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# Seed Potatoes, Virus Management, and the Nonadoption of an Agricultural Innovation*

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Abstract Beginning in 2012, seed potatoes in Washington State were associated with an outbreak of *Potato virus Y* (PVY), one of the oldest known plant viruses. The PVY outbreak seriously impacted commercial potato growers, who unknowingly purchased infected seed potatoes. Commercial potato growers, university researchers, and extension personnel blamed Washington seed potato growers for the PVY outbreak. Drawing on the literature about perceptions of innovation attributes, nonadoption of agricultural innovations, and farm-level disease management, we offer a broader perspective on PVY management among Washington seed potato growers. We explore the reasons behind seed potato growers' nonadoption of a specific innovation that has the potential to protect potatoes from PVY problems. We argue that seed potato growers approach PVY management in logical and intentional ways, and have distinct reasons for choosing not to adopt certain PVY management practices. Our study contributes to scholarship on the perceived attributes and nonadoption of agricultural innovations, as well as interdisciplinary work on plant disease management. A better understanding of PVY management decision making can help efforts to ensure agricultural biosecurity, maintain crop quality and yield, and prevent economic losses within the potato industry in Washington State, the second largest producer of potatoes in the United States.

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## Introduction

Beginning in 2012, seed potatoes in Washington State were associated with an outbreak of *Potato virus Y* (PVY), one of the oldest known plant viruses. The PVY outbreak seriously impacted commercial potato growers, who unknowingly purchased infected seed potatoes. Since the outbreak, commercial potato growers, as well as university research and extension personnel, have "individually blamed" Washington seed potato growers for the PVY outbreak.[1] These groups have argued that seed potato growers are reluctant to adopt management practices (specifically, winter field testing of seed lot samples in Hawaii followed by laboratory verification of PVY presence or absence) that have the potential to protect potatoes from the problems associated with PVY. Commercial potato growers, university researchers, and extension personnel have not focused on the larger context in which Washington seed potato growers operate, nor explored in depth the experiences and perceptions of seed potato growers. However, gathering information about the sociocultural context of farmers' perceptions (especially with regard to innovation attributes and potential risks) is essential for understanding farm-level disease management decisions (Breukers et al. 2012; Ilbery 2012; Maye, Ilbery, and Little 2012; McRoberts et al. 2011; Mills et al. 2011; Rogers 2003). The purpose of this article, therefore, is to offer a broader perspective on PVY management decisions in Washington State.

Drawing on the literature about perceptions of innovation attributes, the nonadoption of agricultural innovations, and farm-level disease management decision making, we explore the case of the nonadoption of winter field testing of seed lot samples in Hawaii followed by laboratory verification of PVY presence or absence among Washington seed potato growers. We argue that Washington seed potato growers approach PVY management in logical and intentional ways, and have distinct reasons for choosing not to adopt certain PVY management practices. Our study contributes not only to scholarship on the perceived attributes and nonadoption of agricultural innovations but also to interdisciplinary work on general plant disease management decision making. Moreover, a better understanding of PVY management can also help efforts to ensure agricultural biosecurity, maintain crop quality and yield, and prevent economic losses within the Washington potato industry.

[1] Individual blame, as defined in diffusion research, is the "tendency to hold an individual responsible for his or her problems, rather than the system of which the individual is a part" (Rogers 2003:118–19). In most cases, a combination of individual- and system-level variables explains innovation adoption and rejection behaviors.

This article is organized into five sections. First, we discuss the classic diffusion-of-innovations framework, and review the literature on the nonadoption of agricultural innovations and farm-level disease management decision making. Second, we provide background on potato production and PVY management in the study region. Third, we describe our research methods. Fourth, we present and discuss our findings. Last, we summarize our results, discuss research and practical contributions, point out study limitations, and suggest ideas for future research.

## Literature Review

### Classic Diffusion-of-Innovations Framework

Research on how, why, and at what rate societies adopt new technologies and ideas has a long history. While anthropological studies of innovation diffusion were popularized in the 1930s, diffusion research was integrated into rural sociology in the 1940s to study new farming practices (Rogers 2004). Ryan and Gross (1943), for example, drew on early anthropological diffusion research to study the noneconomic factors influencing farmers' decisions to adopt hybrid seed corn in two Iowa communities. They found that the rate of adoption of hybrid seed corn followed an "S-shaped curve": adoption was slow at first followed by a "take off" period and then a gradual leveling off as fewer farmers remained to adopt (see also Rogers 2004). Ryan and Gross's study of the exchange of information about hybrid seed corn and timing of innovation adoption provided the basic framework for the study of the diffusion and adoption of innovations (Rogers 2004).

In the decades following Ryan and Gross's work, Everett Rogers (1962, 1971, 1983, 1995, 2003) further refined the diffusion model. According to Rogers in the fifth edition of his book *Diffusion of Innovations* (2003:5), diffusion is "the process in which an innovation is communicated through certain channels over time among the members of a social system." An *innovation* is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (12). A *communication channel* (e.g., mass media or a face-to-face exchange) is "the means by which messages get from one individual to another" (2003:18). The diffusion of new ideas can be planned or spontaneous, but communication always involves the creation and sharing of information. The passage of *time* is necessary for an individual to move through the five stages (knowledge, persuasion, decision, implementation, and confirmation) of the innovation–decision process. Lastly, a *social system* is defined as "a set of interrelated units that are engaged in joint problem solving to accomplish a common goal" (23). These four elements—an innovation, communication channels, time, and a social system—are "identifiable in every diffusion research study and in every diffusion campaign or program" (11).

Because the spread of new ideas has important consequences for the members of a social system, diffusion is a type of social change (Rogers 2003). More specifically, the diffusion of innovations is a "universal micro-process of social change" that can be "applied to a variety of real world problems, often with useful results" (Rogers 2004:16, 18). The accumulation of over 5,000 diffusion publications since the 1940s attests to the generalizability of the diffusion model (Rogers 2004).

## Nonadoption of Agricultural Innovations

Historically, diffusion studies have focused on innovations that are popular and easy to track (Rogers 2003; Ryan and Gross 1943; Strang and Soule 1998). Consequently, diffusion research often exhibits a "proinnovation bias" based on the assumption that all innovations are inherently good and eventually adopted by the members of a social system (Rogers 2003). Moreover, some studies wrongfully assume that innovation decisions take place within a static environment, without the influence of external factors such as political climate, advancing technologies, or societal changes (for more on this issue see Kremer et al. 2001; Moser and Barrett 2003; Rogers 2003). Buttel, Larson, and Gillespie (1990:46) describe the proinnovation bias as "a promotional posture toward technological change" whereby the goal of diffusion research was often to devise ways to enable "change agents" (e.g., extension personnel) to increase the rate of adoption of "improved" or "recommended" innovations. This "promotional posture" has resulted in a significant gap in the diffusion literature: it lacks research specifically on the *nonadoption* of innovations.

