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Distribution and incidence of viruses in Irish seed potato crops

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Abstract

Virus diseases are of key importance in potato production and in particular for the production of disease-free potato seed. However, there is little known about the frequency and distribution of potato virus diseases in Ireland. Despite a large number of samples being tested each year, the data has never been collated either within or across years. Information from all known potato virus testing carried out in the years 2006–2012 by the Department of Agriculture Food and Marine was collated to give an indication of the distribution and incidence of potato virus in Ireland. It was found that there was significant variation between regions, varieties, years and seed classes. A definition of daily weather data suitable for aphid flight was developed, which accounted for a significant proportion of the variation in virus incidence between years. This use of weather data to predict virus risk could be developed to form the basis of an integrated pest management approach for aphid control in Irish potato crops.

Keywords

potato seed • potato virus • seed certification scheme • DAS-ELISA • aphid

Introduction

Potato seed production in Ireland is a specialised industry that produces disease-free seed of recognised cultivars for production of ware (food) crops. Ireland is designated a high-grade seed production area because of its northerly latitude and relatively low populations of aphid species that transmit virus diseases of potato (Anon., 2014a).

In Ireland, the Department of Agriculture, Food and the Marine (DAFM) has responsibility for the seed certification scheme under the EU Seed Directive, to control the quality and varietal purity of seed for the consumer and the market to ensure that it is a guaranteed traceable product. Land intended for seed production is sampled and tested before planting to ensure freedom from potato cyst nematode (PCN). The crops are visually inspected for varietal purity, diseases and viruses. Random and routine leaf samples are taken and subjected to virus testing, seed is formally classified; harvested tubers are visually inspected, certified and labelled (Anon., 2014b). An additional responsibility of DAFM is to maintain small quantities of nuclear certified seed which is provided to seed growers to multiply over a number of generations for commercial production. Inspection, testing and quality standards are maintained at a high level during each generation. As the stock is bulked up and proceeds through the generations, it becomes exposed to pathogens, diseases and viruses.

Tissue cultures (nuclear stock) are maintained in the laboratory in growth medium containers under controlled lights and temperatures. These plants are potted up in the glasshouse in March/April and are harvested in July/August to produce Pre-Basic tissue culture/mini-tubers (PBTC) which in turn is supplied directly to seed growers. Mini-tubers are planted by the growers and harvested to produce Pre-Basic 1 (PB1) seed, which in turn produces Pre-basic 2 (PB2) and is then grown to produce Pre-Basic 3 (PB3), which in turn produces Pre-Basic 4 (PB4) seed. Super Elite 1 (SE1) is produced from PB4 seed and so on down the generations through Super Elite 2 (SE2) and Super Elite 3 (SE3) to Elite 1, 2 and 3 class seed. Class H is the lowest class after Elite 3 and may be used to produce ware potatoes; potatoes that may not be used for further multiplication. There is zero tolerance for diseases/viruses in PBTC and Pre-Basic 1–4 with tolerances ranging from 0 to 0.25% in the Super Elite classes 1–3 and 0 to 0.50% in Elite classes. Standards are relaxed in the H Class ranging from 0.10% to 1.00%.

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The use of SE1 and SE2 seed for ware production means that there is less seed available for growers than if it remained in seed production for lower grade Class H seed. Seed may be downgraded on visual inspection by DAFM inspectors if the crops do not meet the required standard (Anon., 2014b).

Viruses are responsible for huge losses in crops globally and, therefore, are of great economic importance. As viruses cannot be directly controlled by crop protection products in the field, early and reliable detection and the control of vectors is essential to prevent their spread.

Infection can occur in different ways depending on the virus species (Salazar *et al*., 2000). Virus can also be carried in the seed from the previous season (secondary infection); infection may be transferred mechanically by physical contact with an infected plant, contaminated machinery, tools or animals. Transmission can occur via nematodes, fungi or insect vectors. Vectored transmission can occur in two main ways: non-persistent and persistent transmission. In the former, aphids contaminate their mouthparts by feeding on the tissue of an infected plant. When the aphid moves to a new plant and feeds on it, infection and spread of the virus occurs. The aphid remains infective for approximately two hours (Kurppa *et al*. 1986) after feeding on an infected plant. In persistent transmission, the aphid must feed on an infected plant for up to 30 minutes. There is an incubation period of several hours once the virus has entered the aphid's body. During this time, the aphid cannot infect any plants. However, the virus remains in the aphid's body for the rest of its life (Kurppa *et al*. 1986).

