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Transfer of Resistance to Multiple Strains of Potato virus Y by Traditional Breeding of Potato Cultivars

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Abstract

Potato virus Y (PVY) is a major pathogen affecting potato crops worldwide, which causes yield and quality losses, and requires intensive management including breeding for host resistance. ‘Cooperation-88’ (C88) and its derivatives show durable resistance in the field to late blight and viral infection. Here, resistance to four PVY strains was evaluated in C88 and derived selections. Plants were mechanically and graft inoculated, and infection assessed by ELISA. No PVY infection was detected in any of the tested cultivar-PVY strain treatments, while susceptible control ‘Russet Burbank’ was infected in all cases. No visible symptoms were observed in foliage or tubers, and plant growth and yield were not significantly affected by inoculation. These results demonstrate strong resistance to multiple PVY strains in C88 and confirm transfer of resistance to derived selections through conventional breeding. C88 represents a valuable resource for developing new potato cultivars with durable resistance to PVY.

INTRODUCTION

Potato crops are susceptible to yield and quality losses from a variety of pathogenic diseases, notably including Late Blight, caused by *Phytophthora infestans*, and mosaic disease caused by Potato virus Y (PVY). These two agents cause substantial economic impact in crop losses around the world, with PVY reducing yield and tuber quality and contributing to seed lot rejection, and late blight requiring intensive fungicide management costing millions of dollars annually in affected production regions (Gray and Power 2018; Johnson et al. 2000). Control of PVY further requires ongoing application of mineral oils and insecticides to suppress aphid vectors, adding additional production costs (Dupuis et al. 2014; MacKenzie et al. 2022). Breeding disease resistance into commercially acceptable cultivars represents a key strategy for managing potato diseases, complementing chemical and cultural control approaches. Host plant resistance is widely recognized as a central and sustainable component of disease management, reducing reliance on chemical inputs and associated production costs (Jimoh and Oluwayomi 2023; Karasev and Gray 2013; Quenouille et al. 2013). Another complication in managing PVY is that it exists as a complex of multiple, rapidly evolving strains, with recombinant forms now predominating in North America and globally (Karasev and Gray 2013; MacKenzie et al. 2019). Many potato cultivars also exhibit strain-specific resistance that can influence both disease expression and strain prevalence (Funke et al. 2017); therefore, evaluation of resistance against multiple representative PVY strains is essential.

Members of the Canadian Private Breeders Network established a goal to verify if resistance to disease could be transferred to progeny from potato crosses (Gibson et al. 2023). The potato cv. Cooperation-88 (C88) widely adopted in China due to its high yield and processing quality (Li et al. 2019), and its sibling cv. Igorota mainly in Vietnam and the Philippines, have shown durable resistance to late blight and several viruses (Chien et al. 2016, Hao et al. 2018, Li et al. 2011). The successful deployment of Igorota in commercial production systems, where it occupies a majority of the cultivated area in some regions, demonstrates the practical value of resistance breeding as a disease management strategy and suggests that related germplasm such as C88 may carry similarly effective resistance traits. The genetic

basis of this resistance is partially characterized, and suggests a rationale for its transfer through breeding. Igorota has been shown to carry the Ry_{adg} gene conferring extreme resistance to PVY, as well as multiple genes associated with late blight resistance (Chien et al. 2016). Similarly, the related cultivar C88 has also been reported to contain multiple R genes contributing to late blight resistance and suspected genetic resistance to PVY (VanderZaag et al. 2024). C88 produces high yields under short-day conditions in China, but lowered yields in long-day Canadian conditions (Li et al. 2011). Thus, interest was expressed from private breeders to verify if these disease resistance traits in C88 could be readily transferred to long-day adapted progeny by traditional crossing procedures. Crosses were successfully made between C88 · Prospect and C88 · Shepody, two established long-day Canadian varieties used in French fry production (Coffin et al. 2009; Young et al. 1983) and the generated progeny (PSPG15-80- 9LB and PSPG 15-81-1) were placed in late blight trials in Alliston, Ontario. These two seedlings showed strong resistance to late blight while the check cultivar Lamoka was severely damaged by late blight (VanderZaag et al. 2024). In field observation trials, several private breeders observed that some seedlings from the crosses developed typical mosaic symptoms of virus infection, sometimes including tuber necrosis (potato tuber necrotic ringspot disease). Seedlings which never developed such symptoms in the field trials were speculated to have inherited viral resistance from the C88 parent, and thus this study was designed to verify resistance of these progeny to a range of PVY strains.