Studies of nonadoption tend to conflict with the larger tradition of diffusion research. In early applications of diffusion theory, nonadopters were often thought to be traditional, resistant to change, or irrational (Belasco 1989; Rogers 2003; Sommers and Napier 1993; Vanclay 1992). However, as Yapa and Mayfield (1978:146) said nearly 40 years ago, "non-adoption is not a passive state caused by apathy or resistance; on the contrary, it is an active state." The rejection of an innovation is often "objectively rational" and "makes sense" from the individual's perspective (Vanclay 1992:10; also see Rogers 2003). Accordingly, understanding the reasons behind nonadoption can help inform the promotion or future adoption of critical innovations such as water filtration systems (Belasco 1989), hybrid rice (Shah, Grant, and

**Table 1. Perceived Attributes of an Innovation.**

| Attribute | Description |
|---|---|
| Relative advantage | The degree to which an innovation is perceived to be better, or to have some kind of measurable benefit over an existing practice or technology. |
| Compatibility | The degree to which an innovation is perceived to be consistent with current practices, past experiences, existing values, and the needs of potential adopters. |
| Complexity | The degree to which an innovation is perceived to be hard to understand, difficult to implement, or overly complex. |
| Trialability | The degree to which an innovation is perceived to have the ability to be experimented with on a limited or short-term basis. |
| Observability | The degree to which the results of an innovation are visible to others. |

Adapted from Rogers (2003).

Stocklmayer 2014), sustainable agriculture practices (Carolan 2006; Goldberger et al. 2015; Rodriguez et al. 2009; Wheeler 2008), environmental or conservation practices (Cullen, Forbes, and Grout 2013; Greiner and Gregg 2011), and climate-smart agriculture (Long, Blok, and Coninx 2016).

Understanding individuals' perceptions of the attributes of an innovation is essential for explaining nonadoption behavior. According to Rogers (2003), the perceived attributes of innovations account for approximately 50 to 90 percent of the variance in the rate of adoption of innovations. The classic diffusion model highlights five attributes of innovations: relative advantage, compatibility, complexity, trialability, and observability (Table 1). An innovation is *less likely* to be adopted if potential adopters perceive it to have few advantages over existing technologies or ideas; to be incompatible with existing values, past experiences, and needs; to be difficult to understand and use; to be difficult to experiment with on a small scale; and/or to have results that are difficult to observe or describe (Kremer et al. 2001; Rogers 2003). Innovations that are deemed too expensive, knowledge intensive, risky, and inflexible are also less likely to be adopted (Vanclay 1992).

A study by Kathy Kremer and colleagues (2001) demonstrates the important influence of farmers' perceptions of innovation attributes on nonadoption behavior. Chase and Korsching (1992) suggested that a new kit to measure cornfield soil nitrogen levels would be quickly adopted by farmers in Iowa. However, company representatives and university researchers later noticed a decline in kit sales for no apparent reason. Seeking to understand this rejection behavior, Kremer et al. found that Iowa farmers either initially adopted and then discontinued the use of the soil test kit or rejected it altogether. They discovered that prior researchers had incorrectly predicted the rapid adoption of the kit in part because they had not taken into account Iowa farmers' perceptions of the attributes of the innovation. Of particular importance were farmers' perceptions that the kit was incompatible with their other farming practices (e.g., the use of anhydrous ammonia), required high labor and capital expenditures, and lacked a comparative advantage over other soil-testing options.

Farmers' perceptions of agricultural innovations can be influenced by motivations, communication channels, social networks, cultural norms, and epistemic distance. Greiner and Gregg (2011) argue that farmers' "motivational profiles" (economic and financial, conservation and lifestyle, and social) influence their perceptions of the barriers to the adoption of on-farm conservation practices (also see Brodt, Klonsky, and Tourte 2006). In her study of agricultural professionals' views on the barriers to further adoption of organic farming and genetic engineering, Wheeler (2008) emphasizes the importance of communication channels and social networks in shaping farmers' perceptions of agricultural innovations. Other researchers (e.g., Compagnone and Hellec 2015; Moore 2008) have studied how the composition of social networks and the conflicts that can arise between different network segments can influence farm-level decisions. Vanclay (1992) discusses the powerful norms associated with the "farming subculture," which often dictate how new agricultural practices "should" be perceived by farmers (also see Rodriguez et al. 2009). In his study of the barriers to the widespread adoption of sustainable agriculture, Carolan (2006:234) focuses on "epistemic distance," which relates to "socio-biophysical objects, effects, and relationships that are beyond direct perception." He argues that socioinstitutional relationships shape how and what farmers "see," and, consequently, the decisions farmers make about the adoption or rejection of agricultural innovations.

### Farm-Level Disease Management Decision Making

Relatively few social science studies have focused on the factors that influence farmers' decisions to adopt (or reject) management practices that can help reduce the spread of plant viruses, which can cause significant losses in crop quality, yield, and income. In recent years, social scientists have been "critical of macro-scale and scientific/technical approaches to biosecurity, calling for more micro-scale and farm-level studies" that focus on farmers' risk perceptions and disease management strategies (Ilbery 2012:310). How farmers "encounter, comprehend, and manage disease" (Ilbery 2012:311) can have important implications for agricultural biosecurity, crop production, food supply chains, and food security (Ilbery 2012; Maye et al. 2012; Mills et al. 2011).

Geographers Brian Ilbery, Damian Maye, and Ruth Little have conducted the most notable research on the human factors that influence the management of plant diseases (Ilbery 2012; Ilbery, Maye, and Little 2012; Ilbery et al. 2013; Maye et al. 2012). Their work on the U.K. potato and wheat sectors has focused specifically on risk perceptions, practical rationality, intuition, and relationships between growers and agronomists. Based on qualitative research in eastern England and the west Midlands, Maye et al. (2012) argue:

> Perceptions of and strategies to mitigate plant disease risk involve scientific deliberation. However, as interviews with growers in both [the potato and wheat] sectors highlighted, scientific rationality is bounded . . . by practical concerns and conditions, grower knowledge, past experiences, professional advisory relations and other farm business factors. Decision-making is rational but encultured as a *practical farm management priority* rather than pure scientific risk. (345, emphasis in original)

Ilbery et al. (2012) emphasize the significance of "risk as feeling" (Slovic et al. 2004), which refers to the practice of growers and agronomists relying on their instincts, intuition, and experiential knowledge—in addition to scientific or technical information ("risk as analysis")—when making risk management decisions or recommendations. The extent of knowledge exchange between growers and agronomists depends on growers' perceptions of their own knowledge and levels of trust within their sociospatial knowledge networks (Ilbery et al. 2012). Taking a broader, industrywide perspective, Ilbery et al. (2013) examine the risk perceptions of not only growers and agronomists but also input suppliers, grain merchants, and flour and feed millers associated with the U.K. wheat sector. The majority of interviewees believed that endemic plant disease is a "controllable risk . . . that rests mainly at the point of production (i.e., with farmers)" (Ilbery at al. 2013:129). However, climate change, changing regulations, and other perceived future threats are increasing the uncertainty about how farmers, agronomists, "upstream" and "downstream" businesses, and policymakers should respond to plant disease risks (Ilbery et al. 2013).

