Bamberg, JB and AH del Rio. 2011. Diversity relationships among wild potato collections from seven "Sky Island" mountain ranges in the Southwest USA. *American Journal of Potato Research* 88(6):493-499

Are local diversity predictions validated by follow-up collecting? Yes. Bamberg, JB, AH del Rio and J Penafiel. 2011. Successful prediction of genetic richness at wild potato collection sites in Southeastern Arizona. *American Journal of Potato Research* 88:398-402.

Does unintentional pesticide exposure reduce genetic diversity of wild populations? Likely not. del Rio, Alfonso H., JB Bamberg, Ruth Centeno-Diaz, J. Soto, A. Salas, W. Roca and D. Tay. 2012. Pesticide contamination has little effect on the genetic diversity of potato species. *American Journal of Potato Research* 89:348-391.

Is there evidence that unintentional pesticide exposure could reduce sexual reproduction of wild populations? Yes. del Rio, Alfonso H., JB Bamberg, Ruth Centeno-Diaz, A. Salas, W. Roca and D. Tay. 2012. Effects of the pesticide Furadan on traits associated with reproduction of wild potato species. *American Journal of Plant Sciences* 3:1608-1612.

Related works

Bamberg, JB and A. H. del Rio. 2007. The canon of potato science-- 50 topics in potato science that every potato scientist should know: 1) Genetic diversity and genebanks. Potato Research 50:207-210.

Hijmans, R., T. Gavrilenko, S. Stephenson, J. Bamberg, A. Salas and D.M. Spooner. 2007. Geographic and environmental range expansion through polyploidy in wild potatoes (*Solanum* section Petota). Global Ecol. Biogeogr. 16: 485-495.

Bamberg, JB and AH del Rio. 2011. Use of native potatoes for research and breeding. *Hortscience Proceedings* 46(11):1444-1445.

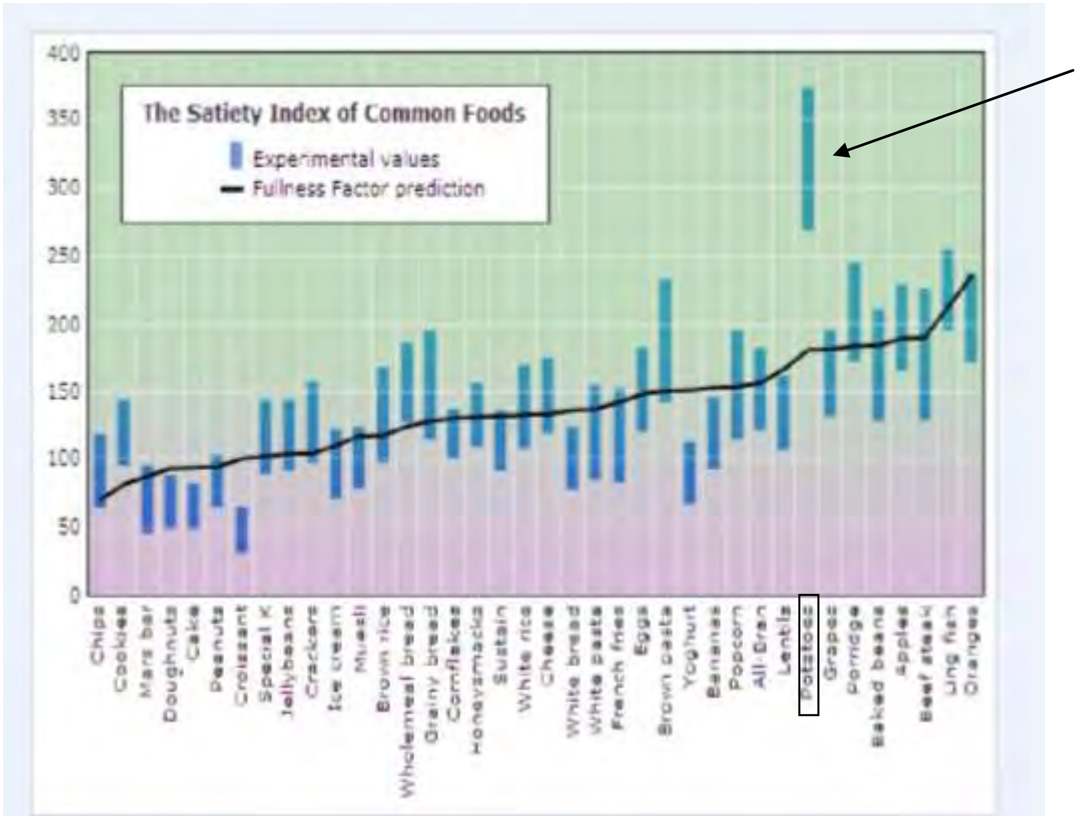
Potato Taxonomic Research generated by genebank staff and associates