There are several known viruses that occur in Irish potato crops, namely, potato virus X (PVX), potato virus S (PVS), potato virus A (PVA), potato virus Y (PVY) and potato leafroll virus (PLRV) (https://www.agriculture.gov.ie).

PVX belongs to the genus *Potexvirus*. It is transmitted mechanically but cannot be transmitted by insect vectors. Strains of PVX were first recognised by Johnson (1925). It is mainly confined to the *Solanacea* family. Plants can often be asymptomatic; however, symptoms can include mosaic, chlorosis and decreased leaf size (Bawden *et al.,* 1948). Tubers can show some necrotic lesions. It can interact and occur with PVA and PVY, displaying severe symptoms and increased loss of yield. Widespread infection can cause yield losses of 15–20% (Burrows and Zitter, 2005).

PVS is a virus of the genus *Carlavirus* and is generally non-persistently transmitted by aphids including *Myzus persicae*. It is unusual in that it can also be transmitted mechanically through tubers. Because its symptoms are inconspicuous, it remained unknown until the 1950s (De Bruyn Ouboter, 1952). Symptoms can show in some cultivars and not in others. Symptoms include mild mottling, deep veins, rough leaves, bronzing or tiny brown necrotic spots on the leaves. PVS can cause yield losses of up to 20% (Burrows and Zitter, 2005).

PVA is a member of the genus *Potyvirus*. It is transmitted in a non-persistent manner. Symptoms elicited depend on the cultivar and the weather (Singh and McDonald*,* 1981). They include mild mosaic, roughness of leaf and waviness around the leaf edge; some hypersensitive varieties can develop necrosis on the top leaves. PVA can interact and occur in combination with PVX and PVY showing crinkle-like symptoms (Murphy and McKay, 1932). It occurs only in members of the *Solanaceae*. The virus can reduce yields by up to 40% (Bartels, 1971).

PLRV is a phloem-limited virus of the genus *Luteovirus* and is transmitted by aphids in a persistent manner. Classic symptoms of PLRV include stunting, chlorosis, leathery feel to the leaves together with rolling and curling. Net necrosis can occur in tubers; its severity depends on when the plant was infected (Burrows and Zitter, 2005). PLRV is mainly found in members of the *Solanaceae* family. If infection is widespread, yield may be reduced (Harrison, 1984).

PVY is a member of the genus *Potyvirus* and was first recognised in potato by Smith in 1931. It is one of the most studied plant viruses and was the type species of the *Potyvirus* genus (Harrison *et al.,* 1971). It is in the top five viruses affecting field-grown vegetables (Milne, 1988).

The economic importance of PVY has been reported worldwide by Tomlinson (1987), Milne (1988) and Shukla *et al*. (1994). Historically, PVY has been divided into three main groups, PVY^O, PVY^N and PVY^C, according to the disease symptoms caused (De Bokx and Huttinga, 1981). The common strain (PVY^O) causes mosaic symptoms; PVY^N can cause necrosis and plant mortality, whilst PVY^C can cause hypersensitive responses such as stipple streak.

The PVY is known to occur worldwide and is found in potato, tobacco, tomato and pepper. The PVY^O strain occurs worldwide in potato crops (Jeffries, 1998). Reports of the PVY^N strain have been recorded in South America, Europe, Africa, Asia (Weidemann, 1988b) and New Zealand (Fletcher, 1989). It is a quarantine pathogen in Canada and the United States (Ellis *et al*., 1997). The PVY^N strain can cause severe veinal necrosis reaction in tobacco. It was responsible for severe potato crop damage in the 1950s and 1970s across many countries in Europe and resulted in yield reductions between 29% and 59% depending on the cultivar (Kurppa and Rajala, 1986).

