

Impact of *Potato virus Y* on the Quality of Specialty Potato Tubers

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Potato virus Y causes a wide range of symptoms on potatoes, including the tubers of specialty potato cultivars. This report focuses on the symptoms of tuber cracking, as well as some of our recent studies on the effects of mechanical transmission and fluctuating soil moisture on incidence and severity of the tuber cracking problem.

Different strains of *Potato virus Y* affect different potato cultivars in different ways (Karasev and Gray, 2013). The common (or ordinary) strain, PVY^O, can cause obvious symptoms of mosaic and mottling and leaf drop on potato foliage, but PVY^O is not known to cause discernable symptoms on potato tubers (Hu, 2009). In contrast, other strains like PVY^{NTN} which are identified in part by their ability to cause necrosis on tobacco leaves and stems, can cause striking symptoms on both potato foliage and tubers. In fact PVY^{NTN} is responsible for Potato Tuber Necrotic Ringspot Disease sometimes referred to as PTNRD (see 'PTNRD' on *Managing Potato virus Y in Seed Potato Production* website at <http://www.potatovirus.com/index.cfm/page/PVYinfo/PTNRDinfo.htm>). A relatively new strain, PVY^{N-Wi}, is becoming widespread throughout many potato production regions, and is notable for causing only very mild mosaic symptoms on potato foliage (Gray et al., 2010). This characteristic makes it very difficult to detect the virus visually during seed potato certification inspections. Depending on cultivar and environment PVY^{N-Wi} has been associated with symptoms on tubers reminiscent of PTNRD (see 'Photo Gallery' on *Managing Potato virus Y in Seed Potato Production* website at <http://www.potatovirus.com/>) and with other tuber defects. The tuber symptoms associated with PVY^{N-Wi} range from mild to severe, and can include roughened skin, uneven pigmentation, and suberized fissures (or cracks). Currently, it is controversial as to whether tuber cracks can be the result of virus infection, and some people wonder whether caution needs to be employed in assigning the symptoms of tuber cracking to infection by PVY.

Generally, cracking in potato tubers is called growth cracking and considered to be a physiological disorder related to soil moisture stresses or herbicide injury. Tuber growth cracks occur when the tuber splits open while growing—the splits heal but they leave fissures. Such splits almost always start at the bud end and severity depends on the stage of growth at which they occur. The incidence increases when there are sudden soil temperature/moisture changes during the growing season, or if the cultivar planted is simply prone to the problem. Jefferies and Mackerron (1987) described two causes: rewetting the soil after tuber growth has stopped, or rapid tuber growth and high turgor. Maintaining uniform soil moisture, especially during tuber bulking, thus is the common recommendation for managing the problem. Cracking in tubers also can result from damage by glyphosate (see *Effect of Glyphosate on Potatoes* at <http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1642.pdf>), and other herbicides.

Two potato researchers in Scotland, Carnegie and McCreath, were the first to demonstrate experimentally that tuber cracking in potatoes can be related to virus infection. Two key statements in the article they published in 2010 stated: (i) The association of growth cracking on tubers with mosaic symptoms on foliage did not seem to depend on any specific virus because it occurred with three different viruses ie., PVA, PVV and PVY^N, and (ii) It is possible that the effect has been overlooked in the past because tuber cracking has only been seen after destruction of foliage and ascribed to the growing conditions.

