Potato Progress

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Potato-related research at USDA-ARS laboratories in Washington and Idaho

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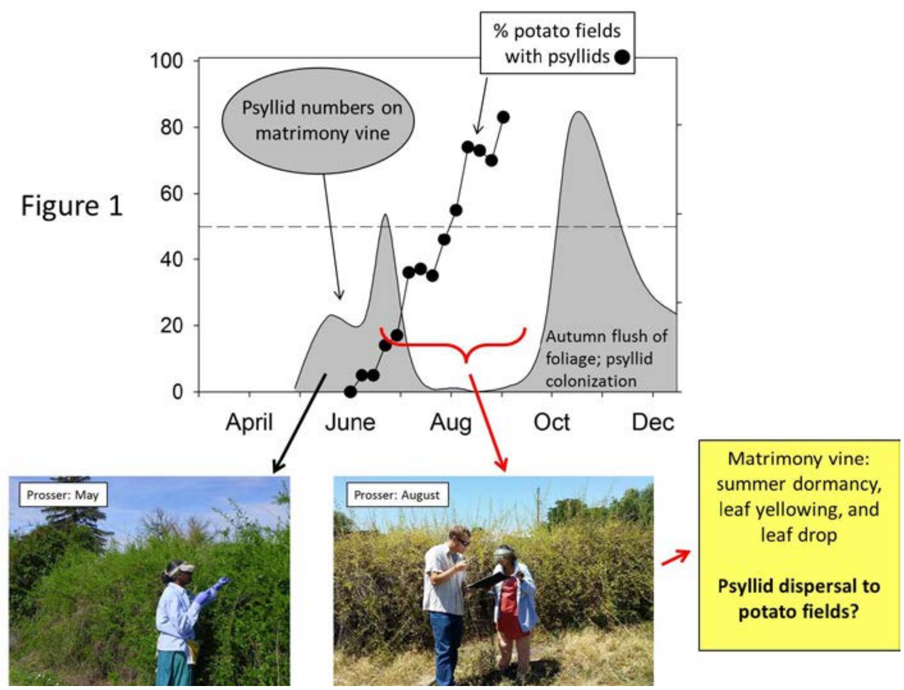
TEMPERATE TREE FRUIT AND VEGETABLE RESEARCH UNIT

Scientists at the USDA-ARS facility near Wapato, WA conduct research on arthropod pests of potatoes and tree fruits. The research group includes 7 full-time entomologists having backgrounds in insect ecology, chemical ecology, insect behavior, molecular biology, biological control, and IPM. The potato unit includes three scientists (**Dr. David Horton, Dr. Rodney Cooper,** and **Dr. Peter Landolt**), each having a split appointment between potato and tree fruit, and one full-time position currently open due to the recent promotion of Dr. Joe Munyaneza to National Program Leader of Specialty Crops. Three post-doctoral entomologists, **Dr. Jenita Thinakaran, Dr. Gene Miliczky,** and **Dr. Navneet Kaur**, are part of our research team, and are conducting studies of weedy plants for suitability to potato psyllid and to the zebra chip pathogen, including studies of how plant stress and plant chemistry affect suitability. **Dr. Horton** has spent his 20+ year career with ARS examining the ecology, host plant relationships, and behavior of psyllids, including pest psyllids in pears and potatoes, and non-pest psyllids in natural habitats. His research currently is focused on understanding psyllid ecology in tree fruit and potato crops, in understanding psyllid movement between non-crop and crop habitats, and in developing new tools with which to monitor psyllids**. Dr. Cooper** has over 15 years of entomological experience in tree fruits, tomato, chestnut, wheat, cotton, and potato cropping systems. His current research focuses on psyllid-plant interactions, and ecological associations among psyllids, plant pathogens, and bacterial endosymbionts. **Dr. Landolt** has been working in the area of insect chemical ecology for 36 years, with a focus on discovering, identifying, and applying chemical attractants for pest monitoring and control. His current research with potato insects involves a renewed effort to develop a chemical attractant for trapping adult wireworm beetles.

Potato-related research at the Wapato location currently includes four projects. **(1) Two perennial shrubs as sources of potato psyllids colonizing potato fields.** Growers are unable to predict when and in what fields psyllids are likely to first arrive, for one simple reason: we do not know with any real certainty what non-crop plants are reservoirs of psyllids in late winter and early spring.

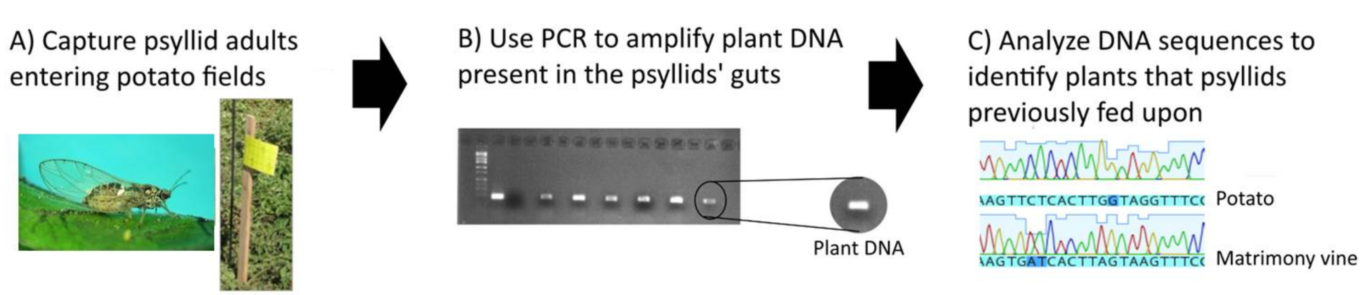
Overwintered psyllids require plant hosts in late winter and early spring for bridging the interval between winter hibernation and emergence of the potato crop in May. These bridge hosts are almost certainly perennial species related to potato, which has led us to focus upon two shrubs, bittersweet nightshade and matrimony vine. Our studies with these two shrub species are being done at two broadly different scales: landscape-wide and molecular.