MATERIALS AND METHODS

Plant material and Experimental Design

PVY-free tubers of Cooperation-88 (C88) and two derived selections (PSPG 15-80-9LB, PSPG 15-81-1), and an independently derived selection, SPT293, with *Solanum berthaultii* background and previously observed field resistance to PVY, were provided by Sunrise Potato (Alliston, ON, Canada) and grown in greenhouses at Agricultural Certification Services Inc. (Fredericton, NB, Canada). Tubers were planted individually in 2-gallon pots containing Pro-Mix BX potting medium. The greenhouse experiment was conducted once. For each selection, 15 plants were established and arranged as five treatments consisting of four PVY strains and a sham-inoculated control (buffer-only inoculation); thus, each cultivar × mechanical inoculation treatment included three independent replicate plants. An additional set of 15 plants of the PVY-susceptible cultivar ‘Russet Burbank’ was included as a positive control for infection by all PVY strains.

PVY mechanical and graft-inoculation, and testing

Mechanical PVY inoculation followed the method of MacKenzie et al. (2019). Leaf tissue infected with each PVY strain was freshly pulverized in chilled inoculation buffer (50 mM glycine, 30 mM K_2HPO_4, pH 9.2), then applied to recipient plants using light abrasion with carborundum powder. Inoculum was gently rubbed onto three leaflets on two leaves per plant, distributed across separate stems. Inoculations were made 29 days after planting (DAP), when plants were 30 to 50 cm in height and had 10 to 15 fully

expanded leaves. PVY isolates used for inoculation were: PVY^{O}-FL, $PVY^{N:O}$-Mb112 and PVY^{NTN}-SI (Nie and Singh 2003, Nie et al. 2004, 2011), and a $PVY^{N\text{-}Wi}$ isolate collected in New Brunswick in 2023. All isolates were previously confirmed by sequencing and routinely tested to ensure absence of contamination by other common potato viruses, including PVA, PVM, PVS, PVX, and PLRV.

Following assessment of resistance to mechanical inoculation, a secondary challenge was conducted using graft inoculation to expose plants to a systemic PVY infection. A single representative plant per cultivar-strain combination was grafted with a scion from PVY-infected 'Russet Burbank' plants representing each of the four PVY strains. Grafting followed the method of Whitworth et al. (2009). A stem section (~ 10 cm) of the recipient plant was removed using a vertical wedge cut and replaced with a similarly sized scion from an infected donor plant prepared with a complementary cut. The graft union was secured with Parafilm and maintained under high humidity by loosely covering with a plastic bag for 3 to 4 days to ensure successful graft establishment.

PVY testing, symptom expression and growth and yield measurements

PVY infection was assessed using enzyme-linked immunosorbent assay (ELISA) following Singh et al. (2003). For mechanically inoculated plants, newly emerged leaves were sampled 15 days after inoculation. For grafted plants, leaf tissue from both the graft scion and the recipient plant immediately below the graft junction was sampled 15 days after grafting to confirm PVY in the scion and assess systemic movement into the host plant.

Plant height was measured weekly beginning 21 days after planting to monitor growth dynamics through inoculation and subsequent development. At onset of natural senescence, vine-kill was simulated by cutting stems at soil level and allowing plant material to dry in place. After ~ 1 week, dried aboveground biomass was collected and recorded as shoot biomass. Tubers were harvested 10 days after vine-kill, counted, and weighed for each plant. Tubers from each treatment were stored under cool, dark conditions, and representative samples were washed and imaged. Following storage, tubers were subjected to a rindite-based dormancy breaking treatment to induce sprouting (Gugerli and Gehriger 1980), after which they were scheduled for later PVY testing. Within each cultivar, growth rate, shoot mass, tuber yield, and tuber number for each PVY strain treatment were compared with the sham control using two-sided independent-samples t-tests ($\alpha = 0.05$).