The PVY^C strain has been identified in Europe, North America, India, South Africa, Australia, New Zealand and Ecuador (Ellis *et al.*, 1997; Jeffries, 1998). Some PVY^C isolates cannot be transmitted by aphids (Watson and Wilson, 1956; De Bokx *et al.,* 1978; Blanco-Urgoiti *et al*., 1998). The former potato virus C (PVC) (non-aphid transmissible) has been identified as a PVY strain (Cockerham, 1943; Bawden and Kassanis, 1947) and is now included in PVY^C.

More recently, novel recombinants of PVY strains have been identified worldwide, which are variants derived from PVY^{N} and PVY^{O}. These strains fall into molecular subgroups such as (European) $PVY^{EU\text{-}NTN}$, (North American) $PVY^{NA\text{-}NTN}$ and PVY $^{N\text{-}Wilga}$ (Lacomme *et al.*, 2014; Karasev and Gray, 2013). Some of these recombinant strains have been reported to cause necrotic symptoms on potato foliage and potato tuber necrotic ringspot disease (PTNRD) on tubers (Visser, 2012). The presence of recombinant PVY strains PVY^{NTN} and $PVY^{N:O}$ were confirmed in Ireland in 2012, and further research confirmed the presence of PTNRD associated with these recombinant strains in 2013 (Hutton *et al.,* 2013). However, these recombinant strains are not specifically included in this paper as they are not routinely tested for in the DAFM seed certification system.

The objective of this work was to collate and interpret existing survey data on the incidence of potato viruses to quantify distribution of the various virus strains and factors underlying their variation.

Materials and Methods

Survey Data 2006–2012

Results for all virus tests carried out by the DAFM on potato samples as part of the potato seed certification scheme for the years 2006–2012 were included. Crops were both routinely and randomly sampled and sent to the DAFM laboratory, Tops, Raphoe, Co. Donegal for virus testing. The detection of PVX, PVS, PVA, PVY, PVY^{N} and PLRV was determined as per the seed certification requirements. The intensity of sampling reduced as seed progressed through the generations/seed classes from tissue culture to elite class: Tissue culture and pre-basic seed classes Pre-Basic 1 (PB1), Pre-Basic 2 (PB2), and Pre-Basic 3 (PB3) were routinely sampled; 40 leaflets per acre (equivalent to 100 leaflets per hectare) were taken and divided into eight samples comprising of five leaflets per sample to be virus tested. In the Pre-Basic 4 seed class, one sample comprising of five leaflets per acre is taken. In the lower classes (Super Elite and Elite), sampling was conducted randomly throughout the field. Whilst sampling in the different seed classes were at different levels of intensity, they represented a significant proportion of the seed potato crop grown across the country. Samples were tested using the DAS-ELISA (double antibody sandwich enzyme-linked immunosorbent assay) following the protocols of Clark and Adams (1977). Test reagents and antibodies for DAS-ELISA were supplied by BIOREBA (Reinach, Switzerland).

A total of 12,845 samples comprising of five leaflets were tested over a seven-year period (Table 1). Background information was supplied for each sample (county, region, seed class), which allowed the analysis of the impact of a range of factors on the incidence of the individual viruses.

The data set was dominated by nine varieties that were present in all seven years: British Queen, Golden Wonder, Home Guard, Kerr's Pink, Lady Claire, Lady Rosetta, Maris Piper, Record and Rooster (Table 2), which could be analysed to see if there were consistent differences in the incidence of individual viruses in different varieties. All samples were grouped into seven regions across Ireland: North (Donegal), South (Cork, Tipperary, Waterford), East (South Dublin, Wicklow, Kildare), West (Galway, Mayo, Sligo), North East (North Dublin, Louth, Meath), South East (Wexford, Carlow, Kilkenny) and South West (Clare, Limerick, Kerry) (Table 3). The seed source was categorised into nine different seed classes (Table 4); however, as there were few samples that could be individually categorised into Elite 1, 2 and 3, they were bulked into an overall Elite class. In total, here were 79 varieties with 20 samples of unknown varieties represented in the full data set. Variety effects were restricted to where there are greater than 149 samples per variety over the seven years.