Do PVY-infected potato plants lead to cracked tubers? In 2013 we asked the question at WSU Mount Vernon, “Do PVY-infected potato plants lead to cracked tubers?” Chieftain tubers that had been saved from a 2013 field study were planted in a 2014 grow-out trial. The tubers were harvested from plants that had been visually assigned and tested (Agdia ImmunoStrips, Elkhart, IN) in the field as ‘healthy’ (PVY negative), or ‘mildly symptomatic’ or ‘severely symptomatic’ (PVY positive). Following 5 months storage, four replications of five tubers in each category were planted in a greenhouse, re-tested for PVY, and weighed and rated for potato tuber defects at harvest. All 2nd generation plants that emerged from seed tubers of ‘mildly symptomatic’ and ‘severely symptomatic’ plants re-tested positive for PVY. Unexpectedly, several (13/20 or 65%) that emerged from seed tubers of ‘healthy’ plants re-tested positive instead of negative for PVY (Table 1). Possibly, (i) virus titer levels in the mother plants had been too low when tested initially by the test strips in late August, and/or (ii) the plants were asymptomatic in the field, (iii) the progeny tubers had become infected in the field at the end of the season due to an unobserved, late flight of viruliferous aphids, and/or (iv) some other type of mechanical transmission had occurred late in the season. Whatever the reason, development of infected but asymptomatic seed tubers from asymptomatic plants late in the growing season could represent a very significant source of PVY inoculum.

Cracking of progeny tubers associated almost exclusively with PVY foliar infection in the field in 2013; likewise, cracking of progeny tubers associated exclusively with PVY foliar infection in the greenhouse in 2014. In some cases tubers were cracked or necrotic; in other cases they had symptoms of both cracking and necrosis. The cracks resembled canoe-shaped indentations that were healed over (Fig. 1). Uneven pigmentation and roughened skins also were observed, but no ringspot symptoms were noted. Karasev laboratory confirmed PVY^{N-Wi} on selected field plant samples in 2013, and on selected greenhouse plants samples in 2014. PVY^{NTN} was not identified. Tuber yield was highest for ‘healthy’ plant category regardless of being PVY negative or PVY positive, demonstrating the negative impact of well-defined and recognizable virus symptoms on both plants and tubers.

Can PVY be mechanically transmitted during seed cutting operations, and lead to tuber cracking? To demonstrate cause and effect, rather than just an association, a second greenhouse experiment was done on mechanical transmission of PVY and development of tuber cracking. It is important to note that throughout all of our PVY studies, all tubers were harvested and stored, and handled and planted, extremely carefully and discretely in order to avoid any potential cross-treatment contamination. Symptomatic and presumed PVY-infected (i.e., from PVY positive plants) Chieftain tubers were pre-sprouted so that sprouts were ‘peeking,’ and sorted as cracked or cracked + necrotic (Fig. 2). Attempted mechanical transmissions then were made either to certified virus-free pre-nuclear Chieftain mini-tubers (or the plants grown from them depending on the treatment). Three types of transmissions were employed: (i) *simulated contact during seed handling* (an infected seed tuber was cut through a bud with a sterile knife, and following, the cut pieces were agitated for 5 min with a sterile-cut recipient pre-nuclear tuber in a plastic bag); (ii) *simulated contact during seed cutting* (an infected seed tuber was cut through the bud with a sterile knife to accumulate sap on the knife, and then a recipient pre-nuclear tuber was cut in half immediately with the same knife); (iii) *simulated leaf-to-leaf contact* between infected and healthy plants (plants growing from an infected seed tuber (~3 oz size) were placed immediately adjacent to plants growing from recipient pre-nuclear tubers, so that some leaves always touched; and, (iv) *non-inoculated, pre-nuclear seed* (control). Four replications of three or five plants were used depending on the treatment. All experimental plants were tested with Agdia

ImmunoStrips for confirmation of PVY infection, and progeny tubers weighed and rated for potato tuber defects.