(1A) Landscape analysis of potato psyllid and host phenology. We are monitoring seasonal phenology of psyllids and host shrubs over a broad geographic region. Our studies are being done to determine whether psyllid build-up on shrubs in spring contributes to May-June arrival in potato fields. Monitoring of matrimony vine has shown that psyllids disperse from these shrubs in early summer, coinciding with summer dormancy and leaf fall by the plant. Importantly, this dispersal event occurs at the very time that psyllids begin arriving in potato fields (see the model in Figure 1), suggesting that psyllids may be arriving in potato fields from matrimony vine sources. Indeed, we may eventually find that the late spring yellowing of matrimony vine can be used as a visual signal to predict seasonal onset of psyllid dispersal and arrival in potato fields, and thus optimal timing for beginning psyllid controls. We are evaluating the model in Figure 1 using sticky cards to monitor timing of psyllid dispersal from shrubs. These studies are being done in collaboration with scientists at Washington State University, Oregon State University, University of Idaho, and the Northwest Potato Research Consortium, and with funding support from the Northwest Potato Research Consortium, the Washington State Commission on Pesticide Registration, and the USDA-Specialty Crop Research Initiative.



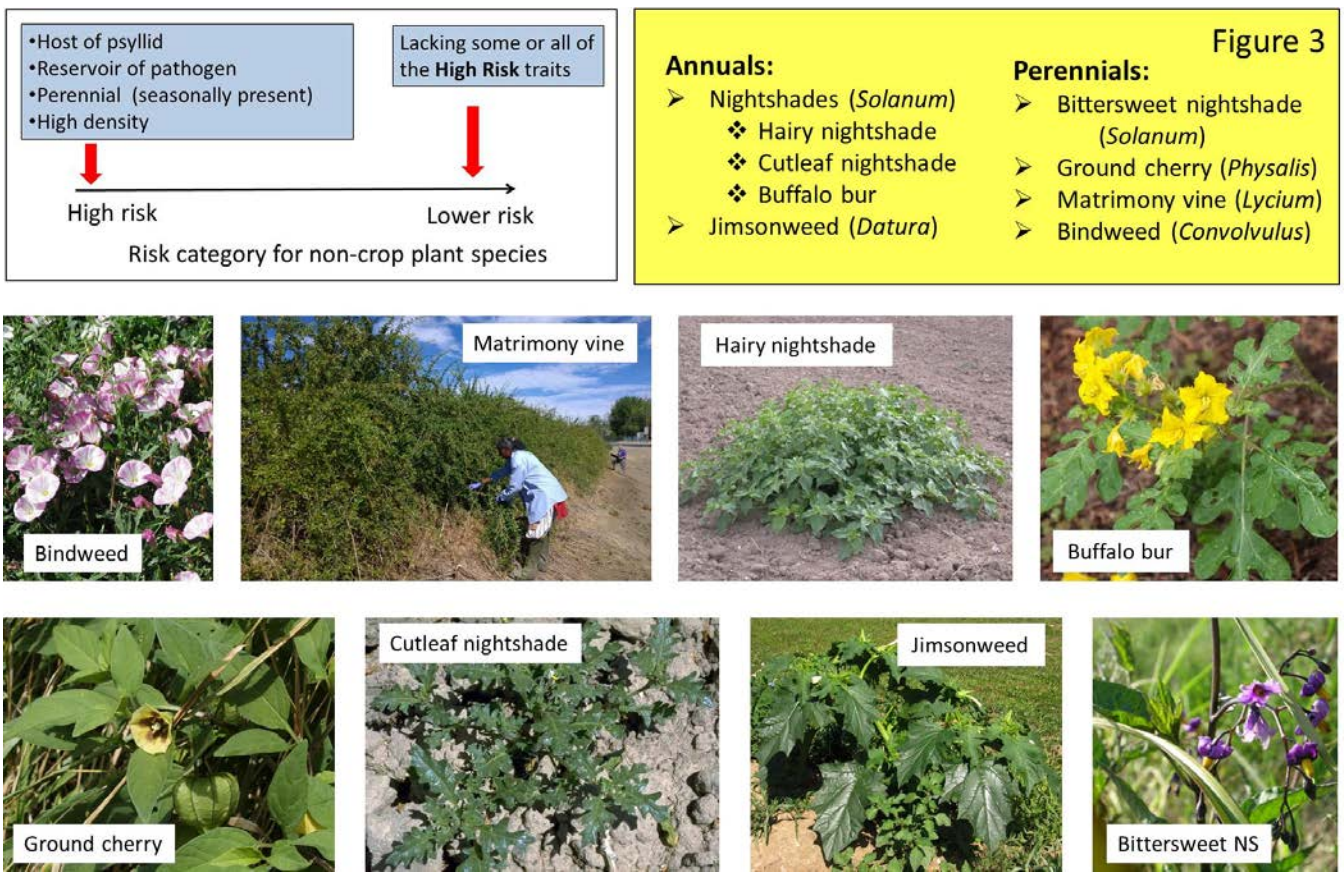
(1B) Molecular determination of psyllid diet. We have developed technology that can be used to determine the dietary history of field-collected potato psyllids (Figure 2). The approach relies on PCR-detection of plant DNA in psyllids. DNA sequences differ among plant species and can act as "markers" to identify what plant species psyllids had previously fed upon. With this technology we are able to

Figure 2



determine if psyllids – of unknown dietary history – had previously fed on bittersweet nightshade, matrimony vine, or other plant species. By trapping psyllids as they arrive in potato fields in June, we can determine whether those psyllids had arrived from a specific plant source (Figure 2). Funding support has been provided by the Northwest Potato Research Consortium and USDA-Specialty Crops Research Initiative.