RESULTS AND DISCUSSION

PVY infection status

No PVY infection was detected in any of the test cultivars following mechanical inoculation with four PVY strains. ELISA testing conducted 15 days post-inoculation showed no detectable virus in any of the replicate plants across all strain treatments for C88, PSPG 15-80-9LB, PSPG 15-81-1, and SPT293

(Table 1). The known-susceptible control cultivar Russet Burbank, however, tested positive for PVY in all plants for each strain, confirming that inoculation procedures were effective and that viral inoculum was viable.

Graft inoculation of a subset of test cultivar plants also did not show systemic infection of host plants, despite detectable PVY persisting in the infected scions. The absence of detectable PVY following graft inoculation indicates that resistance in these cultivars is maintained even under conditions of prolonged and direct vascular exposure to infected tissue. This result is consistent with a strong form of resistance in the host plants that restricts systemic virus movement or viral replication.

Table 1
Detection of Potato virus Y (PVY) by ELISA 15 days after mechanical inoculation with four PVY strains or a sham control. Values are the number of ELISA-positive plants divided by the number tested.

Cultivar	Control	PVY^{O}	$PVY^{N:O}$	PVY^{N-Wi}	PVY^{NTN}
Cooperation-88	0/3	0/3	0/3	0/3	0/3
PSPG 15-80-9LB	0/3	0/3	0/3	0/3	0/3
PSPG 15-81-1	0/3	0/3	0/3	0/3	0/3
SPT293	0/3	0/3	0/3	0/3	0/3
Russet Burbank (susceptible control)	0/3	3/3	3/3	3/3	3/3

Symptoms

No visual symptoms characteristic of PVY infection were observed in any of the tested genotypes following either mechanical or graft inoculation. Plants across all strain treatments appeared visually similar within each genotype, with no evidence of mosaic, chlorosis, or deformation typically associated with PVY infection (Fig. 1, Fig. 2).

Minor differences in plant development and senescence patterns were observed between cultivars but were not associated with different PVY inoculation strains within cultivars. C88 exhibited some loss of older leaves during development, while PSPG 15-81-1 showed a tendency toward earlier senescence relative to other genotypes. PSPG 15-80-9LB and PSPG 15-81-1 both showed localized leaf drop at the inoculation sites, but otherwise no typical PVY symptoms. While these responses were not accompanied by detectable PVY infection, they may represent a specific resistance response in the cultivars as this reaction only occurred in plants inoculated with pulverized leaf tissue containing PVY, and was not noted simply from mechanical injury in the sham-inoculated control.

Table 2
Growth, yield, and notable observations for genotypes mechanically inoculated with four Potato virus Y strains or a sham control. Values are means ± standard errors (n = 3). *Significantly different from the sham control within the same genotype (α = 0.05).

Cultivar	strain	Growth rate (cm day^{-1})	Shoot mass (g)	Tuber Yield (g)	Tubers (per plant)	Notable symptoms
Cooperation-88	control	2.37 ± 0.16	119 ± 22	12 ± 1	4.3 ± 0.9	none
	O	2.07 ± 0.21	128 ± 4	75 ± 39	7.3 ± 2.4	Older leaf drop
	N:O	2.66 ± 0.16	120 ± 8	141 ± 31*	6.7 ± 0.9	none
	N-Wi	2.25 ± 0.1	98 ± 3	108 ± 30*	8.3 ± 0.9*	Older leaf drop
	NTN	1.99 ± 0.11	116 ± 13	118 ± 39	9.7 ± 2.8	Older leaf drop
PSPG 15-80-9LB	control	1.83 ± 0.1	165 ± 21	240 ± 65	2.7 ± 0.7	none
	O	1.59 ± 0.03	185 ± 10	152 ± 34	2.3 ± 0.7	Inoculated leaf drop
	N:O	1.6 ± 0.16	202 ± 32	242 ± 19	4 ± 0.6	Inoculated leaf drop
	N-Wi	1.74 ± 0.12	177 ± 10	201 ± 44	3 ± 0.6	Inoculated leaf drop
	NTN	1.88 ± 0.03	201 ± 23	109 ± 51	2.3 ± 0.7	Inoculated leaf drop
PSPG 15-81-1	control	1.32 ± 0.17	49 ± 8	321 ± 17	4.7 ± 0.7	none
	O	2.2 ± 0.27	21 ± 3	277 ± 27	5.7 ± 1.2	Inoculated leaf drop
	N:O	1.42 ± 0.22	39 ± 5	351 ± 12	7 ± 0.6	Inoculated leaf drop
	N-Wi	1.77 ± 0.26	64 ± 12	293 ± 44	5.3 ± 0.3	Inoculated leaf drop
	NTN	1.77 ± 0.38	56 ± 4	332 ± 4	5.3 ± 0.9	Inoculated leaf drop
SPT293	control	1.31 ± 0.06	135 ± 30	211 ± 18	4.7 ± 0.9	none