Twenty-five percent of plants (5 of 20 in three of four replications) originating from pre-nuclear mini-tubers that were cut with a PVY-contaminated knife, showed obvious foliar symptoms of the virus and proved positive for PVY when tested (Table 2). However, sap transmission from an infected seed tuber via handling/tumbling, or mechanical transmission via the progeny plant leaves touching, did not occur; and, such plants were negative for PVY when tested. Interestingly, cutting cracked seed tubers led to PVY transmission while cutting cracked + necrotic seed tubers, did not. We have no explanation for this result at this time, but believe it could be an important observation. Cutting through the sprout of a PVY-infected tuber seemed to be critical for successful transmission. We plan to continue our mechanical transmission studies, especially given new reports by Fageria et al. (2014) where wounding but not cutting did transmit PVY^O, PVY^{N:O} and PVY^{NTN} (PVY^{N-Wi} not tested, however), and Coutts, et al. (2014) where blades with infected sap transmitted PVY^O, but blades used to cut healthy tubers after cutting infected tubers, did not transmit PVY^O (cutting directly through sprouts or with PVY^{N-Wi} was not tested, however). In our next experiments we will hypothesize that cutting through the sprouts of PVY^{N-Wi} infected tubers can lead to mechanical transmission of this strain during seed cutting operations.

Can constant soil moisture remedy tuber cracking in PVY positive plants? A greenhouse factorial experiment was done at WSU Mount Vernon. There were four treatment combinations: either PVY infected/symptomatic or non-infected Chieftain tubers, exposed to either constant or alternating wet/dry periods. Four replications of ten plants were used for each treatment. Water was delivered via single drip irrigation emitters (Woodpecker DNPC1; DripWorks Willis, CA) affixed to each pot and soil moisture was monitored daily with two tensiometers. At vine kill, each plant was rated for PVY symptoms and randomly tested for presence of PVY. Tubers were harvested, and weighed, graded, and rated for defects. Statistical analysis revealed no significant interactions among the two experimental factors (PVY seed status and irrigation method).

All plants from healthy pre-nuclear seed were healthy and tested plants proved negative for PVY. However, every plant from infected/symptomatic seed had obvious symptoms of mosaic and tested plants proved positive for PVY (Table 3). No significant differences in average yield per plant existed between healthy and infected/symptomatic plants. None of the progeny tubers from the healthy plants had any symptoms of cracking in either irrigation treatment—cracking only was observed on tubers from infected/symptomatic plants (Table 4). Interestingly, PVY^{N-Wi} was the only strain identified in this study. Currently, we do not know whether there is a relationship between tuber cracking and PVY^{N-Wi}, and we plan future work comparing tuber defects caused by different PVY strains on multiple specialty potato cultivars. We also do not know what titer levels of the virus in the plant or what other conditions may be required for optimal expression of tuber cracking symptoms.

The total amount of water applied during the two irrigation regimes was nearly the same (44.5 hr for constant and 46.5 hr for alternating; or, approximately 11.1 and 11.6 in., respectively). However, the amount of water applied per treatment varied from 0.25 in./day for constant irrigation, to 0 to 0.50 in./day for alternating irrigation treatment (Fig. 3). Surprisingly, the tuber cracking index and the number of cracked and cracked/necrotic progeny tubers was higher for the constant than alternating irrigation treatment. All constantly irrigated plants, regardless of PVY seed status, had a more lanky growth and the plants senesced earlier than the alternating irrigation plants which actually looked healthier. Jefferies and Mackerron at the

Scottish Crop Research Institute (*Potato Research*, 1987) reported that tuber cracking is associated with either re-wetting of soil after tuber growth has stopped or with rapid tuber growth and high turgor. Perhaps, in our experiment, both types occurred, but the latter (rapid tuber growth and high turgor) was imparted by the constant irrigation regime which accentuated the cracking effect. Nevertheless, we were unable to alleviate cracking symptoms by either irrigation regime, and tuber cracking directly associated with PVY infection in our experiment.



Fig. 1. Cracking in potato tubers associated with infection by *Potato virus Y*.



Fig. 2. Seed tubers used in *Potato virus Y* mechanical inoculation trial. Cracked (left) and cracked + necrotic (right).