Other researchers (Breukers et al. 2012; McRoberts et al. 2011; Mills et al. 2011; Wilkinson et al. 2011) have emphasized the importance of improved dialogue among natural scientists (e.g., plant pathologists), social scientists, and on-farm decision makers regarding plant disease management practices. Plant disease management approaches that are too narrowly focused on epidemiological issues fail to recognize that farmers may *not* make "rational decisions based on objective risk assessment" (Breukers et al. 2012:609). Rather, farmers' perceptions of risk—both the probability of an undesirable event and the intensity of potential negative impacts—are socially constructed (subjective) and influenced by a wide range of sociocultural, economic, and other factors (McRoberts et al. 2011; also see Naylor and Courtney 2014). Social science understandings of why farmers do not act "rationally" (resulting in low adoption rates of important disease management practices) can help plant disease specialists, agriculture service providers, and policymakers tailor their research, outreach, and policy decisions, respectively, to better meet farmers' needs (Breukers et al. 2012; Mills et al. 2011). Responding to this call for interdisciplinary approaches to understanding on-farm plant disease management, our research team consisted of two plant pathologists, one sociologist, and one agriculture extension educator, working in close collaboration with farmers in the study region.

**Background on Washington Potatoes and PVY**

Potato production is a critically important component of Washington State's agricultural economy. Planted on over 160,000 acres, potatoes are Washington's fourth most important crop (WSPC 2007). Because of nutrient-rich soils and climate, Washington potato farms rank number one globally in total yield per acre (WSPC 2007). The Washington potato industry has an economic impact of more than $4.6 billion, and produces over 20 percent of all potatoes in the United States (NASS 2015; WSPC 2007). The state's fresh market potato industry is located primarily in western Washington, on approximately 12,000 acres with a value of $60 million (McMoran 2015). Four percent of Washington potatoes are grown for seed (NASS 2015). Nine certified seed potato operations, concentrated primarily in western Washington, grow more than 120 varieties of seed potatoes on approximately 3,215 acres (NASS 2015; WSSPC 2015). Many fresh market potato growers in the state purchase certified seed potatoes from operations in the region, effectively linking the two industries.

Unlike many other vegetable crops that are grown from true seed, potatoes are propagated by vegetative methods. This practice is due in part to the high genetic variability of true potato seed, and because some potato cultivars do not flower or form fruit. Growing tubers by

**Table 2. Characteristics of Certified Seed Potato Programs in the United States.**

| State | 2014 Certified Acreage | Percentage of U.S. Seed Potato Industry | Winter Grow-Out Location |
|---|---|---|---|
| Alaska | 32 | 0.03 | Hawaii |
| California | 1,018 | 0.92 | Hawaii or S. California GH[a] |
| Colorado | 10,975 | 9.91 | Hawaii |
| Idaho | 32,367 | 29.21 | Hawaii |
| Maine | 10,861 | 9.80 | Florida |
| Michigan | 2,185 | 1.97 | Florida |
| Minnesota | 5,580 | 5.04 | Hawaii |
| Montana | 10,194 | 9.20 | Hawaii |
| Nebraska | 6,016 | 5.43 | Hawaii |
| New York | 617 | 0.56 | Florida |
| North Dakota | 16,104 | 14.53 | Florida |
| Oregon | 2,623 | 2.37 | Oregon GH |
| Pennsylvania | 367 | 0.33 | Florida |
| Washington | 3,215 | 2.90 | Washington GH |
| Wisconsin | 8,643 | 7.80 | Hawaii |
| Total | 110,797 | | |

*Source*: PAA Certification Section (2015); NASS (2015); Sather et al. (2014); personal communications with representatives from Minnesota, Nebraska, New York, Oregon, Pennsylvania, and Wisconsin.

[a]GH = greenhouse.

vegetative propagation produces progeny tubers that are genetic clones of parents. While genetic uniformity is ideal for mechanized agriculture systems, the practice of vegetative propagation makes tuber-borne (often referred to as seedborne) plant pathogens, especially plant viruses, an increasing threat to each subsequent potato generation (Karasev and Gray 2013). In an attempt to help ensure that progeny tubers are disease free, seed potato growers adhere to seed certification rules and regulations.

Seed certification programs began in North America in 1913 as a result of the National Plant Quarantine Act of 1912 (Whitworth and Davidson 2008). After recognition of the need to have more consistency between country and state-province borders, the Certification Section of the Potato Association of America (PAA) was established in 1964. The members of the group implemented standardized protocols to address different issues of concern including establishing the "U.S. No. 1 Seed Potato Grade," uniform disease tolerance levels for early generation seed, and U.S. Export Seed Potato Standards (Whitworth and Davidson 2008). Throughout North America today, 15 states (Table 2) and 10 Canadian provinces grow and certify more than 240 cultivars of seed potatoes on over 197,000 acres (PAA Certification Section 2015; Whitworth and Davidson 2008). A major purpose of these programs is to help manage different seedborne potato diseases including those caused by viruses such as PVY.

PVY is the fifth most economically harmful plant virus in the world (Scholthof et al. 2011), and is recognized as the most impactful viral pathogen with a global distribution (Kerlan and Moury 2008). PVY has a wide host range and can infect major solanaceous crops (eggplant, pepper, potato, tobacco, and tomato), hundreds of species of weeds, and some ornamental plants (De Bokx and Huttinga 1981; Kerlan 2006; Shukla, Ward, and Brunt 1994). The virus can contribute to yield losses of 10–100 percent in potatoes, and lead to tuber necrosis and defects that render tubers unmarketable (De Bokx and Huttinga 1981).

PVY can be transmitted by infected seed tubers or from potato plant to potato plant by aphids or by mechanical means. Because potatoes are grown as genetic clones of parent tubers and parental diseases passed on to progeny tubers increase with every generation, PVY-infected seed potatoes represent a primary source of inoculum within a field (Gray et al. 2010). The appearance of diseased plants early in the growing season enables secondary spread of the virus by its aphid vectors, or through sap transfer when plants are wounded (Gray et al. 2010).

There are different strains of PVY that can cause infection. The oldest strain, PVY$^{O}$, causes symptoms that vary in severity and appearance depending on the potato variety. Generally, PVY$^{O}$ causes mosaic,

Figure 1. Common Foliar Symptoms Caused by PVY$^{O}$. Left: Mosaic. Right: Veinal Necrosis. [Color figure can be viewed at wileyonlinelibrary.com]

mottling, leaf drop, leaf necrosis, and reduced tuber yield (Figure 1) (Crosslin et al. 2006; Gray et al. 2010; Karasev et al. 2010). Because the mosaic symptoms induced by PVY$^{O}$ on potato foliage are relatively easy to identify by trained field inspectors (Gray et al. 2010), PVY$^{O}$-infected plants are typically removed (or rogued) from fields during seed potato certification.

A relatively new strain to the United States, PVY$^{N}$, was first reported in potato fields in the northwestern region in 2002 (Crosslin et al. 2002; Nolte, Alvarez, and Whitworth 2009). Other new strains of PVY have also emerged with genome structures that are a combination of PVY$^{O}$ and PVY$^{N}$ (Glais, Tribodet, and Kerlan 2002; Lorenzen, Meacham, et al. 2006; Lorenzen, Piche, et al. 2006; Nie and Singh 2002; Schubert, Fomitcheva, and Sztangret-Wiśniewska 2007). Recombinant strains, such as PVY$^{NTN}$ and PVY$^{N\text{-}Wi}$, are now endemic to potato fields in Washington and Idaho (Benedict et al. 2015; Crosslin et al. 2006), and they present significant challenges to these states' potato industries (Chikh-Ali, Gray, and Karasev 2013). PVY$^{NTN}$ and PVY$^{N\text{-}Wi}$ cause asymptomatic or mild symptoms on potato leaves (Chrzanowska and Doroszewska 1997; Weidemann 1988), rendering traditional visual field inspections ineffective. As a result, many seed potato certification programs throughout the United States have mandated laboratory testing for PVY in representative seed lot samples to improve accuracy over that of visual disease assessments (Crosslin et al. 2006; Piche et al. 2004; Singh et al. 2003).