Cultivar	strain	Growth rate (cm day^{-1})	Shoot mass (g)	Tuber Yield (g)	Tubers (per plant)	Notable symptoms
	O	1.26 ± 0.33	105 ± 21	240 ± 22	5.3 ± 0.3	none
	N:O	1.41 ± 0.24	111 ± 22	213 ± 40	4.3 ± 0.9	none
	N-Wi	1.27 ± 0.13	107 ± 18	260 ± 16	6.3 ± 1.5	none
	NTN	1.55 ± 0.14	109 ± 22	259 ± 14*	4.7 ± 1.2	none

Overall, visual appearance of whole plants (Fig. 1) and individual leaves (Fig. 2) were consistent within each cultivar regardless of PVY strain, and measured parameters of growth and tuber yield were generally not different across PVY strain treatments (Table 2). Plant growth rates, measured as increase in height in the weeks following inoculation, and final above-ground shoot mass were not significantly different across PVY strain treatments. Following simulated top kill and harvest of tubers, in general neither the total yield averaged among the replicate plants nor number of tubers per plant within each cultivar were significantly different. The most notable exception was that yield from the sham-inoculated control C88 plants was substantially lower than the inoculated plants. This difference likely reflects variation in tuber bulking stage at the time of vine kill rather than an effect of PVY inoculation. Photographic panels of cleaned, representative tubers from each cultivar · strain combination are shown in Fig. 3. After several weeks of storage, then dormancy breaking and sprouting, none of a subset of tubers from each cultivar · strain combination showed any detectable PVY in daughter tubers by ELISA sprout test.

The absence of detectable PVY infection by four PVY strains, following both mechanical and graft inoculation methods, provides strong evidence for broad PVY resistance in the parental C88 cultivar, that was maintained in the derived selections evaluated in this study (PSPG 15-80-9LB, PSPG 15-81-1). The ability to resist infection under both primary mechanical inoculation and systemic graft challenges suggests a strong mechanism of resistance that is effective across PVY strains. These results support the transferability of PVY resistance from C88 to progeny through conventional breeding, and show the potential for developing potato cultivars with durable, multi-strain resistance to PVY. The absence of PVY infection in SPT293, an independently *S. berthaultii*-derived selection, indicates that strong resistance to PVY is not limited to C88-derived germplasm and may arise from distinct genetic sources. This supports the potential for identifying and incorporating multiple sources of PVY resistance in potato breeding programs.

CONCLUSIONS

This study shows that the potato cultivar Cooperation-88 (C88) and its derived selections possess strong resistance to multiple strains of PVY, as shown by the absence of detectable infection following both mechanical and graft inoculation under controlled greenhouse conditions. The lack of infection across all tested strains suggests a strong and heritable resistance that was effectively transferred from C88 to its progeny through conventional breeding.

These findings support the continued use of C88 as a valuable parent in potato breeding programs aimed at developing cultivars with durable, multi-strain PVY resistance. The inclusion of an independently derived selection (SPT293) showing a similar resistance to PVY across strains further suggests that strong resistance to PVY may be obtained from other genetic sources as well. The ability to combine virus resistance with agronomically acceptable traits in long-day adapted germplasm highlights the practical potential of this approach for improving potato production systems. While transgenic approaches have previously been used to introduce virus resistance into potato cultivars, such as the “NewLeaf” lines developed in the 1990s, these technologies did not achieve sustained market acceptance despite demonstrated efficacy. Consequently, conventional breeding strategies remain the primary pathway for developing virus-resistant cultivars for commercial production, and the results presented here reinforce the feasibility of this approach.