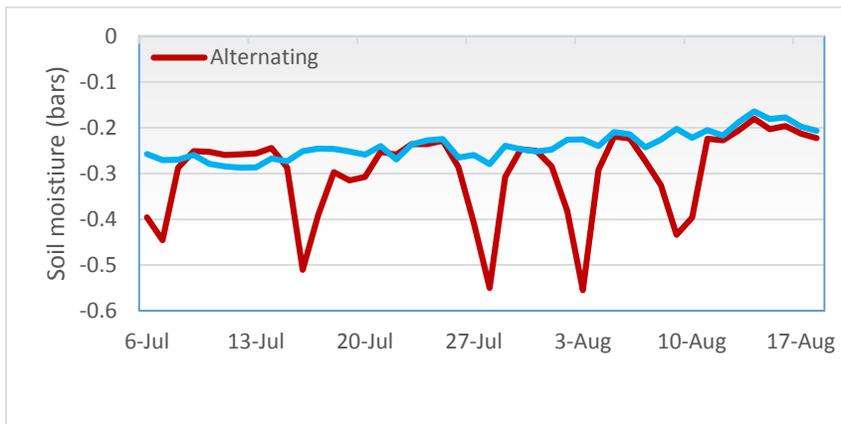


Fig. 3. Soil moisture readings over time (via tensiometers) in the *Potato virus Y* screenhouse experiment.

Table 1. Greenhouse winter grow-out test results on *Potato virus Y* and tuber cracking, cv. Chieftain.

Field grown plants, 2013									Greenhouse grown plants, 2014						
PVY foliar symptoms		PVY+ foliar test results ^a		PVY symptoms, 1 st generation progeny seed tubers ^b				PVY+ foliar test results ^{c,d}		PVY symptoms, 2 nd generation progeny tubers ^e					
No.	%	No.	%	None	Crk	N	Crk + N	No.	%	Total no. plants	Avg. no. tubers	Total no. crk	% Crk tubers	Avg. tuber wt. (g)	
Healthy				20	0	0	0								
PVY-	12	100	12	100	---	---	---	---	7	35	7	2.7	0 a	0 a	129.0 a
PVY+	0	0	0	0	---	---	---	---	13	65	13	2.7	9 ab	25 b	107.2 ab
Mild				11	4	4	1								
PVY-	0	0	1	8	---	---	---	---	0	0	0	---	---	---	---
PVY+	12	100	11	92	---	---	---	---	20	100	20	2.6	11 b	22 b	98.7 b
Severe				1	1	12	6								
PVY-	0	0	0	0	---	---	---	---	0	0	0	---	---	---	---
PVY+	12	100	12	100	---	---	---	---	20	100	20	2.9	19 b	32 b	123.5 a
<i>LSD (P=0.05)</i>											---	<i>NSD</i> ^g	<i>12.51</i>	<i>24.55</i>	<i>22.25</i>

^aAll plants assigned healthy were PVY- by Agdia ImmunoStrips on 8/20/13; plants assigned mildly symptomatic or severely symptomatic were confirmed to be PVY+ by the same method (data not presented). ^bFour replications of five tubers each, obtained from each assigned foliar category; none = no tuber symptoms, Crk = tubers with cracks, N = tubers with external or internal necrosis, Crk + N = tubers with both cracks and necrosis. ^cVisual foliar assignment after greenhouse grow-out. ^dTested by Agdia ImmunoStrips on 3/25/14; leaflets from randomly-selected PVY positive plants later confirmed by Karasev lab to all be infected with PVY^{N-WI}. ^eYield data expressed on a per plant basis, across replications. ^f--- = not applicable. ^gMeans in a column followed by the same letter are not significantly different by Fishers LSD test at $P = 0.05$; NSD = not significantly different.

Table 2. Mechanical transmission test results with cv. Chieftain and *Potato virus Y*. All ‘stock’ seed tubers were symptomatic for PVY, and obtained from PVY+ tested plants. All ‘recipient’ seed tubers during the transmission treatments were nuclear mini-tubers obtained from tissue cultured plants, certified to be virus free.