In the United States, seed potato certification is managed by each state's department of agriculture. The states adhere to the same general rules that were established by the Certification Section of the PAA, but allow for flexibility depending on the needs of their region's seed potato industry. One practice that is consistent across all U.S. programs is winter grow-out testing. The goal of winter grow-out testing is to determine the health of seed potatoes that will be planted on commercial potato fields during the next season. The location of winter grow-out testing, however, can vary based on the protocols mandated by each state's seed potato certification program.

Eighty percent of the certified seed potato programs in the United States hold winter grow-out testing in a tropical location, either Hawaii or Florida (Table 2). A winter grow-out test in a tropical location, with a preference for Hawaii, aids in visual symptom expression because the temperature and light conditions enable the plant to grow rapidly and the symptoms to be more readily recognized (A. Karasev, personal communication). Also, Hawaii has low aphid incidence and no risk of frost during the winter, conditions that minimize unwanted aphid transmissions and plant injury. The winter grow-out process requires individual state programs to pack tubers, which have been treated to sprout earlier than normal, onto pallets that are shipped and delivered to one farm on Oahu. Each state is assigned a planting date and designated agents plant each state's seed lots in a specific (isolated) area of the Hawaii farm. Once plants are growing, trained inspectors collect leaf samples that are immediately sent to a designated laboratory for PVY testing in the state where the seed potatoes originated. All of these practices increase both the likelihood that potato plants will be accurately certified and the speed at which test results can be returned to seed potato growers.

In contrast, for the winter grow-out in Washington, growers transport and submit samples of tubers from different seed lots to a heated semi-permanent hoop house or greenhouse managed by the Washington State Department of Agriculture (WSDA). The submitted seed tubers are treated to break dormancy, planted into pots or trays, and inspected visually for symptoms after plants have grown approximately 15 centimeters high. Certification of potatoes using this grow-out procedure is dependent on plants expressing recognizable symptoms of PVY. Accordingly, prevailing hoop house or greenhouse conditions can have significant effects on PVY symptom expression, especially if a recombinant strain of PVY that does not cause *obvious* plant symptoms is present within a seed lot.

Despite the scientific evidence suggesting that winter grow-out testing works best under tropical conditions for accurate disease assessment and seed certification (A. Karasev, personal communication), seed potato growers in Washington State remain in favor of keeping winter grow-out testing in local greenhouses without confirmatory laboratory testing. The nonadoption of a Hawaii winter grow-out, in particular, has confused seed potato buyers, PVY researchers, and extension personnel in the region because of the tangible benefits (from their perspective) in limiting seedborne PVY. Thus, a disconnect lies between the apparent benefits of winter field testing of seed lot samples in Hawaii followed by laboratory verification of PVY presence or absence (as understood by commercial growers or buyers, researchers, and extension personnel) and seed potato growers' perceptions of what constitutes successful PVY winter detection techniques.

The primary objectives of our case study are to (1) establish a profile of commercial potato growers and certified seed potato growers in the study region, and (2) identify the reasons why seed potato growers in the region choose *not* to adopt the winter field testing of seed lot samples in Hawaii followed by laboratory verification of PVY presence or absence (hereafter referred to as the Hawaii winter grow-out innovation).

**Research Methods**

To understand the context surrounding the nonadoption of the Hawaii winter grow-out innovation, we sought information from commercial potato growers, certified seed potato growers, and university researchers and extension educators. To protect the confidentiality of participants, specific locations of the potato-growing areas are not revealed. In October 2015, we collected preliminary data to assess the knowledge, perceptions, and management practices of PVY among commercial potato growers with operations greater than 100 acres. We completed an initial round of 18 interviews that lasted approximately 10 minutes each in conjunction with Washington State University (WSU) Extension's Annual Potato Research Needs Survey of commercial potato growers in the area. Topics included the severity of PVY infections observed by the interviewees since 2012 and the reasons behind the observed decrease in PVY during the 2015 season. Following the short preliminary interview, we asked potato growers if they would be interested in participating in a longer, semistructured interview to discuss their experiences with PVY and the effects of the virus on their potato-growing operation. Twelve of 18 commercial potato growers agreed to participate. In addition, we asked seven seed potato growers at a Washington State Seed Potato Commission (WSSPC) meeting on October 8, 2015, or over the telephone if they would be interested in participating in an interview to discuss their experiences with PVY. All seven seed potato growers expressed interest in participating in this study.

We contacted the 12 commercial potato growers and seven seed potato growers who agreed to participate to arrange an audio-recorded, semistructured interview that would be conducted either in person or by telephone. If we received no response, we contacted the grower at least one more time. Six commercial potato growers (50 percent) and six seed potato growers (85 percent) completed interviews.

The second round of interviews took place in November and December 2015 for commercial potato growers, and between November 2015 and February 2016 for seed potato growers. The interviews lasted between 15 and 45 minutes and included questions about farm characteristics, experiences managing PVY on farms, seed potato practices, and economic impacts of PVY. The types of questions differed slightly for the two groups of growers, but had similar themes. We asked each participant all of the questions on the list, but some declined to answer certain questions. We transcribed all of the interviews and arranged answers by question for analysis, with the exception of one interview that was not recorded. In that instance, we transcribed interview notes and analyzed them in the same manner.

We also collected data for this study via informal telephone calls, e-mails, and in-person conversations with three university researchers and one winter grow-out manager. This information was used to provide "expert" opinions and as a means for fact-checking statements made by growers. We did not audio-record communication with these individuals. Their responses are summarized, instead of directly quoted, in this article.

## Findings

### Profile of Potato Growers in the Study Region

In the region of study in Washington State, commercial potato growers produce red, yellow, white, purple, and fingerling varieties. These potatoes are sold primarily to grocery stores, restaurants, and distribution centers. The majority of the commercial potato farms are family corporations, with long histories of potato farming. Seventeen potato-growing operations (ranging between approximately 500 and 1,000 acres) are managed using conventional agriculture techniques, and make up the majority of the industry in the area. Eight additional farms (100 acres or less) operate as certified organic. All of the six commercial potato growers we interviewed during the second round of interviews were men. Five were owners of their farming operation, while one previously owned an operation, but currently worked for a different commercial potato farm. Commercial potato operations had an average area of 707 acres. On average, seven different varieties of potatoes were grown, and the most common rotation crops were silage corn, vegetables, and wheat.