(2) The "weed-link" in zebra chip epidemiology. We are developing an index which ranks 8 weedy host plants of potato psyllid by each plant's possible threat as a source of infective psyllids (Figure 3). The index will rank plants according to each species' combined scores of several risk traits: suitability to potato psyllid; attractiveness to egg-laying psyllids; suitability to the zebra chip pathogen; seasonal availability; and regional availability. We are currently in the middle of an intensive screening of target plants to estimate for each species suitability to the psyllid (including egglaying preferences, survival, and development) and suitability to the zebra chip pathogen (including as a source of inoculum for feeding psyllids). Screening studies have been completed for over half of our targeted species. Funding support has been obtained from the Northwest Potato Research Consortium and the WSDA-Specialty Crops Small Block Grants program.



(3) Building a better psyllid trap. Psyllid monitoring programs in Washington, Oregon, Idaho, and Canada use yellow sticky cards to detect arrival of psyllids in potato fields. These cards are messy and expensive, require weekly replacement, and collect many unwanted non-target species that make the cards difficult to process. We have begun to field-test prototype traps developed for citrus psyllid constructed using 3D-printing technology (Figure 4). Field tests are being conducted in collaboration with entomologists at Washington State University and the Florida Department of Agriculture, and with funding support from the Northwest Potato Research Consortium and the USDA-State Partnerships Potato Research program. Use of 3D-printing technology allows us to design traps that take advantage of behavioral traits of psyllids, such as psyllid attraction to yellow and the tendency of psyllids to walk upwards toward light. Additionally, the traps are designed to minimize captures of non-target species. We find that psyllids readily land on the traps and then walk upwards towards the light, entering the interior of the traps through psyllid-sized holes in the trap walls, and eventually falling into a vial of preservative attached at the trap's bottom (Figure 4). We are comparing efficiency of prototype traps against the standard sticky card under field conditions (Figure 4). These data include comparisons in captures of potato psyllids, other psyllids, winged aphids, predatory insects, and non-target species of no interest. An optimized trap will readily capture psyllids or other psyllid-sized insects of interest, exclude non-target taxa of no interest, be easy to service, and survive a full field-season without need for replacement.

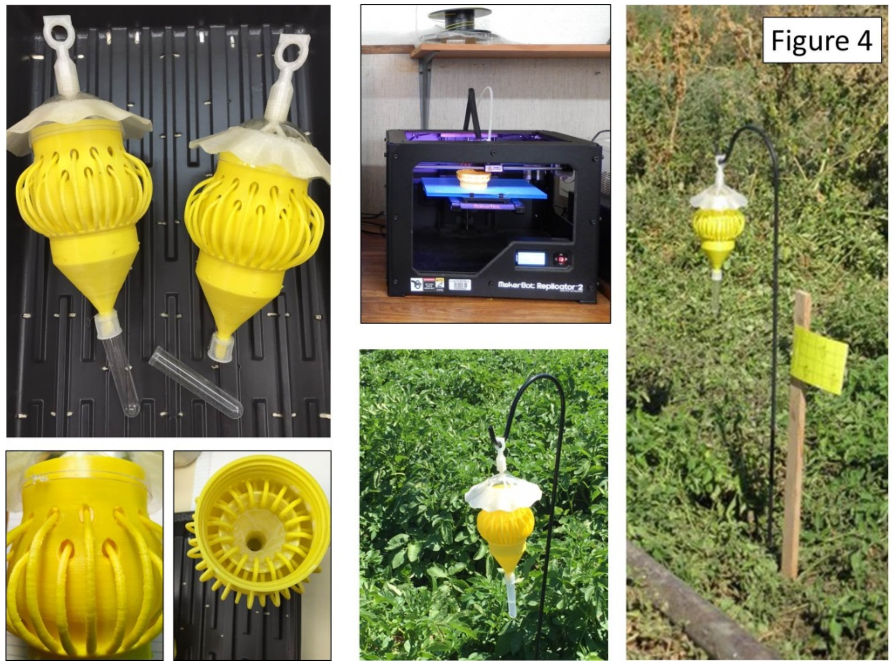


Figure 4

(4) Finding a better lure for wireworm beetle traps. The adult (or click beetle) stage of pest wireworms can be captured in Japanese beetle traps because of beetle movement towards yellow (Figure 5). A more powerful or sensitive trap could be produced by the addition of a chemical attractant. Two possible attractants for click beetles are odors from rotting vegetation and sex pheromones. One very old study (Lehman 1932) reported trapping of these beetles with several compounds. Our efforts to demonstrate beetle attraction to the Lehman chemicals failed to show activity. We then investigated wheat bran as a holder or base for the chemical in the traps. The wetted wheat bran ferments in the trap and provides an attractive material for click beetles, independent of the chemical treatment. We are now renewing efforts to determine the attractant chemical(s) from fermented wheat bran. The work to identify sex attractant pheromones of pest click beetles is part of a collaborative effort with Dr. Jocelyn Millar of the Department of Entomology at the University of California, Riverside. Dr. Millar is providing chemical lures that are putative pheromones for a set of pestiferous wireworm species, including our local pest species. A set of these chemicals is being tested at several field sites (Figure 6).

Figure 5. Click beetle (adult wireworm)

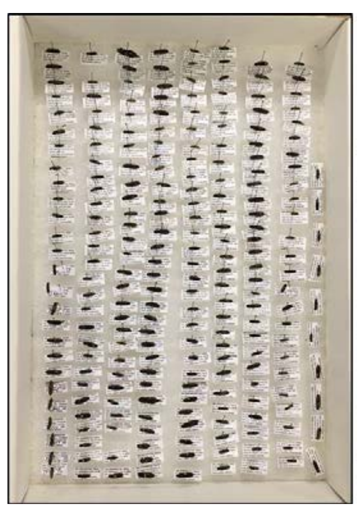


Figure 6. Click beetles captured in field-test of sex attractants.