Data Analysis

The virus incidence results were analysed by fitting a binomial model using logistic regressions in Genstat (Windows version 14, VSN International Ltd., Hemel Hempstead**,** UK). Logistic regression measures the relationship between categorical-dependent variable and one or more independent variables, which are usually continuous, by using probability scores as the predicted values of the dependent variable. In the logistic regression, Genstat automatically selected the comparative variable based on the first one on the list (in alphabetical order), which contains positive results for the dependent variable. It is important to note that this choice of comparative variable did not affect the results obtained.

Meteorological Data 2006–2012

Meteorological data for the years 2006–2012 was received from Met Eireann for Oak Park, Carlow. The spring/summer data was collated and an estimate of the number of days suitable for aphid flight (aphid flight days) was calculated for the months of April to June. A day where average wind speeds were below 3.0 kmh^{-1}, the average temperature was between 13 and 30°C and rainfall less than 0.2 mm was defined as being suitable for aphid flight on the basis that at least part of the day would fit the conditions outlined by Taylor (1974). The influence of the number of days suitable for aphid flight was investigated by comparing the total number of days suitable for aphid flight in April, May and June (as these months preceded the virus testing) with virus incidence data using linear regression.

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Results

Of the 12,845 samples, 2,265 samples tested positive for at least one of the five viruses screened for.

Potato Virus Y (PVY)

PVY was the most prevalent virus with a mean incidence of 9.9%, which also differed significantly between the years from 1.12% in 2011 to 16.45% in 2007. In comparison to 2006, there was significantly greater incidence of PVY in 2007, 2008 and 2009, whilst there was significantly lower incidence in 2011 and 2012 (Table 1). The majority of the PVY positive samples were PVY^N, which had an average incidence of 6.33% (69% of all the PVY positive samples). The highest PVY^N incidences were in 2007, 2008 and 2009, which all had significantly higher incidence than 2006, whilst 2011 and 2012 had significantly lower incidence (Table 1).

Potato Virus X (PVX)

The second most prevalent virus was PVX with an average incidence of 5.1%. However, there was significant variation between years ranging from 2.21% in 2010 to 7.98% in 2007. In 2007 and 2009, there was a significantly higher incidence than in 2006, and in 2010, 2011 and 2012, there was significantly lower incidence and no significant difference in 2008 (Table 1).

Potato Virus A (PVA)

The third most prevalent virus was PVA with a mean incidence of 2.46% (Table 1). In 2006, PVA was detected in 2.13% of the samples, and there were no significant differences in its occurrence in 2007, 2009, 2011 or 2012. The highest rates of detection were recorded in 2008 and 2010, where 3.53% and 3.24% of samples were positive for PVA, respectively, both of which were significantly different to the detection rate of 2006.

Potato Virus S (PVS)

The PVS had a low incidence with an average incidence of only 0.06%. The virus was only present at low levels in 2008 (0.25%) and 2010 (0.14%).

Potato Leafroll Virus (PLRV)

PLRV occurred at an average of only 0.23% across years, there was no significant annual effect (Table 1).

Virus incidence across varieties

The incidence of PVY was significantly lower in Golden Wonder, Kerr's Pink and Home Guard compared to British Queen. There was a significantly higher incidence in Lady Claire, Rooster, Maris Piper and Record. Lady Claire had the overall highest PVY incidence at 38.46% with Home Guard having the lowest at 5.37% (Table 2). The incidence of PVY^N was significantly higher in Lady Claire, Rooster and Record than in British Queen and significantly lower in Golden Wonder, Kerr's Pink, Lady Rosetta and Home Guard. The highest incidence of PVX was recorded at 10.91% in the variety Kerr's Pink and the lowest in Maris Piper at 0.41%. In comparison to British Queen, there was significantly greater incidence in Kerr's Pink and Rooster and significantly lower incidence in Golden Wonder, Record, Maris Piper, Home Guard and Lady Rosetta. Golden Wonder had a significantly higher incidence of PVA compared to all the other varieties, which did not differ significantly from each other (Table 2). Owing to very low levels, there was no significant difference in PVS incidence across the nine varieties, with only Golden Wonder showing any infection (Table 2). The incidence of PLRV was significantly higher in Maris Piper than in British Queen (Table 2).