Experiment set-up:		Progeny plant and tuber symptoms:										
Transmission treatment ^{a, b, c}	No. stock seed tubers at planting, by PVY symptom ^c		No. with PVY foliar symptoms ^c		No. PVY+ foliar test results ^d		Avg. no. cracked progeny tubers, across reps		Avg. % cracked progeny tubers, across reps		Avg. progeny tuber wt. (g), across reps	
	Crk ^e	Crk+N ^e	Crk	Crk+N	Crk	Crk+N	Crk	Crk+N	Crk	Crk+N	Crk	Crk+N
1. Tumbling	12	12	0/12	0/12	0/12	0	0.00	---	0.0	---	227	---
2. Cutting	20	20	5/20	0/20	5/20	0	0.20	0.00	3.8	0.00	234	216
3. Touching	4	4	0/12	0/12	0/12	0	0.17	0.00	2.4	0.00	228	216
4. Control	---	---	0/4	0/4	0/4	0	---	---	---	---	---	---
<i>LSD</i>												
<i>(P=0.05)^g</i>												
	---	---	---	---	---	---	NSD ^g	NSD	NSD	NSD	NSD	NSD

^aControl is pre-nuclear seed of Chieftain, not inoculated. ^bSee text for treatment descriptions. ^cFour replications of three to five tubers from each assigned category used as recipient tubers/plants. ^dVisual foliar symptoms included leaf crinkling, mottling and mosaic, but no necrosis. ^eAccording to Agdia ImmunoStrips; three leaflet per each plant was tested. ^fCrk = cracked; Crk+N = cracked and necrotic. ^g--- = not applicable. ^hMeans in a column followed by the same letter are not significantly different by Fishers LSD test; NSD = not significantly different.

Table 3. Irrigation experiment results on yield with cv. Chieftain and *Potato virus Y*. All ‘stock’ seed tubers were symptomatic for PVY, and obtained from PVY+ plants. All ‘healthy’ seed tubers were nuclear mini-tubers obtained from tissue cultured plants, certified to be virus free.

Plant status	Plants testing PVY+	Total no. cracked progeny tubers
PVY +	25/25	52
PVY-	0/24	0

Seed source	Average yield (g)	Average no. tubers
PVY infected	758.68	10.63 b
Pre-nuclear	760.33	14.35 a
<i>LSD (P=0.05)</i>	<i>NSD</i>	<i>0.98</i>

Irrigation treatment	Average yield (g)	Average no. tubers
Alternating	670.40 b	11.40 b
Constant	848.62 a	13.58 a
<i>LSD (P=0.05)^d</i>	<i>47.36</i>	<i>0.98</i>

^aMeans in a column followed by the same letter are not significantly different by Fishers LSD test; NSD = not significantly different.

Table 4. Irrigation experiment results on tuber cracking with cv. Chieftain and *Potato virus Y*. All ‘stock’ seed tubers were symptomatic for PVY, and obtained from PVY+ plants. All ‘healthy’ seed tubers were nuclear mini-tubers obtained from tissue cultured plants, certified to be virus free.

Irrigation treatment ^a	Cracking index ^b	Avg. no. progeny tubers		Avg. % progeny tubers	
		Crk ^c	Crk+N ^c	Crk	Crk+N
Alternating	0.55 a	0.73 a	0.43 a	8.60 a	5.21 a
Constant	1.54 b	3.28 b	2.43 b	30.08 b	21.72 b
<i>LSD (P=0.05)^d</i>	<i>0.51</i>	<i>0.70</i>	<i>0.61</i>	<i>7.46</i>	<i>6.65</i>

^aConstant irrigation was delivered daily; alternating irrigation was delivered sporadically. ^bCracking index was calculated by tuber weight and percent of cracking on the tuber surface; ^cCrk = cracked; Crk+N = cracked and necrotic. ^dMeans in a column followed by the same letter are not significantly different by Fishers LSD test; NSD = not significantly different.

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