Potato Research (2010) 53:17–24
DOI 10.1007/s11540-010-9147-0

Mosaic Virus Symptoms in Potato Crops and the Occurrence of Growth Cracking in Tubers

S. F. Carnegie · M. McCreath

Received: 8 October 2009 / Accepted: 10 March 2010 /
Published online: 13 April 2010

Abstract Infection of potato plants by viruses causing mosaic symptoms may result in a reduction in crop yield, depending on severity of symptoms and incidence. In 2004 and 2007, an investigation was undertaken to examine the relationship between plants with mosaic symptoms and the occurrence of growth cracking in daughter tubers. Samples of pairs of plants affected by mosaic symptoms and plants with no symptoms were collected from nine potato crops, of which seven were cv. Estima, containing at least 20% mosaic-affected plants. Growth cracking was more prevalent on mosaic-affected plants of cv. Estima than on plants with no symptoms. The incidence of growth cracking was much greater on plants showing mosaic symptoms caused by a mixed infection of *Potato virus A* and *Potato virus V* together than on symptomatic plants infected by either virus alone. The presence of virus in plants with no symptoms did not affect the incidence of tubers affected by cracking. In a crop of the advanced selection Blue Tzar, plants with mosaic symptoms caused by *Potato virus* Y^N produced more tubers with cracking than plants with no symptoms. Growth cracking did not occur in the one sampled crop of cv. Désirée infected by *Potato virus A*.

Keywords ELISA · *Potato virus A* · *Potato virus V* · *Potato virus* Y^N

Abbreviations
DAS-ELISA Double antibody sandwich-enzyme-linked immunosorbent assay

Introduction

Infection by viruses such as *Potato virus A* (PVA), *Potato virus V* (PVV), *Potato virus X* (PVX), and *Potato virus Y* (PVY) may cause mosaic symptoms on the leaves of potato plants. The severity of the symptom varies with virus and cultivar. In

S. F. Carnegie (✉) · M. McCreath
Science and Advice for Scottish Agriculture (SASA), Roddinglaw Road, Edinburgh EH12 9FJ, UK
e-mail: stuart.carnegie@sasa.gsi.gov.uk

certification schemes, mosaic diseases are classified as mild or severe, irrespective of the causal virus (United Nations Economic Standard for Seed Potatoes 2008). Mild mosaic is a mottling of the leaflet but with severe mosaic, the mottling is accompanied by a slight to severe distortion and/or a reduction in size of the leaflet or plant. In practice, however, the division between mild and severe mosaic is not clear-cut but requires subjective judgement. The size of the reduction in tuber yield is related to symptom severity (Banttari et al. 1993). However, infection by these mosaic-causing viruses is not known to affect the quality of the tubers although misshapen tubers may be produced by plants derived from seed tubers infected by PVY^O (Logan 1986). In addition, new variants of PVY have been recorded causing symptoms of Potato Tuber Necrotic Ringspot Disease (superficial necrotic rings on the tuber surface) in Europe (Beczner et al. 1984) and North America (Piche et al. 2004).

Growth cracks are healed fissures in the surface of the tuber and can vary from shallow to very deep, normally extending from rose- to heel-end. Tuber cracking is a physiological response to changes in the growing conditions, e.g. water availability although it has also been associated with infection by certain pathogens, e.g. *Potato yellow dwarf virus* (Hiller and Thornton 1993). During potato crop inspections in Scotland in 2004, some observations indicated that growth cracking of tubers of cv. Estima was more prevalent on plants affected by mosaic symptoms than those with no symptoms. A systematic field investigation of the relationship between mosaic symptoms and the occurrence of growth cracking was, therefore, undertaken in a number of crops of cv. Estima and other cultivars containing relatively high amounts of mosaic-affected plants.

Materials and Methods

In 2004, five crops of cv. Estima, one crop of an advanced selection Blue Tzar and one crop of cv. Désirée containing mosaic-affected plants were identified for investigation (Table 1). In 2007, two crops of cv. Estima were studied. Paired plants comprising one plant affected by mosaic symptoms and one nearby plant with no symptoms were chosen. Ten pairs of replicates were sampled from three different areas (blocks) in each crop in order to take account of variability within the crop. A sample of four leaflets was collected from the middle of stems of each plant and tested by DAS-ELISA for PVA, PVV, PVX, *Potato virus S*, *Potato virus M*, PVY^O, PVY^N, *Potato leaf roll virus*, *Tomato black ring virus*, and *Potato mop top virus* (Fox et al. 2005). The tubers produced by each plant were harvested carefully by fork to ensure that, as far as possible, harvested tubers were from the test plant and placed separately in new paper bags. The number of tubers of each plant affected by cracking was counted.