IRRIGATED AGRICULTURE RESEARCH AND EXTENSION CENTER

The USDA-ARS facilities at Prosser are co-located with Washington State University's Irrigated Agriculture Research and Extension Center. Eight USDA-ARS scientists and sixteen WSU scientists, plus technicians and staff are based at Prosser with a total employment of ~200 people. In addition to potato research, numerous other crops are studied including legumes, alfalfa, grapes, hops and tree fruit. Breeding programs for potatoes, cherries, alfalfa and legumes are based at Prosser, along with the Clean Plant Center Northwest, the Center for Precision & Automated Agricultural Systems, and AgWeatherNet. The scientists working on potatoes are **Dr. Chuck Brown**, **Dr. Kylie Swisher** and **Dr. Roy Navarre**, with the invaluable help of three technicians. **Dr. Brown** has over 35 years of experience with potato genetics and breeding, and was with the International Potato Center in Peru before joining the USDA-ARS. **Dr. Navarre** has over 20 years of experience in the molecular physiology of plant disease resistance, and potato phytonutrients. **Dr. Swisher** joined the team in 2016 following Dr. Jim Crosslin's retirement and has a focus on new and emerging diseases of potato. She has a background in molecular biology which includes several years as a postdoctoral research associate where she applied molecular tools to the study of zebra chip disease.

The potato program at Prosser has had a decades-long interest in developing improved new potato varieties with an emphasis on disease resistance and enhanced nutritional value. The scientists work closely with our colleagues in the Northwest (Tri-State) Potato Variety Development Program (NWPVD) at Oregon State University, the University of Idaho, Washington State University, and USDA-ARS Aberdeen, Idaho.

Research objectives of the project on developing improved potato varieties include the following:

- Incorporation of disease and pest resistance, with a focus on soil-borne pests and pathogens.
- Improved tuber qualities, especially phytonutrient content of both processing and fresh-market varieties.

Disease and Pest Resistance Work: Work on multiple pests and diseases takes place at Prosser, but the primary focus is on soil-borne diseases because of the expenses and difficulties of fumigation, along with the negative impact on potato appearance. Skin appearance is critical for potatoes, especially for varieties destined for the fresh-market, and the absence of internal defects is important for both processing and fresh-market potatoes. New fresh-market varieties usually have a superior appearance, but this advantage can be lost if grown in fields containing Columbia root-knot nematode, corky ringspot disease caused by *Tobacco rattle virus* (TRV), powdery scab, and *Potato mop top virus* (PMTV). The long warm growing seasons that characterize much of Washington, Oregon and Idaho provide high potato yields, but also diseases and pests that profit from these conditions. Two of the major problems are caused by nematodes. The first is Columbia root-knot nematode (CRKN). It is well-adapted for the Northwest and has high reproductive rates. The ability of CRKN to reproduce on the roots and then penetrate tubers *en masse* leads to damage that the industry cannot tolerate. The females produce egg masses which appear as small brown dots within the outer 1/8 inch of the tuber. Even after peeling they are very visible. CRKN is the primary reason Northwest growers have to fumigate their potato fields. CRKN infests such a broad range of weeds and rotation crops that it is not feasible to control by depriving it of a suitable host.

We found resistance effective to a broad range of CRKN in the wild species *Solanum bulbocastanum*, *S. fendleri* and *S. hougasii*. Over a period of years, somatic hybrids using these species were developed and used as parental material. Subsequent experiments showed that resistance is actually due to two linked genes, one that confers resistance to roots, and the other that confers resistance to tubers. Molecular markers were identified for use in marker assisted selection. Several years of screening trials have shown a strong resistance in a long russet skin type breeding line with suitable processing quality (Figure 7). However, an increase in damage in year 3 occurred, possibly due to resistance breaking down under higher soil temperatures. This requires further study.

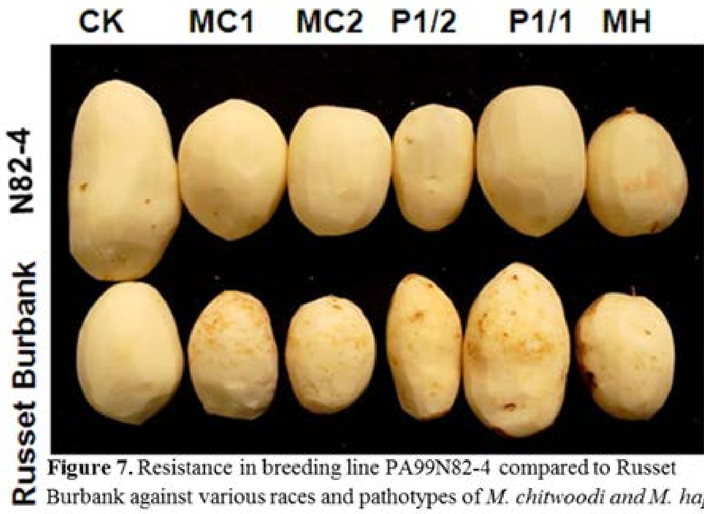


Figure 7. Resistance in breeding line PA99N82-4 compared to Russet Burbank against various races and pathotypes of *M. chitwoodi and M. hapla*

Corky ringspot is the second nematode related problem we work on. In this case, the virus causing corky ringspot (TRV) is vectored by the stubby root nematode. TRV is acquired from infected hosts and re-transmitted to potato. This leads to internal necrosis in the form of dots, arcs and larger necrotic lesions. At present, the disease is managed by killing the stubby root nematode vector with soil fumigants. Complicating breeding for resistance to TRV is that some lines may be resistant to the virus and asymptomatic, whereas other genotypes might be asymptomatic, but still harbor the virus ("insensitivity"). Castle Russet is a new Tri-State variety originating from our breeding program that has resistance to TRV. Preliminary results suggest this line may convert stubby root nematodes to an aviruliferous state in a single cropping of potato.

Lack of symptoms serves the needs of growers, processors, and fresh-market buyers, but the standards of seed certification and interstate and international movement require actual resistance. We are using a molecular approach to take a close look at the relationship between viral titer, disease symptoms, resistance and cultivar. We are also testing different sampling methods to evaluate the best method that accurately identifies TRV infection in a tuber.