Declarations

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Competing interests

The authors have no relevant financial or non-financial competing interests to declare.

Author Contribution

P. V., J. C., R. C., D. G., and A. G. conceptualized study and provided seed tubers. M. S. and T. M. conducted PVY infection trials and analysis. P. V. and T. M. drafted and edited manuscript. All authors read and approved the final manuscript.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figures

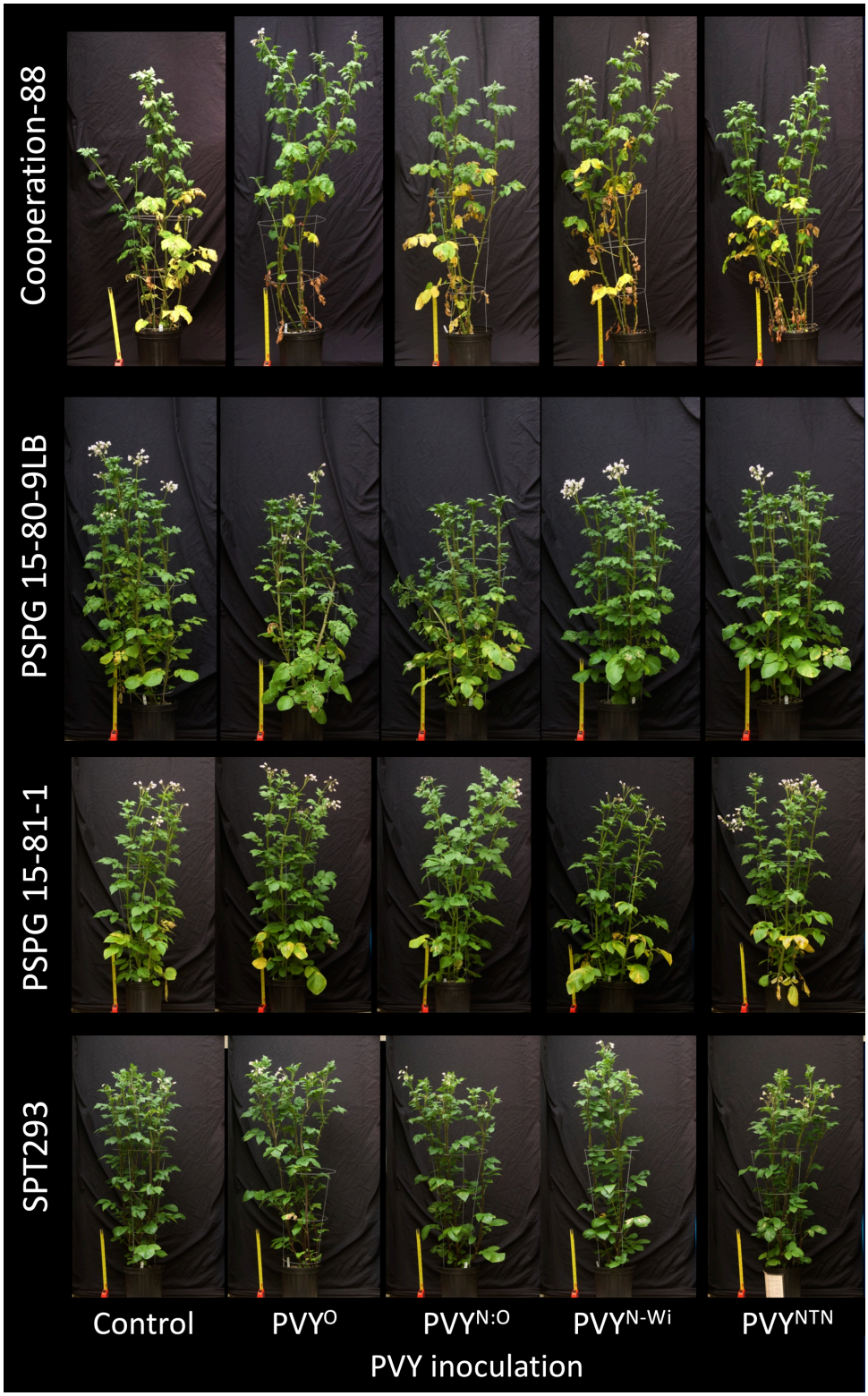


Figure 1

Whole-plant images of four cultivars 24 days after mechanical inoculation with four PVY strains and a sham control. No visible symptoms of PVY infection were observed across strain treatments. Scale measure ~33 cm.