Table 1. Number of samples tested and percentage of total number of samples collected in each year testing positive for each virus from the Department of Agriculture, Food and Marine survey 2006–2012. Reference level = 2006.

Year	No. Tested	PVX	PVY	PVY^N	PVA	PVS	PLRV
2006	*1973*	*5.98%*	*9.68%*	*4.76%*	*2.13%*	*0.00%*	*0.35%*
2007	2420	7.98%*	16.45%***	10.04%***	3.02%	0.00%	0.37%
2008	2405	5.11%	16.34%***	10.60%***	3.53%**	0.25%	0.58%
2009	1764	7.70%*	12.82%**	9.27%***	1.46%	0.00%	0.11%
2010	1450	2.21%***	9.86%	6.14%	3.24%*	0.14%	0.21%
2011	1344	2.53%***	1.12%***	0.60%***	2.38%	0.00%	0.00%
2012	1489	4.23%*	3.22%***	2.89%**	1.48%	0.00%	0.00%
Significance between years		***	***	***	***	**	***

**** P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001***

Table 2. Number of samples tested and incidence of virus in the nine most commonly grown potato varieties (Department of Agriculture, Food and Marine) in Ireland. Reference level = British Queen.

Variety	No. Tested	PVX	PVY	PVYN	PVA	PVS	PLRV
British Queen	*1914*	*5.85%*	*11.86%*	*9.77%*	*0.00%*	*0.00%*	*0.26%*
Golden Wonder	1943	2.26%***	6.89%***	4.48%***	15.23%	0.05%	0.51%
Home Guard	149	0.68%*	5.37%*	4.70%*	0.00%	0.00%	0.00%
Kerr's Pink	4704	10.91%***	6.80%***	2.78%***	0.04%	0.00%	0.23%
Lady Claire	52	1.92%	38.46%***	36.54%***	0.00%	0.00%	0.00%
Lady Rosetta	298	2.68%*	9.06%	1.34%***	0.00%	0.00%	0.00%
Maris Piper	244	0.41%**	16.80%*	13.11%	0.82%	0.00%	1.64%**
Record	947	0.53%***	14.78%*	12.57%*	0.11%	0.00%	0.00%
Rooster	1567	8.30%**	18.70%***	16.91%***	0.13%	0.00%	0.13%
Significance between varieties		***	***	***	***	NS	**

**** P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001***

Virus incidence across regions

There were significant differences in virus incidence between the regions (Table 3). The incidence of PVY was significantly higher in the East, North East and West regions than in Donegal and significantly lower in the South (Table 3). The incidence of PVY^N was significantly higher in the East, North East and West regions than in Donegal, which was not significantly different to other regions (Table 3). In comparison to the Donegal region, PVX incidence was lower in the East, North East, South East, South and West. The incidence of PVA was significantly higher in the North East, South East, South, South West and West regions than in Donegal (Table 3). There was very little PVS incidence recorded with no significant difference across regions. The incidence of PLRV was significantly higher in the North East and significantly lower in the South regions than in Donegal which did not differ significantly to the other regions (Table 3).

Virus incidence across seed class

Virus incidence was significantly affected by seed class. The results for PVY showed that there was significantly lower virus incidence in the early generations compared to the Elite class. It increased significantly when descending the classes from PBTC to SE3 (Table 4). The incidence of PVY^N was significantly lower in PBTC, PB1, PB2, PB3 and PB4 than in Elite (Table 4). Similarly, the incidence of PVX in comparison to Elite class was significantly lower in seed classes PBTC, PB1, PB2, PB3, PB4, SE1 and SE2 with increased incidence as seed quality decreased (Table 4). The incidence of PVA was significantly lower in all of the classes compared to the Elite (Table 4). There was no significant difference in PVS incidence, as there was very little positive PVS recorded. The occurrence of PLRV showed that there was no significant difference in incidence compared to Elite class.

Table 3. Number of samples tested and percentage of total number of samples collected in each region testing positive for each virus from the Department of Agriculture, Food and Marine survey between 2006 and 2012. Reference level = Donegal.