There are nine seed potato operations in Washington State (WSSPC 2015). Similar to the commercial potato farms, the majority of the seed potato operations are family corporations, with farm management passed down generationally, or to members of the same family managing different enterprises of affiliate companies. One seed potato farm (62 acres) is managed using certified organic farming practices, while the other seed potato farms (ranging between approximately 450 and 1,000 acres) operate using conventional agricultural practices. The seed potato growers produce over 120 varieties of russet, red, yellow, white, purple, and fingerling seed potatoes (Sather et al. 2014). They sell their seed potatoes to commercial potato growers throughout the state, the United States, Canada, and Pacific Rim countries. Of the seed potato growers we interviewed, two were women and four were men. All

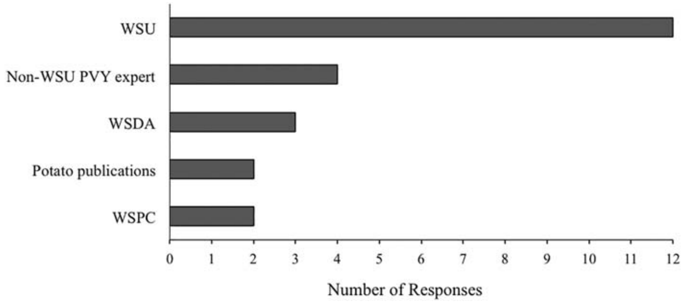


Figure 2. Commercial and Seed Potato Growers' Responses to "Where Do You Prefer to Get Your Information on PVY?"
*Note*: Growers could provide multiple responses. Data from the second round of interviews.

interviewees were either owners of or partners in certified seed potato farms. The average potato production area was 578 acres. The farms grew an average of 27 varieties of seed potatoes, and most commonly planted silage corn, grass, and wheat as rotation crops.

## Sources of Information about PVY

Scholarship concerning PVY is abundant, and in recent years, key review articles on current PVY research have been published (Gray et al. 2010; Karasev and Gray 2013). In 2015 alone, 68 peer-reviewed journal articles were published about PVY.[2] Despite the available research and resources about PVY, all 12 interviewees responded that they had obtained their information about PVY from only one or two WSU researchers (Figure 2), who are situated within growers' sociospatial knowledge networks (Ilbery et al. 2012). Most study participants reported also completing their own searches of available resources about PVY, relying primarily on grower magazines, the Internet, and various university extension bulletins.

It is not surprising that WSU is the most common source of information about PVY for potato growers, given that a main responsibility of WSU personnel is to communicate research findings to the greater agricultural community of the state. Moreover, potato growers in the region tend to seek out advice and expertise from the researchers with whom they are most familiar. It is evident that the majority of

[2] We conducted our search for articles in a similar manner to Kremer et al. (2001) for a nonsystematic sampling of journal articles listed on Google Scholar. Parameters included publishing date (January 1–December 31, 2015) and containing the words "*Potato virus Y.*"

Figure 3. Tuber Cracking Symptoms Likely Caused by PVY. Photo by B. Gundersen. [Color figure can be viewed at wileyonlinelibrary.com]

potato growers have relied on the expertise of only a few go-to researchers to provide important recommendations on PVY management on their farm. However, interestingly, they have not followed these researchers' recommendations regarding the Hawaii winter grow-out innovation.

## Origin of Recombinant Strains of PVY in Washington

$PVY^{NTN}$ and $PVY^{N\text{-}Wi}$ were first reported in 2012 in seed-potato-growing areas of western Washington State (Benedict et al. 2015). The recombinant strains created challenges for WSDA inspectors and seed potato growers, because the characteristic $PVY^{O}$ symptoms did not appear on potato plant foliage during winter grow-out tests. As a result, many seed lots were inaccurately certified by inspectors and unintentionally sold as healthy certified seed to commercial potato growers. When commercial potato growers who planted Washington certified seed potatoes harvested their crop at the end of the season, they saw prominent symptoms on some tubers—particularly suberized, canoe-shaped cracks (Figure 3), which had not been observed previously. Initially, commercial growers suspected the tuber symptoms were growth cracks, a physiological condition that affects tubers when potato plants are overirrigated. The commercial growers began communicating with each other to investigate if any of the other local potato-growing operations had noticed seed and harvested tubers with similar symptoms. Commercial potato growers estimated that yield and tuber quality losses during this time were between 10 percent and 40 percent, confirming the significant impact plant diseases can have on crop quality and yield. Because these cracking symptoms had not been observed at such high levels before, commercial potato growers wondered if the observed symptoms had originated in the fields of the seed potato growers, and if the problem had been caused by a virus introduced on the certified seed potatoes they had purchased. According to one commercial grower, "Originally, we thought everything was a growth crack—maybe we did overirrigate it. But I'd given [the tubers with symptoms] to our . . . guy, and I thought he took them up to [WSU], and had them [tested], and said, 'Um, yeah. That's PVY'" (commercial potato grower 2). While some seed potato growers were not convinced that the tuber cracking was a viral symptom or that it originated in their fields, work by Benedict and collaborators (2015) demonstrated the relationship. As evidence mounted that the asymptomatic strains of PVY were increasingly problematic (Benedict et al. 2015; Gray 2014; Karasev and Gray 2013), WSSPC moved to remedy the situation.

The WSSPC works in conjunction with the WSDA to regulate seed potato production in Washington State. The commission comprises representatives from the seed-potato-growing operations in the state, as well as representatives and plant inspectors from the WSDA. In response to the asymptomatic strains of PVY, the WSPCC chose to mandate laboratory testing for seed potatoes submitted for certification in 2013, a regulation to which most other states with seed certification programs already adhered at the time (PAA Certification Section 2015).

While the new regulation was intended to enhance the quality of certified seed potatoes, it had unfortunate ramifications. The laboratory that was contracted to carry out the testing made technical errors that contributed to false positive results. This led to the complete loss or noncertification of thousands of seed potato tubers. One seed potato grower described the situation:

> We had changed our regulations. We felt that everything should be tested at [an early generation] as a check. Some of us felt that anything that was being replanted should be retested, but [this regulation] was a compromise. Some growers went along with it reluctantly. And then, we had a

> problem. . .. It’s never really been explained to us what happened, but all this [early generation] material that was sent there, they were getting hits all over the board. Like 80 percent of all seed lots came back positive, probably 60 percent of them were exceeding threshold levels. We had a hard time believing that that was right. It was unfortunate. We found this information out in March and [commercial potato growers] were going to be planting in April, and [were] told we didn’t have clean seed. There [are] no other alternatives at that point, and a lot of the [seed potato] growers said we can’t ever do that to ourselves again. We backed ourselves into a corner and we almost tore the industry down to not have seed and not have material eligible to plant based on our change in the regulations and [being at] the mercy of this one lab. (Seed potato grower 2)

As a result of the inaccurate laboratory testing, the new regulation was removed, and the protocols reverted to the previous year’s protocols, while the WSSPC considered alternative ways to effectively manage the recombinant strains of PVY. Throughout the course of our interviews, we found this incident was at the root of nonadoption of the Hawaii winter grow-out innovation. The seed potato growers had acted conscientiously by implementing new protocols to manage PVY, which directly resulted in a nearly devastating impact on the industry. This distrust of laboratory testing for the winter grow-out and subsequent certification has affected the state’s ability to institute the Hawaii winter grow-out innovation.