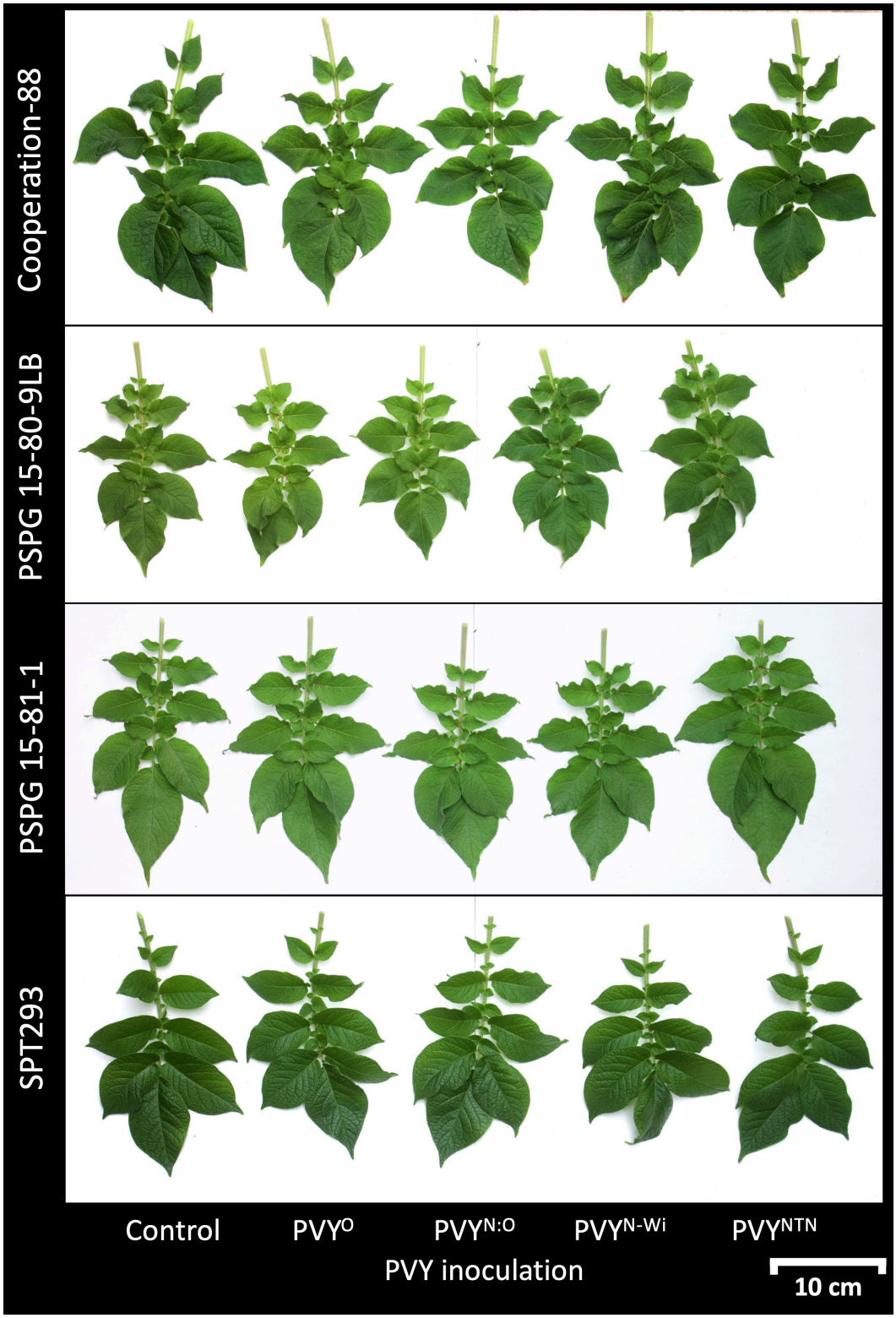


Figure 2

Leaf images of cultivars 17 days after mechanical inoculation with PVY strains. Leaves sampled from non-inoculated positions on inoculated stems showed no visible symptoms of PVY infection. Scale bar 10 cm.