Region	No. Tested	PVX	PVY	PVY^N	PVA	PVS	PLRV
Donegal	*8385*	*8.37%*	*7.70%*	*4.59%*	*1.18%*	*0.08%*	*0.13%*
East	251	3.59%*	13.94%***	13.15%***	1.99%	0.00%	0.00%
North East	833	4.8%***	39.5%***	30.01%***	5.76%***	0.12%	1.56%***
South East	1445	1.59%***	5.12%	3.94%	2.56%***	0.28%	0.00%
South	1095	3.01%***	4.57%***	4.57%	5.21%***	0.00%	0.91%***
South West	264	6.06%	9.85%	4.17%	12.12%***	0.00%	0.38%
West	570	1.58%***	20.7%***	18.95%***	8.25%***	0.00%	0.00%
Significance between viruses		***	***	***	***	NS	***

**** P ≤0.05, ** P ≤0.01, *** P ≤0.001***

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Table 4. Number of samples collected and percentage of total number of samples in each seed class testing positive for each virus from the Department of Agriculture, Food and Marine survey between 2006 and 2012. Reference level = Elite.

Seed Class	No. Tested	PVX	PVY	PVY^{N}	PVA	PVS	PLRV
PBTC	1893	0.11%***	0.32%***	0.2%***	0.05%***	0.00%	0.00%
PB1	1304	0.54%***	5.98%***	3.83%***	0.69%***	0.00%	0.00%
PB2	2118	1.37%***	6.23%***	3.64%***	0.90%***	0.00%	0.00%
PB3	2416	2.94%***	5.05%***	3.06%***	1.08%***	0.00%	0.08%
PB4	1981	6.36%***	9.49%***	7.17%***	1.36%***	0.00%	0.30%
SE1	1265	14.31%***	22.37%***	18.02%	4.43%***	0.00%	0.55%
SE2	733	17.33%***	26.06%**	21.00%	7.23%***	0.00%	1.36%
SE3	181	38.67%	25.41%*	15.47%	6.08%***	0.00%	2.21%
Elite	*454*	*38.55%*	*34.14%*	*19.82%*	*18.94%*	*0.22%*	*0.00%*
Significance between classes		***	***	***	***	NS	***

**** P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001***

Weather as a method of virus prediction

The number of aphid days calculated using a wind speed of <3 km/h are presented in Table 5. There were very few aphid days in April with only two in 2007 and 2011. June 2006 had the highest number of aphid days overall with a mean value of 6.7 days. The 2006 and 2010 seasons were the most conducive seasons for aphid flight with 27 and 25 days, respectively, between the months of April and July inclusive. A combination of April, May and June gave a total of 13 days in 2006, 13 in 2007, 10 in 2008, 12 in 2009, 16 in 2010, 4 in 2011 and 6 in 2012.

Table 5. Number of "Aphid Days" in the months of April to June 2006–2012

Year	April	May	June	Total
2006		1	12	13
2007	2	3	8	13
2008		7	3	10
2009		2	10	12
2010		6	10	16
2011	2		2	4
2012		4	2	6
Grand Total	**4**	**23**	**47**	**74**

Aphid Day = calculated at wind speed of less than 3 km h^{-1}, temperature 13–30°C and rainfall less than 0.2 mm

There was a significant correlation between aphid days calculated using wind speeds less than 3 km/h and PVY incidence by year (Figure 1a) but none with incidence of the other viruses. If the incidence of all aphid transmitted viruses (PVY, PVA, PVS and PLRV) was combined, the aphid days calculated with wind speeds less than 3 km/h accounted for a marginally higher proportion of the variation (Figure 1b).

Discussion

Whilst the overall incidence of virus on seed crops tested may appear high, it is worth noting that the classes of seed quoted are those awarded the previous year, that is, the class of the seed planted and not the class awarded following inspection. The virus incidence quoted includes the results for crops that have subsequently been downgraded to a lower class or rejected for certification.