PMTV is vectored by *Spongospora subterranea,* which itself causes powdery scab on the tuber surface. PMTV is an emerging disease in the United States. It was once considered a quarantine pest with no presence in the U.S., but over the last 15 years a number of disease notes report its presence in Colorado, Idaho, Maine, North Dakota, New Mexico, Oregon, and Washington. Like TRV, PMTV can be present in tubers that show no symptoms. In 2016 a large number of U.S. potatoes were stopped at the Mexican border upon detection of PMTV in symptomless tubers. PMTV symptoms are nearly identical to lesions caused by TRV, so distinguishing the two is difficult without laboratory testing (Figure 8). Evaluating breeding lines in fields with PTMV pressure identified Castle Russet and some advanced breeding lines as resistant to PMTV. For the last two years we have been evaluating certified seed lots for PMTV and have detected it at a rate of 2 to 4%, a concerning development.

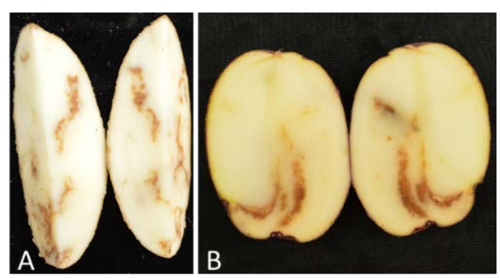


Figure 8. Internal necrotic symptoms caused by TRV (A) and PMTV (B).

In 2006 the quarantine potato cyst nematode (PCN) *Globodera pallida* was found in eastern Idaho. An ongoing eradication effort is being spearhead by APHIS. This nematode can persist in the soil for over 20 years in the absence of a host. Its cysts are filled with hundreds of eggs that hatch in response to compounds in potato root exudates called hatching factors. One approach to eradication is to stimulate the eggs to hatch in the absence of a host. Unlike the cysts, once the eggs hatch the juveniles must find a host and reproduce, or quickly perish. Therefore, treatment of soil with hatching factors in the absence of a host would induce a "suicide hatch." One way to achieve this is through the use of plants that stimulate hatch but do not allow reproduction, so called "trap crops." Litchi tomato (*Solanum sisymbriifolium*) is a PCN trap crop. We selected a population of Litchi tomato that has smaller thorns, making it more amenable for use as a trap crop. Litchi tomato fruit is edible, and we showed it has high amounts of phytonutrients, a fact that might also facilitate its use as a trap crop. We are also working to purify hatching factors directly and understand their biochemistry.

Two projects involve characterizing potentially emerging issues. One project involves an early dying phenomenon that was seen in potato fields in the Pacific Northwest in 2016, and that seems different from the traditional early die complex. As of yet, it is unclear what caused this issue or whether a pest or pathogen is involved. If this early dying issue arises again in 2017, studies will be done to identify the source of the phenomenon.

The second project is exploring the possibility that the beet leafhopper transmitted virescence agent (BLTVA) phytoplasma is being transmitted by an insect host other than the well-known beet leafhopper vector. In collaboration with Dr. Rodney Cooper, the aim of this study is to identify the likelihood of BLTVA acquisition and transmission by an alternative phloem-feeding insect pest of potato and other solanaceous crops. Here, insect cages are set up in a controlled greenhouse environment where insects are allowed to feed on BLTVA-infected plants. Then the pathogen acquisition by the insect is determined using molecular analysis tools. Results from this study will provide information regarding the potential spread of phytoplasmas between different crop hosts, and may allow growers to improve their pest management strategies to prevent the spread of this disease.

Phytonutrient research at Prosser: Maximizing the amount of phytonutrients in potatoes is a major goal of the Prosser team. Nutritional value is a consumer-oriented trait: Consumer surveys list nutritional value as one of the most important purchasing criteria for potatoes, along with flavor and appearance. Potatoes were targets of legislation to eliminate them from school lunch programs, and were the only vegetable excluded for purchase under the WIC (women, infants and children) program until the Institute of Medicine recently recommended their inclusion. There is a common misperception that potatoes do not have much nutritional value, but in actuality potatoes are a nutrient-dense food, and provide an equal or greater amount of nutritional value as they do calories (Figure 9). We focus on carotenoids and phenylpropanoids, compounds that besides being dietarily desirable also influence appearance and flavor. Our team also screens for a broader range of phytonutrients, including vitamin C, vitamin B9, total protein, potassium and iron. We have bred potatoes with large concentrations of carotenoids (deep yellow potatoes), and one need for such potatoes moving forward is longer tuber dormancy. The presence of two genes in the carotenoid biosynthetic pathway (Chy2 and Zep1) results in a dramatic increase in the synthesis of zeaxanthin.

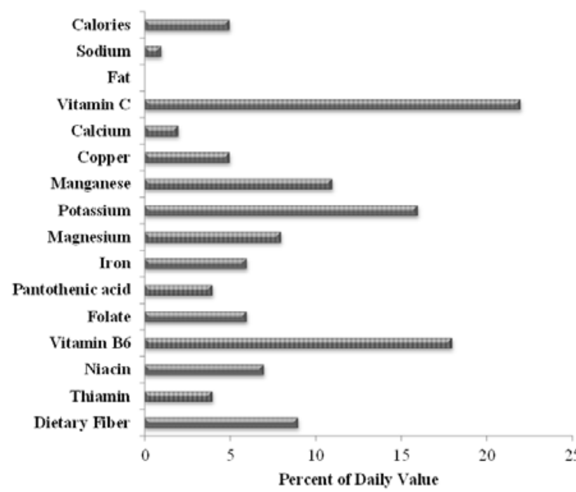


Figure 9. Percentage of the recommended daily values of various nutrients provided by a 100 gram portion of baked potato. Based on a 2000 calorie per day diet (data from USDA SR-21).