**Perceived Attributes of the Winter Grow-Out Innovation**

Throughout our interviews with seed potato growers, we collected data on perceptions of the five attributes of innovations (Rogers 2003) associated with the diffusion model (Table 1). We found that Washington seed potato growers perceived that the Hawaii winter grow-out innovation did not have a relative advantage, was not compatible with current PVY management practices mandated in their certification program, was overly complex, was not particularly easy to try on a small scale, and had difficult-to-observe impacts.

*Relative advantage.* Two-thirds of the seed potato growers said they were uncertain that holding winter grow-out testing in Hawaii would provide a relative advantage:

> Hawaii has failures too. They've been hit with weather or other problems and they've had their own share of failures. So there's no guarantee wherever you go. (Seed potato grower 3)

> I'm not convinced that Hawaii would be any better. (Seed potato grower 4)

> I've heard through the years that there [are] multiple states being tested [in Hawaii], and there has been in question some cross contamination between horrible lots right beside clean lots. Some [seed potato] growers didn't quite feel it's accurate or right, but there's been some haggle and questions about it. There's been certain [PVY] movement in Hawaii from seed lot to seed lot. . .. I haven't been there or seen it myself, but it's just rumors. (Seed potato grower 6)

These comments demonstrate that the seed potato growers believe that a new winter grow-out location would not necessarily be more successful than the winter grow-out system they already have. Moreover, some seed potato growers (particularly seed potato grower 6) think that the accuracy of seed potato virus readings would diminish if samples were planted in Hawaii because of potential cross contamination from other states' submitted lots that may contain infected seed. The perception of higher incidence of PVY transmitted by insect or mechanical means from other states' seed lots also contributes to why Washington seed potato growers have not adopted the innovation.

Interestingly, one university researcher and one grow-out manager from a state other than Washington reported that their winter grow-out in Hawaii provided substantial benefits including speed of grow-out results, improvements in certification accuracy, and enhanced symptom expression. Coincidentally, these three benefits address problems that the Washington greenhouse winter grow-out had experienced in previous years. Additionally, neither the researcher nor the manager was aware of contamination between seed lots on the Hawaii farm, largely because each state's seed potatoes are planted in areas that are isolated from one another. The grow-out manager further noted that sometimes seed potato growers who receive poor test results during the winter grow-out blame these results on cross contamination or current season transmission and infection. These findings, like those of Ilbery et al. (2013), show the importance of understanding perceptions and management of disease risks across an industry rather than focusing solely on growers' perceptions and experiences.

*Compatibility.* Conforming to "farming subculture" norms and beliefs about agricultural management practices is a "fundamental aspect of social behavior" (Vanclay 1992:11). In the case of PVY management, Washington seed potato growers place high importance on isolating their seed potatoes from other states' seed potato winter grow-outs. This need suggests that Washington seed potato growers perceive that winter grow-out tests in Hawaii are not compatible with their priorities and standards if they do not have an isolation component:

> There are benefits to where we can keep our seed lots away from any other state's testing seed crop. There may be some drawbacks on some efficiency [to growing out in Hawaii], and the speed of growth that the plants or certain varieties perform in a greenhouse.... I'm not sure if they do better in a tropical climate or not. (Seed potato grower 6)
>
> If it goes to Hawaii, it's not as controlled. (Seed potato grower 3)
>
> Maybe [there'd be] even new environmental symptoms or growth cracks. (Seed potato grower 4)

One university researcher and one grow-out manager said that during the winter grow-out, each state's seed potatoes are indeed planted in isolated areas of the farm, and that they have not encountered issues with cross contamination between states' seed potatoes on the Hawaii farm. However, Washington seed potato growers believe (albeit likely incorrectly) that other states' potatoes may be a source of PVY that could contaminate seed lots and confound grow-out testing. These statements demonstrate possible misinformation being perpetuated among the Washington seed potato growers.

*Complexity.* Two-thirds of the seed potato growers indicated that the learning curve associated with adopting the Hawaii winter grow-out innovation would be challenging. This perception speaks to the complexity of the logistics that would be required to implement a new grow-out location.

> First, does Hawaii have the space or time for us? The next is the logistical problem of loading up a container and getting it over there, and unloading the container and making sure that everything's sorted through and done correctly—and then just that distance and travel factor. (Seed potato grower 2)
>
> We'd probably have new learning curves to deal with—we'd be the Johnny [Come] Lately to the game. There's a bad leaf

> miner problem that makes readings difficult. It would be hard to start the process up again. Where would we find new ground? Who are the new people to work with? Flooding happens, there'd be new insects to deal with. (Seed potato grower 4)
>
> I know there's quite a few states that send their stuff to Hawaii. I'm not really familiar with the whole process. (Seed grower 5)

These responses show that the seed potato growers believe they would have to overcome numerous hurdles to implement a Hawaii winter grow-out. These perceptions are particularly surprising, given that 80 percent of the states with a seed potato certification program in the United States hold their grow-out test in a tropical location (Table 2).

The perceived complexity of the system as held by the Washington seed potato growers seems to stem from a perception that starting something new is inherently complex, which may be somewhat of a misconception. When a grow-out manager was asked to describe the logistical process of shipping tubers to Hawaii and planting the tubers for a grow-out, he noted that the first year "did take a little getting used to." However, during each subsequent year of the tropical winter grow-out, the test performance exceeded his expectations. It is important to note, however, that other states have much larger programs and more personnel to deal with implementation of certification standards.

*Trialability.* Geographically, the Hawaii winter grow-out innovation is not easy to implement at a large scale because of the distance and transit required. Once seed potatoes are packed onto a shipping container, delivered, and planted in the ground in Hawaii, seed potato growers cannot abandon the grow-out in the middle of a test, because of the requirement to obtain plant samples for laboratory verification of the visual assessments. It may be possible for growers to conduct a trial of a small-scale subset of seed tubers in a grow-out in Hawaii and test a subset of samples in a Washington laboratory to explore the practicality and usefulness of the testing. Regardless of the viability of these options, Washington seed potato growers currently believe that the Hawaii winter grow-out followed by confirmatory laboratory testing is an all-or-nothing practice.

The failure of laboratory testing during the 2013 growing season (as described above) is likely the main reason for seed potato growers' aversion to what is now routine winter grow-out and testing practices in other states for PVY verification. Moreover, we know from classic diffusion research (Rogers 2003:258) that potential early adopters perceive trialability to be a significant adoption barrier, while later adopters can look to early adopters who "act as a kind of vicarious trial," making personal trials less important. In other words, until one or more Washington seed potato growers try (and eventually adopt) the Hawaii winter grow-out innovation and encourage other seed potato growers to follow suit, industrywide adoption in Washington State may not be likely.

*Observability.* Because of the distance that separates Washington and Hawaii, seed potato growers expressed concern that they would not be able to observe plants while the winter grow-out was taking place:

> We feel like we're better off controlling [PVY] where we're able to see it every week. If [the grow-out] is in Hawaii, we can't see and monitor what's gong on. (Seed potato grower 3)
>
> I think we have benefits in the way we do it, keeping it in the state in a private, isolated greenhouse, mainly because we're our own testing facility. We have only our own [seed] in there, no other state's for the risk of cross contamination. It's all in-house and isolated under a roof. (Seed potato grower 6)

These comments demonstrate that the perceived lack of personal control over winter grow-out testing in another state is another factor contributing to nonadoption. Growers place a high value on being able to observe that grow-out testing is executed in a way whereby they can provide feedback and suggestions, and be able to physically see how plant symptoms progress. Despite the fact that Washington is geographically closer to Hawaii than other states that implement a Hawaii winter grow-out, the Washington seed potato growers' emphasis is on immediate observability. This finding relates to the importance of reducing both geospatial and phenomenological "epistemic distance" to change growers' perceptions and behaviors (Carolan 2006).