As expected, there appeared to be large differences between varieties in their susceptibility to virus infection. Both Rooster and Kerr's Pink had a higher incidence of PVX than Golden Wonder, which was unexpected, as they are all classified as low resistance on the European Cultivated Potato Database (ECPD) based on the data from the Scottish Agriculture Science Agency (SASA) *(http://www.europotato.org)*. This could be the result of confounding between variety and region, as 83% of Kerr's Pink and 74% of Rooster samples were grown in Donegal which had the highest incidence of PVX of all regions. Golden Wonder seed was distributed more evenly across regions with only 44% produced in Donegal.

Lady Claire is ranked as having medium to high PVY resistance on the ECPD which contradicts the results found in this data set. However, there were only 52 samples of Lady Claire in the data set, and over 80% of these were grown in

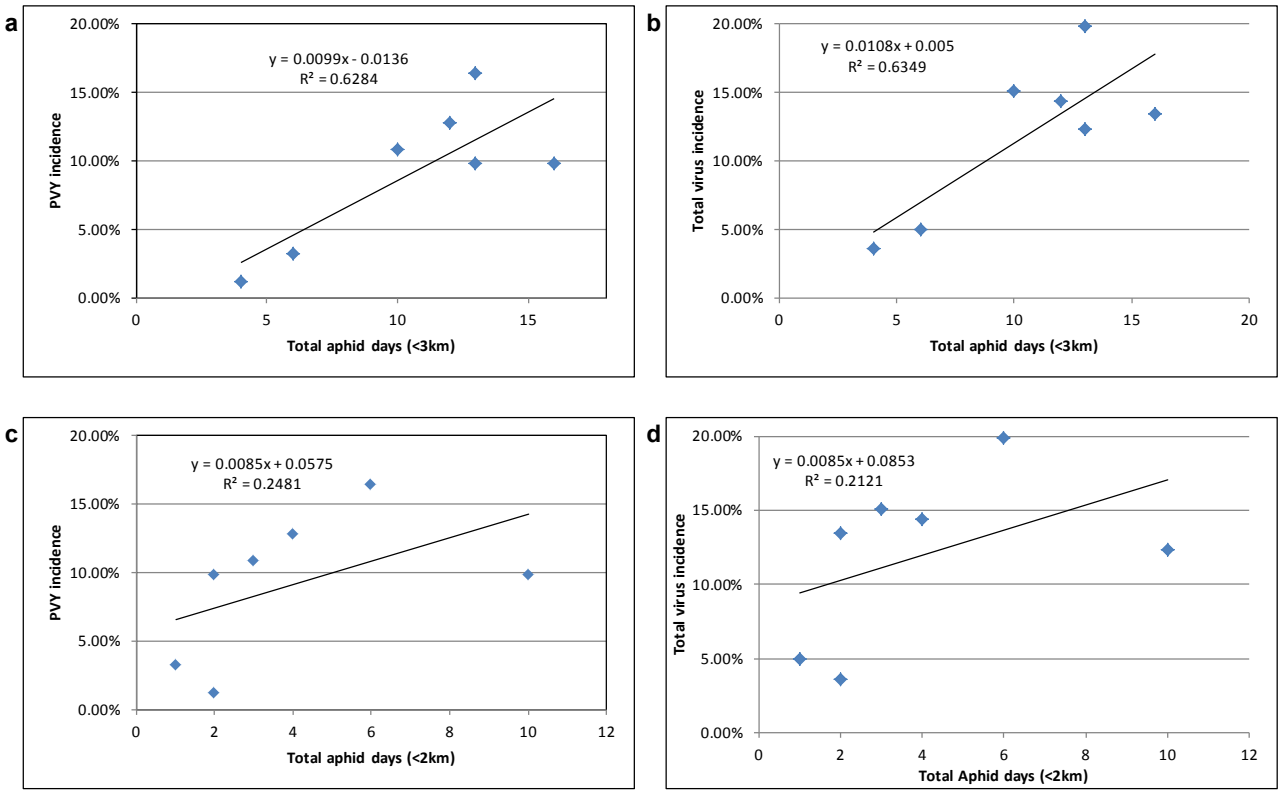

Figure 1. Relationship between aphid days calculated for the months of April, May and June where temperature was 13–30oC and rainfall less than 0.2 mm, for (a) wind speed was less than 3 km/h and PVY incidence and (b) wind speed was less than 3km/hr and total aphid transmitted virus incidence.

the North East region, which had by far the highest incidence of PVY. It is important to note that high-grade Lady Claire seed is not produced by the DAFM and that seed appearing in the Irish Certification system may be lower grade seed being imported from other countries.