In addition to being antioxidants, phenylpropanoids have a wide range of positive effects not limited to cardiovascular health, longevity, mental acuity, vision, and anticancer activity. Plants have thousands of different types of phenylpropanoids. Potatoes with high amounts were shown to reduce inflammation in a human feeding study, which is an important finding given inflammation is thought to be an underlying cause of many diseases. We have identified primitive potato germplasm with exceptionally high amounts, and found that some immature potatoes ("baby potatoes") have antioxidant levels that rival kale. We and our Tri-State colleagues have developed potatoes with high levels of anthocyanins, one class of phenylpropanoid (Figure 10).

Figure 10. Ama Rosa and Purple Pelisse

Media coverage about the link between diet and health has become so common that it is likely shaping consumer attitudes about nutrition. Indeed, numerous lines of evidence suggest that consumers are increasingly prioritizing the nutritional value of foods. In this context we think new specialty and baby potatoes with high phytonutrient content, striking and novel appearances, and faster preparation can provide more choices and help ensure that growers can satisfy rapidly evolving consumer preferences and changing market dynamics.

Another important point about phenylpropanoids is that many are colorless, so theoretically they can be present in high amounts in white potatoes. American consumers overwhelmingly prefer white potatoes. Thus, to be attractive to the greatest number of consumers, high-phytonutrient white potatoes are needed. For reasons not understood, white potatoes contain markedly lower amounts of colorless polyphenols, such as CGA, than are found in colored potatoes. We are using a molecular and biochemical approach to determine exactly what controls the amount and types of phenylpropanoids in potatoes. Such information will help us produce potatoes with the different types of phenylpropanoid profiles that are needed for white, yellow, or red/purple potatoes. In addition to enhancing the nutritional value of potatoes, knowledge of tuber phenylpropanoid regulation can lead to potatoes with enhanced skin appearance, and biotic and abiotic stress resistance.

Glycoalkaloid (GLK) biology is another area of research. At higher concentrations, glycoalkaloids can have adverse effects including nausea, and are historically perceived as toxins with no redeeming characteristics from a dietary standpoint. However, numerous recent studies report potential health benefits, including protection against multiple types of cancers. However, in these increasingly risk-averse modern times, there is growing reluctance by breeding programs to release lines with GLKs in the historically accepted 10-20 mg/100 g fresh weight (FW) range, with >20 mg/100 g FW being considered unacceptably high for human consumption. A worry for new cultivars is that GLK levels established as acceptable over years of evaluation may inexplicably spike to an unacceptable amount under certain environments. Such fear of unanticipated spikes in GLKs is one factor driving breeding programs to select genotypes containing GLKs at $\leq$10 mg/100 g FW. Adhering to unnecessarily low limits of GLKs can exclude superior new cultivars that present no health hazard and make it even more difficult to incorporate improved traits from wild germplasm into new cultivars. With collaborators around the country, we are growing the same 10-15 potato lines/varieties in trials in six different states. If marked differences in concentrations of GLKs are seen in the same line/variety grown at different locations, we will try to pinpoint the reason for the difference using a molecular and biochemical approach. We are also working with Dr. John Bamberg and the U.S. Potato Genebank (USDA-ARS, Wisconsin) to screen primitive germplasm for optimal glycoalkaloid profiles, and to identify germplasm resistant to greening for use by breeders.

Small Grains and Potato Germplasm Research Laboratory

A diversity of research is conducted at this facility located in Aberdeen, Idaho. Research includes small grains and potato breeding and genetics, as well as conservation, evaluation, and distribution of germplasm from the National Small Grains Collection which is located at Aberdeen. Additionally, research on increasing rainbow trout production through breeding and genetics and the development and use of plant-based feeds is conducted at satellite facilities in Hagerman, Idaho and Bozeman, Montana. Potato research scientists at Aberdeen include **Dr. Rich Novy** and **Dr. Jonathan Whitworth** and four project technicians. **Dr. Novy** has 21 years of experience in potato breeding and genetics, and has collaborated in the release of 39 varieties, which include Alturas, Bannock Russet, Blazer Russet, Clearwater Russet, Classic Russet, Payette Russet, and Teton Russet. **Dr. Jonathan Whitworth** is a plant pathologist with 24 years of experience, which included 7 years as manager of seed potato certification in Idaho and 3 years as assistant manager in Colorado. **Dr. Whitworth** has also collaborated in the release of 22 varieties. Aberdeen has historically had a close working relationship between a geneticist and a plant pathologist in the potato project, and this has proven to be a very successful collaborative arrangement that has contributed to the success of the project.

The development of improved potato varieties for the western (and U.S.) potato industry is the primary objective of the Aberdeen potato project. Five of the ten most widely-grown varieties in the U.S. in 2016 (Ranger Russet, Umatilla Russet, Alturas, Bannock Russet, and Clearwater Russet) originated from the Aberdeen potato breeding program and were developed and released with our colleagues of the Northwest (Tri-State) Potato Variety Development Program (NWPVD). These five varieties, and an additional nine varieties, accounted for approximately 24% of the planted acreage in the Fall- production states of Idaho, Maine, Minnesota, North Dakota, Oregon, Washington, and Wisconsin in 2016 (NASS, Crop Production, December 2016).

Research objectives of the project in developing improved potato varieties include the following:

- Incorporation of disease and pest resistance
- Improved tuber qualities for processing and fresh use
- Improved sustainable production by reducing production inputs such as pesticides and nitrogen

Incorporation of disease and pest resistance: Potato is susceptible to an impressive array of diseases with 52 identified as pathogen-induced and an additional 15 abiotic diseases recognized. Several of our primary breeding efforts and associated successes in releasing varieties with enhanced disease resistance are detailed in this article; however, other diseases and pests such as Verticillium wilt, early blight, common and powdery scab, zebra chip, potato leafroll virus, corky ringspot, potato cyst nematode, and dry and soft rots of tubers are important components of our resistance breeding efforts as well.