See Spooner faculty web page for publications:
http://horticulture.wisc.edu/faculty-profiles/spooner_publications/

Calories of common "vegetables"

Source: USDA National Nutrient Database

NDB_NO	Vegetable (raw)	cal/100g
11167	Corn, sweet, yellow	86
11507	Sweet potato, unprepared	86
11304	Peas, green	81
11352	**Potato**, flesh and skin	77
11080	Beets	43
11098	Brussels sprouts	43
11300	Peas, edible-podded	42
11124	Carrots	41
11282	Onions	40
11863	Squash, winter	37
11090	Broccoli	34
11052	Beans, snap, green	31
11979	Peppers, jalapeno	29
11422	Pumpkin	26
11109	Cabbage	25
11135	Cauliflower	25
11209	Eggplant	25
11457	Spinach	23
11260	Mushrooms, white	22
11011	Asparagus	20
11333	Peppers, sweet, green	20
11529	Tomatoes, red	18
11143	Celery	16
11429	Radishes	16
11695	Tomatoes, orange	16
11054	Beans, snap, green	15
11253	Lettuce, green leaf	15
11206	Cucumber, peeled	12



Potato is much more satisfying than its calorie content would predict

Orientation to Crop Vulnerability Statements v. 2014

Crop vulnerability statements (CVS) communicate periodic assessments of the challenges that crops face, particularly from reduced genetic diversity resulting from genetic erosion. Collections of genetic resources are key mechanism for reducing crop vulnerability resulting from genetic erosion and uniformity, and for supplying crop breeding and research programs with novel traits and underlying genes to satisfy evolving demands.

Crop vulnerability statements will be reviewed as part of the periodic (usually annual, sometimes biennial) Crop Germplasm Committee (CGC) meetings. During the CGC meetings, the crop-specific curators will be encouraged to communicate a status update for the crop germplasm collection along the lines of CVS section 3 (see outline below).

After the CGC meetings, the CVS will be updated by the CGC chair, secretary, or designate, and submitted to the CGC for review along with the meeting minutes. After internal review by the CGC, the updated CVS text will be provided tothe CGC Coordinator at the National Germplasm Resources Laboratory (NGRL). The updated CVS will then be posted on the GRIN-Global website for public access.

Following an initial update according to the outline below, the CVS might change relatively little from one year to another, but considerably over a multi-year time span. CGCs should conduct a more comprehensive assessment of current conditions every five or so years, focused particularly on updating CVS sections 2 and 5.

Maximum page lengths are suggested for the different sections of narrative text. Additional information in the form of text, tables, illustrations, etc. could be included as appendices to the narrative text.

Crop Vulnerability Statement Outline

Summary of key points (1 p. maximum)

1. Introduction to the crop (2 pp. maximum)

- **1.1 Biological features and ecogeographical distribution**
- **1.2 Genetic base of crop production**
- **1.3 Primary products and their value (farmgate)**
- **1.4 Domestic and international crop production**
  - **1.4.1 US (regional geography)**
  - **1.4.2 International**

2. Urgency and extent of crop vulnerabilities and threats to food security (4 pp. maximum)

- **2.1 Genetic uniformity in the "standing crops" and varietal life spans**
- **2.2 Threats of genetic erosion in situ**
- **2.3 Current and emerging biotic, abiotic, production, dietary, and accessibility threats and needs**
  - **2.3.1 Biotic (diseases, pests)**
  - **2.3.2 Abiotic (environmental extremes, climate change)**
  - **2.3.3 Production/demand (inability to meet market and population growth demands)**
  - **2.3.4 Dietary (inability to meet key nutritional requirements)**
  - **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)**

3. Status of plant genetic resources in the NPGS available for reducing genetic vulnerabilities (5 pp. maximum)

- **3.1 Germplasm collections and in situ reserves**
  - **3.1.1 Holdings**
  - **3.1.2 Genetic coverage and gaps**
  - **3.1.3 Acquisitions**
  - **3.1.5 Maintenance**
  - **3.1.5 Distributions and outreach**
- **3.2 Associated information**
  - **3.2.1 Genebank and/or crop-specific web site(s)**
  - **3.2.2 Passport information**
  - **3.2.3 Genotypic characterization data**

3.2.4 Phenotypic evaluation data

3.3 Plant genetic resource research associated with the NPGS

3.3.1 Goals and emphases

3.3.2 Significant accomplishments

3.4 Curatorial, managerial and research capacities and tools

3.4.1 Staffing

3.4.2 Facilities and equipment

3.5 Fiscal and operational resources

4. 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) (2 pp. maximum)

5. Prospects and future developments (2 pp. maximum)

6. References

7. Appendices (number and lengths at the CGC's discretion)