The ECPD does not, however, specify the strain of PVY for which it reports resistance, and the contradictory results may reflect differential resistance to different strains of PVY between the varieties. Owing to the evolution speed of PVY, results on previously tested varieties against PVY resistance may no longer be relevant. There is clearly a genetic component in varieties that confers resistance to viruses. However, the lack of consistency between these results and the ratings given in the ECPD and indeed in the ECPD ratings reported from different countries implies that the resistance may be race specific, a result that is in agreement with Ritter *et al.* (1991).

The PVX was notably higher in the north of the country. This may be due to climatic/geographic effects, with slightly duller, cooler and wetter conditions being more conducive to mechanical virus transmission, correlating with the report of Qamar *et al.* (2003). Because of the nature of the transmission of PVX, the spread of this virus should be limited by using clean seed and cleaning machinery and tools as well as controlling volunteer potatoes (Groves *et al.,* 2009).

The incidence of both PVY and PVY^{N} was notably higher in the North East Region (North Dublin, Louth and Meath) of the country. This increase in virus incidence may be attributed to planting near warm coastal regions where climatic and environmental factors favour virus spread. The East and West had slightly lower incidence with the South East having the lowest PVY incidence. The low incidence in the South East is surprising, given the higher temperatures and lower rainfall compared to the north during the growing season that favours aphid transmission of virus (Warren *et al.,* 2005).

There was a definite correlation between virus incidence and seed class right through from PBTC to Elite with higher incidences of virus in the later generations, demonstrating the deterioration of seed quality through each generation. The objective of the potato seed certification scheme is to ensure that potato seed available to Irish growers meet specific standards of quality. The data presented provides confidence to Irish growers that these standards are being met and also highlights the importance of using high-grade seed where

high-quality crops are required. Whilst control measures such as oil-based sprays, roguing of diseased plants, insecticide applications, crop borders, isolating seed crops and cleaning down machinery will minimise further spread, the use of high-quality virus-free seed should be regarded as the initial control measure.

It has been widely reported that weather conditions can significantly affect virus incidence (Llewellyn *et al.,* 2003). A comparison of individual spring/summer weather variables (wind speed, temperature and rainfall) explained little of the variation in virus incidence. However, when temperature, rainfall and wind speed were combined to identify days suitable for aphid flight, there was a significant correlation between the number of 'aphid days' and aphid-transmitted virus in the data, accounting for over 60% of the variation in seasonal virus incidence (Figure 1). It is important to note that the weather data set is from one site only. It is encouraging that it explains such a large proportion of the variation in seasonal virus incidence on a natural basis. It could be expected that if meteorological data was used in closer proximity to the crops, then the amount of seasonal variation accounted for could be improved. It is also likely that further refinement of the definition of an 'aphid day' might improve this correlation and account for more of the variation in seasonal virus incidence. In turn, the identification of days suitable for aphid flight (within season) could form the basis for improving potato virus risk prediction and, hence, reduce the prophylactic use of insecticides to reduce virus incidence.

It should be noted that such a system could only predict the risk of primary (aphid transmitted) and not secondary virus (tuber transmitted) infection on high-grade seed, which could be expected to be related to the conduciveness of conditions for aphid transmission in the previous season. The virus status of planted seed was not available in this data set, and therefore, this effect could not be assessed.

Clearly improved virus resistance offers a route to minimising the use of pesticides in the potato industry. Development of molecular markers for selecting improved virus resistance in new varieties would offer a more practical route than traditional breeding techniques. The data in this study was collected for another purpose (assessing quality of seed crops); however, it is clearly a very useful and critical resource for establishing the distribution and incidence of the different viruses in Irish seed potato and provides an insight into the many factors influencing virus incidence.

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