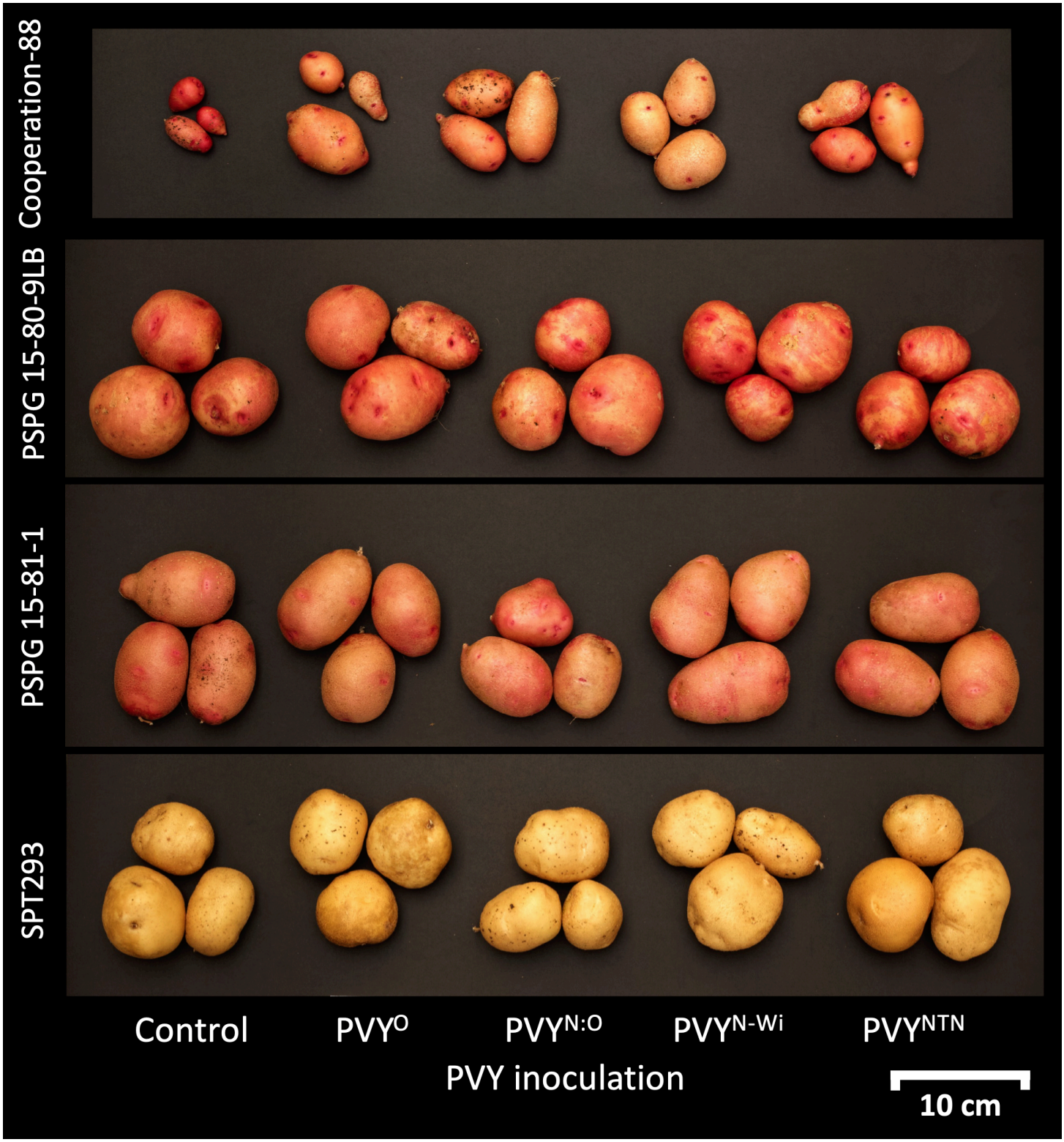


Figure 3

Photographic panel of tubers, imaged at 18 days post-harvest. Three representative tubers for each cultivar-strain combination are shown, demonstrating no notable symptoms of PVY infection. Scale bar 10 cm.