**Perceived Status of the Current PVY Management System**

The winter grow-outs that take place in Washington hoop houses and greenhouses have had mixed results in recent years. In 2014, a combination of late scheduling and poor growing conditions led to the failure of the winter grow-out, with many lots having inconclusive results. Nonetheless, seed potato growers prefer relying on the Washington-based approach rather than switching to the Hawaii winter grow-out innovation. One seed potato grower reflects on the Washington grow-out results: "We needed to have done our homework, and [written]

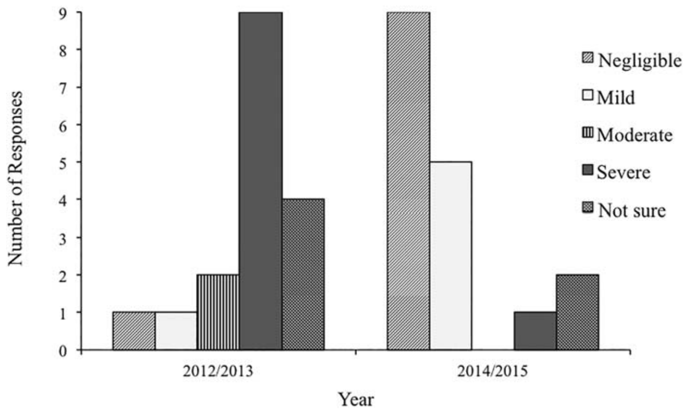


Figure 4. Commercial Potato Growers' Characterization of the Severity of PVY During 2012/2013 and 2014/2015.
*Note*: Data from the first round of interviews.

specifications that required certain temperatures and moisture levels and sunlight. And we learned from it for this year [2015]" (seed potato grower 2). Despite the unpredictable performance of a greenhouse winter grow-out test, one-third of the Washington seed potato growers believe that the current management strategies, as written in the WSDA's Washington State Certification of Seed Potato Protocols (2008), are sufficiently successful for managing PVY. "I think we're doing a really good job with what we're doing," said one grower. "It's just patrolling of it if anything, making sure that our standards are being met" (seed potato grower 3). Another said, "Washington is pretty on par with any of the other states [that have seed potato certification programs]" (seed potato grower 4). According to commercial potato growers who were interviewed, the 2014 and 2015 growing seasons experienced significantly less PVY than previous years (Figure 4). Sixty-seven percent of commercial potato growers attributed this decline to less seedborne PVY (Figure 5).

## Possibility of Future Adoption

Although seed potato growers have not adopted the Hawaii winter grow-out innovation for the reasons outlined above, there may be a possibility of adoption in the future. Most of the seed potato growers interviewed said they would be interested in considering the winter grow-out innovation if commercial potato growers demanded and were willing to

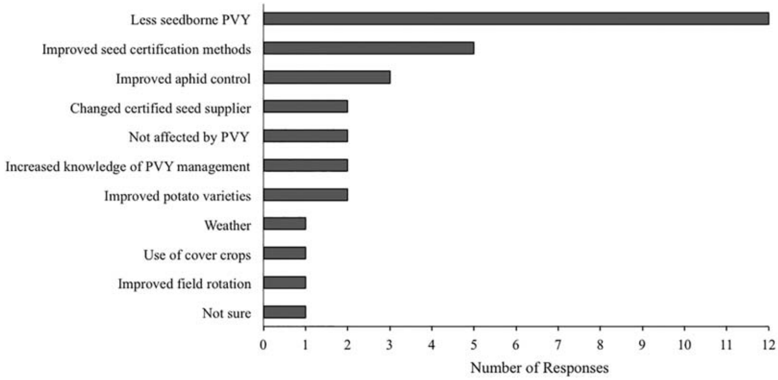


Figure 5. Commercial Potato Growers' Explanations for the Decrease of PVY During the 2015 Growing Season.
*Note*: Growers could provide multiple responses. Data from the first round of interviews.

pay a premium to cover the costs associated with making the switch to Hawaii grow-outs:

> If that's something that [commercial potato growers] requested and were willing to pay for, then absolutely [we'd consider a Hawaii winter grow-out]. [Commercial potato growers] need to have confidence in the material. I guess a lot of that's our philosophy here. Our success is built on theirs. (Seed potato grower 2)

> If a commercial customer would demand it, I don't think I would have a problem with it personally. (Seed potato grower 6)

However, two seed potato growers were not convinced that commercial potato growers would actually be willing to pay such a premium: "We have a 'customer is always right' mentality," the first said. "But I don't think that the commercial growers give a shit about PVY" (seed potato grower 4). The second said, "If they were willing to pay more for me to test [seed potatoes] in Hawaii, I would do it. I mean, if they're willing to, heck yeah. But I know that's not going to happen" (seed potato grower 2).

These comments suggest two things. First, some seed potato growers recognize that switching to a Hawaii winter grow-out would be a wise business decision if their customers (i.e., commercial potato growers) expressed interest. Second, seed potato growers believe that the Hawaii winter grow-out innovation is more expensive than their current winter grow-out practices. The perceived high cost of an innovation is a common barrier to adoption (Goldberger at al. 2015; Kremer et al. 2001;

Long et al. 2016; Rogers 2003; Vanclay 1992). A premium paid by commercial potato growers would incentivize and alleviate some of the burden of additional costs that may be associated with adopting the Hawaii winter grow-out innovation.

When commercial potato growers were asked about their opinions on winter grow-out testing in Hawaii, they had mixed responses. Fifty percent responded that they would be willing to consider paying a premium for certified seed potatoes that were grown-out in Hawaii:

> I've requested for years to have our seed growers do the grow-outs [in Hawaii]. I'd really like them to have a winter grow-out in Hawaii, but I feel that they've been doing a good job of getting better. (Commercial potato grower 4)

> I guess it would depend on what the premium would be. And [it] depends on if the first time it's like, "oh, this stuff is dynamite, it doesn't have anything, right?" (Commercial potato grower 2)

> Well, but a premium, I mean I don't know how expensive it is, but I suppose it would be worth a little bit more to me, yes. (Commercial potato grower 5)

However, the remaining commercial potato growers were concerned that they already paid a sufficiently high cost for certified seed potatoes that were sometimes inaccurately certified. These commercial potato growers suggested that there were more factors to consider than just the winter grow-out test in Hawaii. They were interested in reintroducing the laboratory-testing requirement for seed potato certification:

> I wouldn't weigh [things on the Hawaii test] as much. If I knew more about the seed [health] and it had more value added to it, so definitely if it's clean and had some sort of pedigree that'd come with it, I could see some upcharges on certain varieties. (Commercial potato grower 3)

> I think we're already paying a premium for seed that's not getting it. I'd love to see the grow-out plus the other testing methods to come back on a different deal.... I think a lot of people are thinking the same thing ... looking at the way that this disease has changed, or is expressing itself, what the relevance of the grow-out has been, and how trusting we can be in that [seed potato certification] program. (Commercial potato grower 6)

It is essential to understand the perceptions and seed potato preferences of commercial potato growers (buyers), as well as the perceptions of seed potato growers, when exploring the possibility of the future adoption of the Hawaii winter grow-out innovation. The responses of commercial potato growers suggest approaches seed potato growers could use to improve PVY management and, consequently, retain or attract customers and provide a high-quality product.