Potato Virus Y (PVY): PVY, a primary virus pathogen of potato, has become increasingly problematic for potato seed certification programs due to the rapid spread of new strains (PVY^{N}, $PVY^{N:O}$, PVY^{NTN}) that produce milder foliar symptoms, making it difficult to visually detect and remove infected plants in the field. Similar to the common strain (PVY^{O}) that was previously prevalent in the U.S., the newer strains also can reduce yield. In addition, many of the newer strains can cause tuber necrosis with an associated negative impact on tuber quality and rejection of the crop for processing/fresh-pack use.

Participation by our program in a multi-discipline tuber necrotic virus grant involves screening widely grown and specialty varieties for their foliar and tuber symptoms caused by necrotic strains of PVY. When completed, this research will characterize 70% of the varieties currently grown in the U.S. Results will help grower and seed certification inspectors in their efforts to control PVY in seed potatoes. In addition to this, PVY demonstration plots that involve growers and industry have been held in Othello, WA to show the interaction between different varieties and PVY strains (Figure 11). In 2018, these demonstration plots will be held in Washington, Wisconsin and Maine. These plots are being coordinated and administered by our program and an ARS program in Ithaca, New York.

Figure 11. Field-days demonstration plots.

Resistance genes, Ry_{adg} and Ry_{sto} derived from *S. tuberosum* subsp. *andigena* and *S. stoloniferum,* respectively, confer extreme resistance to all strains of PVY with germplasm in our program confirmed as having both resistance genes. Marker-assisted selection has been successfully utilized by our project to develop potato varieties with resistance to all strains of PVY using molecular markers linked to Ry_{adg} and Ry_{sto}. Payette Russet, with extreme resistance to all strains of PVY conferred by Ry_{sto}, is a recent example of our success in the development of PVY-resistant potato varieties. Payette Russet represents the first russet-skinned potato variety suitable for processing with extreme resistance to PVY and can be of aid to the potato industry in addressing this problematic virus.

Late Blight: Our program, in collaboration with colleagues in NWPVD Program, bred, developed and released the potato varieties Defender, Palisade Russet, Payette Russet, and Yukon Gem which are notable for their resistance to late blight in both the foliage and tubers (Figure 12). Defender, Payette Russet, and Palisade Russet are currently the only late blight resistant varieties with the long tuber type suitable for processing into French fries, with Palisade Russet and Payette Russet also having russet skin—an important trait for the western U.S. market. Our program continues its research in late blight resistance with a primary emphasis on developing potato varieties through breeding with more pronounced russet skin that better meets the needs of the western U.S. fresh-pack industry, and the use and incorporation of new sources of late blight resistance.

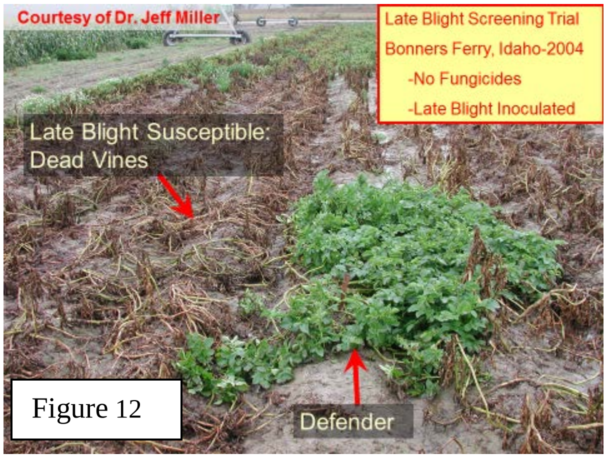


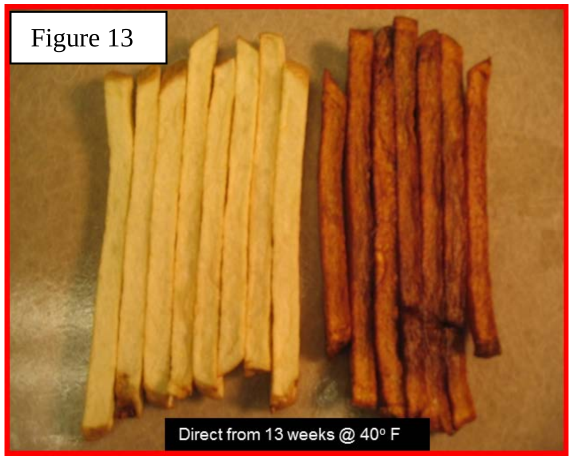
Figure 12

Potato Mop-Top Virus (PMTV): Since it was first detected in Maine in 2002, PMTV has been documented as being present in six additional states in the Midwest and West. As previously mentioned, PMTV is vectored by the causal agent of powdery scab (*Spongospora subterranea*), with this soil borne vector present in most potato-producing states in the U.S. No fungicides are available for the control of powdery scab, and spore balls of *S. subterranea* can survive for more than ten years in the soil. Genetic resistance to powdery scab alone has been demonstrated to be inadequate for managing tuber necrosis caused by PMTV, and genetic resistance to PMTV appears to be the only viable option for managing the tuber necrosis caused by this virus. Researchers at North Dakota State University have screened varieties in four market classes of potato varieties grown in the U.S. for sensitivity to PMTV-induced tuber necrosis in North Dakota field trials and found a range of expression within market classes. A pattern was also observed, with varieties having russet skin displaying a lower incidence of tuber necrosis relative to varieties representing market classes having red, white, or yellow-skin. Pomerelle Russet, originating from our project and released in 2015, also has been identified as having tolerance to PMTV-induced tuber necrosis. As participants in a grant to address PMTV and other tuber necrotic viruses, we are actively engaged in the development of PMTV-resistant potato varieties.