Statistical Analysis

The incidence of tuber growth cracking on plants with mosaic symptoms and no symptoms was examined by analysis of variance by treating sampled areas as blocks

Table 1 Details of crops studied

Crop No.	Cultivar/selection	Location	Intended crop use	Date of sampling
1	Estima	Borders	Consumption	20 July, 2004
2	Estima	Borders	Consumption	20 July, 2004
3	Estima	Aberdeenshire	Consumption	5 August, 2004
4	Estima	Borders	Consumption	17 August, 2004
5	Estima	Morayshire	Consumption	20 August, 2004
6	Blue Tzar	Inverness-shire	Seed	4 August, 2004
7	Désirée	Kincardineshire	Seed	29 July, 2004
8	Estima	Angus	Consumption	14 August, 2007
9	Estima	Berwickshire	Consumption	16 August, 2007

in order to take account of possible differences within the test crop. Percentages were angularly transformed for analysis. In comparisons in which the mean for plants with no symptoms was zero, formal analysis was considered to be redundant. Numbers of cracked versus normal tubers for plants infected by different viruses and combinations of viruses were analysed using χ^2 (chi-squared) test of significance for plants with mosaic symptoms and no symptoms because the number of tubers varied amongst various viruses and their combinations.

Results

In the crops of cv. Estima, the main viruses causing mosaic symptoms were PVA and PVV alone or in mixed infections (Table 2); the other viruses detected were PVX, PVS and PVY^N. Symptoms on the selected plants were relatively mild, being mottling accompanied by a slight distortion of leaflet shape and surface (blistering). The height of mosaic-affected plants was similar to or only slightly less than that of plants with no symptoms. With mosaic-affected plants, the frequency of plant infection by PVA and PVV together was greatest in crops 3, 4 and 5 and was at least twice as great as that for plants infected with PVA or PVV alone. The incidence of infection by PVA and PVV together was less than that for PVA or PVV alone only in crops 1 and 8. Viruses were detected in plants with no symptoms in all crops but were least prevalent in crops 1 and 2 which were the earliest sampled crops (Table 1). The greatest incidence of infection in plants with no symptoms occurred in crop 5 in which 47% of plants were infected by both PVA and PVV. In the crop of advanced selection Blue Tzar (crop 6), the virus causing mosaic symptoms was PVY^N and, in cv. Désirée (crop 7), the main virus was PVA followed by PVX which infected 20% of plants. Symptoms on affected plants of these cultivars were mild mosaic. Virus was not detected in plants with no symptoms in crops 6 and 7.

No growth cracking was found on the tubers sampled from the crop of cv. Désirée, crop 7. With the crops of cv. Estima, the proportion of plants with no symptoms which produced tubers with growth cracking ranged from nil for crop 1 to

Table 2 Percentage of plants infected by various viruses in plants with mosaic symptoms and no symptoms in nine potato crops

Crop No.	Cultivar/selection	Symptom	Virus			
			PVA	PVV	PVA+PVV	Other
1	Estima	Mosaic	36.7	40.0	13.3	10.0
2	Estima	Mosaic	20.0	16.7	53.3	10.0
3	Estima	Mosaic	0	24.1	69.0	6.9
4	Estima	Mosaic	6.9	20.7	62.1	10.3
5	Estima	Mosaic	0	13.3	80.0	6.7
6	Blue Tzar	Mosaic	0	0	0	100
7	Désirée	Mosaic	80.0	0	0	20.0
8	Estima	Mosaic	10.0	46.7	33.3	6.7
9	Estima	Mosaic	10.0	20.0	46.7	23.3
1	Estima	None	0	6.7	0	3.3
2	Estima	None	10.0	6.7	0	0
3	Estima	None	37.9	10.3	6.9	3.4
4	Estima	None	51.7	0	3.4	0
5	Estima	None	20.0	16.7	46.7	0
6	Blue Tzar	None	0	0	0	0
7	Désirée	None	0	0	0	0
8	Estima	None	23.3	3.3	6.7	3.3
9	Estima	None	26.7	10.0	10.0	6.7

30% for crop 9 (Table 3). With mosaic-affected plants, the proportion of plants which produced some tubers with growth cracking ranged from 31% for crop 8 to 83% for crop 5. In all these crops, the incidence of tubers with growth cracks was much greater for plants showing mosaic symptoms than for plants with no symptoms although differences were significant in only 6 out of 8 comparisons. Most of the growth cracks, characteristically, were from rose- to heel-end (Fig. 1). With crops 2, 3, and 5 of cv. Estima, more than 35% of tubers produced by mosaic-affected plants developed growth cracking compared with less than 3% for plants with no symptoms (Table 3). With the advanced selection Blue Tzar (crop 6), the difference was even greater, with 47.6% of tubers of plants affected by PVY^N mosaic having growth cracks compared with 0.8% for plants with no symptoms. In 2004 (crops 1-5), the proportion of plants with no symptoms producing cracked tubers was less for earlier sampled crops (1 and 2) than for later sampled crops (4 and 5) but this trend was less evident for the incidence of tubers affected by cracking.