**Conclusion**

The purpose of this study was to investigate the reasons behind the nonadoption of a winter grow-out innovation among certified seed potato growers in Washington State by conducting interviews with commercial potato growers, certified seed potato growers, university researchers, and others associated with the state's potato industry. We found that the primary reasons for nonadoption related to seed potato growers' perceptions of the winter grow-out innovation were lack of advantages compared with existing PVY management practices, incompatibility with growers' priorities relating to the desire for isolation and avoidance of cross contamination, overly complex logistics, inability to conduct trials on a small scale, and lack of readily observable impacts. Growers' sociospatial knowledge networks and experiences with inaccurate laboratory testing also help explain why Washington seed potato growers rejected the innovation. Nonetheless, some seed potato growers were willing to consider the Hawaii winter grow-out innovation if commercial potato growers expressed an interest and were willing to pay a premium. It is evident from our work that commercial potato growers, as well as university researchers and extension personnel, individually blamed seed potato growers for not adopting the winter grow-out innovation. Lacking the social science insights provided by our study, these groups were not aware of the factors—specifically, growers' perceptions of different innovations and risks, long-standing sociospatial knowledge networks, and broader sociocultural, economic, and institutional contexts—that influence decisions to adopt (or reject) disease management practices.

Our case study makes several significant research and practical contributions. Our study adds to the body of knowledge about the nonadoption of agricultural innovations. Since the 1940s, researchers working within the diffusion-of-innovations tradition have not devoted adequate attention to why certain innovations are *not* adopted by the members of a social system. Exhibiting a proinnovation bias, diffusion scholars (and change agents) have focused primarily on the spread of popular innovations rather than the rejection of unpopular technologies, practices, and ideas (Buttel et al. 1990; Rogers 2003). To overcome the proinnovation bias, Rogers (1995, 2003) has encouraged diffusion scholars to select "unsuccessful innovations" as objects of study, acknowledge that rejection behavior may be "rational and appropriate" from an individual's point of view, understand the broader policy and research and development (contexts of innovation decisions), and explore the "why" of adoption, rejection, and discontinuance. Despite the call for more research, the number of nonadoption studies is limited (see, e.g., Belasco 1989; Cullen et al. 2013; Greiner and Gregg 2011; Kremer et al. 2001; Long et al. 2016; Shah et al. 2014; Wheeler 2008). In line with these past studies, our case study shows that seeking to understand decisions to reject certain agricultural innovations is a worthwhile endeavor. Research on the nonadoption of agricultural innovations is critically important for understanding perceptions and behaviors that have been ignored or overlooked by diffusion researchers. In addition, such work can lead to new and creative ideas for how best to design, introduce, and broadly diffuse critical agricultural innovations.

Our study also contributes to the sparse social science literature on farm-level disease management. Specifically, it meets the call for more microscale studies of risk perceptions and disease management strategies (Ilbery 2012). Our study serves as a U.S. counterpart to the important work on the human factors that influence the management of plant diseases in the U.K. potato and wheat sectors (Ilbery 2012; Ilbery et al. 2012, 2013; Maye et al. 2012). Moreover, our work meets the call for partnerships among natural scientists, social scientists, and on-farm decision makers when attempting to understand plant disease management practices (Breukers et al. 2012; McRoberts et al. 2011; Mills et al. 2011; Wilkinson et al. 2011). To accomplish our goal, we assembled an interdisciplinary team—two plant pathologists, one sociologist, one agriculture extension educator, and participating seed potato and commercial potato growers—to carry out our study of farm-level management of PVY, one of the most economically impactful plant viruses in the world. More thorough understandings of risk perceptions and disease management practices can help inform local, regional, national, and international efforts to ensure agricultural biosecurity, maintain crop quality and yield, safeguard food distribution and security, and prevent economic losses within the agricultural sector (Ilbery 2012; Maye et al. 2012; Mills et al. 2011).

Our work also offers valuable insights to applied researchers, extension educators, and other agriculture service providers who work in the broad area of pest management (insects, weeds, and diseases). Social science understandings of why farmers do not act "rationally" can help applied researchers, change agents, and policymakers tailor their research, outreach, and policy decisions, respectively, to better meet farmers' needs (Breukers et al. 2012; Mills et al. 2011). As Breukers et al. (2012:609) argue, "once the incentives and barriers growers experience in applying farm-level risk management measures are understood, effective intervention strategies can be designed to further improve risk management at the farm level." In Washington State, for example, we believe information about the logistical steps, cost, and time needed to implement the Hawaii winter grow-out innovation, as well as reliable potato virus testing laboratories, could be assembled and disseminated to help seed potato growers make informed decisions about different winter grow-out options. In addition, Washington seed potato growers could benefit from the knowledge and experiences of seed potato growers in other states where adoption of these potato virus management practices has already taken place. Arranging opportunities for seed potato growers to hear such testimonials from early adopters of the winter grow-out innovation could be helpful.

It is important to recognize the limitations of our study. First, potato growers are quite aware of the different types of risks inherent in producing potatoes. Numerous potato pathogens exist in addition to PVY, all of which present unique management challenges. In some cases, it was difficult for our interviewees to describe management strategies for PVY independently from those for other potato pathogens. As a result, some opinions from growers about management strategies for PVY may have inadvertently been influenced by those for other pathogens that also pose risks to potatoes. Analysis of how farmers make management decisions *simultaneously* about multiple pathogens (e.g., viruses, bacteria, or fungi) based on different levels of perceived risks is lacking in the literature on farm-level disease management decision making and would be an interesting topic for future research.

Second, not everyone who was asked to participate in the study wanted to be interviewed. Some potential interviewees said they were not familiar with PVY, or that they were too busy. The growers who did not participate might have been more inclined if data had been collected via focus groups (more relaxed environment) or written surveys (more anonymous). The responses of individuals who chose not to participate might have provided useful insights into PVY management and winter grow-out options; however, we have no way of knowing if nonparticipants' perceptions would have differed significantly from those of the study participants.

Last, our study focused on the nonadoption of the Hawaii winter grow-out innovation among seed potato growers in only one state. Our analysis would have benefited from primary research on seed potato growers' PVY management decision making in Oregon and California, the only other states that do not carry out winter grow-out testing in a tropical location (Hawaii or Florida). However, it is worth noting that perceptions and contextual factors likely differ from state to state, making geographically (and socioculturally) situated case studies of disease management decision making more appropriate than attempts to generalize findings across multiple states. We thus encourage interdisciplinary teams in other U.S. states to undertake case studies focused on farmers' (and other stakeholders') perceptions and management of plant disease risks.

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