Improved Tuber Qualities for Processing and Fresh Use

Tuber Sugars: Sixty-two percent of the 2015 U.S. potato crop was used for processing into potato products such as fries, chips, and dehydrated potato products with the northwestern states of Idaho, Oregon, and Washington providing 80% of the total U.S. potato production used for processing (NASS, Potatoes 2015 Summary, September 2016). Low tuber sugar content is a key varietal characteristic in the utilization of potatoes for processing for chips or French fries. Reducing sugar concentrations are generally low and acceptable following harvest in the field, but with extended storage, reducing sugar levels in tubers increase. When tubers with higher reducing sugar concentrations are fried, the sugars react with free amino acid groups resulting in a dark, commercially unacceptable product (known as Maillard browning). Higher concentrations of reducing sugars also promote the formation of acrylamide, a suspected carcinogen in humans, in processed potato products. Lower storage temperatures (40° to 44°F) can further exacerbate the accumulation of reducing sugars in potato tubers. Accordingly, the majority of potato storage facilities maintain temperatures of 45° to 50°F to minimize reducing sugar accumulations in stored tubers of standard varieties such as Russet Burbank. However, lower storage temperatures can be of benefit by: 1) reducing water loss of tubers (shrinkage), 2) prolonging tuber dormancy, thereby maintaining tuber quality with no or reduced applications of sprout inhibiting chemicals, and 3), reducing the incidence of storage diseases. Therefore, the development of potato varieties with the ability to resist the accumulation of reducing sugars at 40 to 44°F, also known as "cold-sweetening resistance", would benefit the potato industry. An example of French fries from cold-sweetening versus non-cold-sweetening resistant breeding clones is shown (Figure 13).

Figure 13



Our project, in collaboration with our Tri-State colleagues, has released ten cold-sweetening resistant, long, russet-skinned, potato varieties since 2000: Gem Russet, GemStar Russet, Alturas, Premier Russet, Clearwater Russet, Alpine Russet, Owyhee Russet, Palisade Russet, Sage Russet, and Payette Russet. Among these ten varieties, Alturas and Clearwater Russet were the 6th and 9th most widely grown potato varieties in the U.S. in 2016 (NASS, Crop Production, December 2016).

Tuber Greening/Glycoalkaloids: Tuber greening can occur due to inadequate soil coverage of developing tubers in the field, or due to exposure to a light source following harvest. An example of post-harvest greening would be exposure of tubers to illumination in a store prior to sale, with subsequent greening occurring. Light-induced greening reflects chlorophyll formation and is not toxic. However, the formation of glycoalkaloids has been associated with tuber greening and can result in bitterness and toxicity to humans at higher concentrations. Tuber greening and associated increases in tuber glycoalkaloids are undesirable and result in economic losses both to the fresh-pack and processing industries, as well as grocery chains. The identification of resistance to tuber greening was reported by Bamberg and colleagues in the potato species, *Solanum microdontum* (mcd), with some clones also showing little increase in tuber glycoalkaloids following illumination. Germplasm from mcd populations that had shown resistance to tuber greening were requested by this project and were successfully used as parents in hybridization to cultivated potato. Progeny of mcd x cultivated potato have shown the resistance to tuber greening of their mcd parent following 4 days of illumination under fluorescent lighting (Figure 14). This germplasm is also being assessed for tuber glycoalkaloid concentrations following illumination, with promising hybrids to be utilized for continued backcrossing to cultivated potato to incorporate resistance to tuber greening and associated tuber glycoalkaloids.

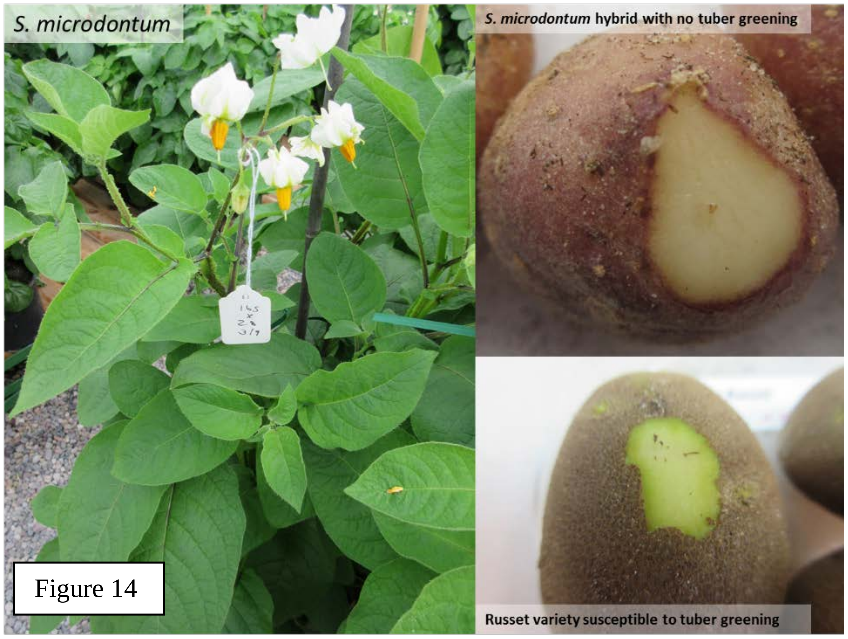


Figure 14

Improved Sustainable Production: Improved sustainability in production has become increasingly important to the potato industry with increasing efforts in reducing production inputs such as pesticides, water, and nutrient applications. Our research efforts in developing potato germplasm and varieties with disease and pest resistances contributes to reductions in pesticide use.

There is also a need for the development of russet-skinned varieties that can produce commercially acceptable yields and quality with less water, with increasing competition for scarce water resources between urban and agricultural sectors in the western U.S. Our program has addressed the need for such water-stress tolerance with the release of several varieties (GemStar Russet, Premier Russet, and Alpine Russet) having a reduced need for water relative to standard varieties such as Russet Burbank.

Improved efficiency in nitrogen use by potato varieties also has the potential to reduce groundwater contamination with nitrates. A substantial reduction (>20%) in nitrogen requirements relative to Russet Burbank, also has been reported for the following potato varieties released by our project with Tri-State collaborators; the percent reduction in nitrogen relative to Russet Burbank is given in parentheses: Alturas (40%), Bannock Russet (40%), Clearwater Russet (25%).

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