Table 4 shows the incidence of tubers affected by growth cracking in relation to virus infection of plants with and without mosaic symptoms in crops of cv. Estima, except for those crops in which virus was not found in plants with no symptoms or the amount of infection was very low (crops 1 and 2). In crops 3, 4, 5, 8 and 9, the incidence of cracked tubers on mosaic-affected plants infected by PVA and PVV together was at least twice as great as for those infected by either virus alone.

Table 3 Association between mosaic symptoms in potato plants and growth cracking in tubers, expressed as angularly transformed percentage of plants with cracked tubers and of tubers with growth cracks

Crop No.	Cultivar/ Selection	Plants with cracked tubers			Tubers affected by cracking		
		Mosaic symptoms	No symptoms	LSD (P=0.05)[b]	Mosaic symptoms	No symptoms	LSD (*P*=0.05)[b]
1	Estima	41 (43)[a]	0 (0)	NA	15.0 (7.0)	0 (0)[a]	NA
2	Estima	64 (80)	12 (7)	43.7	44.8 (49.7)	3.8 (0.7)	13.69
3	Estima	63 (76)	16 (10)	56.1	37.1 (36.5)	4.2 (0.7)	20.45
4	Estima	52 (62)	17 (14)	38.9	26.1 (19.7)	5.2 (0.9)	1.55
5	Estima	66 (83)	29 (23)	18.4	44.8 (48.4)	9.6 (2.9)	18.10
6	Blue Tzar	81 (93)	24 (14)	58.6	45.7 (47.6)	5.3 (0.8)	23.73
8	Désirée	33 (31)	13 (7)	25.7	12.8 (4.6)	4.3 (0.7)	9.64
9	Estima	49 (57)	33 (30)	34.2	28.9 (19.1)	12.3 (4.5)	23.70

[a] Figure in parenthesis is untransformed mean percentage

NA means statistical analysis was not applicable

[b] Analysis of variance conducted for randomised block layout with 3 replications, each of 10 pairs

However, in crop 2, growth cracking was as frequent on plants infected by PVA alone as on those infected by both PVA and PVV. Also in crop 2, the incidence of growth cracking was significantly ($\chi^2_{(1)}$ 10.8 **) greater for mosaic-affected plants infected by PVA alone than for those infected by PVV alone. This difference was not found in the other crops. The proportion of tubers affected by growth cracking on plants with no symptoms was not affected by the specific virus infecting the plant. However, in crops 3, 5, 8 and 9, growth cracking was less frequent on plants with no symptoms which were infected by PVA and PVV together than on similarly infected mosaic-affected plants.

Fig. 1 Growth cracking on tubers of a mosaic-affected plant of cv. Estima infected by both *Potato virus A* and *V*

Table 4 Numbers of cracked/normal tubers produced by mosaic-affected and asymptomatic plants infected by various viruses in seven potato crops of cv. Estima

Crop No	Symptom	No virus infection	Virus					Significance
			PVA	PVV	PVA+PVV	PVA+PVY^N	PVY^N	
1	Mosaic	-	5/85	6/109	6/39	-		$\chi^2_{(2)}$ 2.3 ns
2	Mosaic	-	23/21	9/38	77/66	-	-	$\chi^2_{(2)}$ 17.8 **
3	Mosaic	-	0/7	6/69	117/124	-	-	$\chi^2_{(2)}$ 40.0 ***
3	No symptoms	0/166	2/154	1/40	0/38	-	-	NA
4	Mosaic	-	1/25	2/74	52/136	-	-	$\chi^2_{(2)}$ 26.1***
4	No symptoms	2/156	2/166	-	1/10	-	-	$\chi^2_{(2)}$ 3.4 ns
5	Mosaic	-	-	5/42	161/127	-	-	$\chi^2_{(1)}$ 33.1***
5	No symptoms	3/55	1/68	5/46	1/160	-	-	$\chi^2_{(3)}$ 12.8 **
8	Mosaic	-	1/44	1/190	14/121	-	-	$\chi^2_{(2)}$ 19.5 ***
8	No symptoms	0/270	2/65	1/10	0/32	-	-	$\chi^2_{(3)}$ 3.9 ns
9	Mosaic	-	3/51	3/65	30/91	14/22	1/7	$\chi^2_{(4)}$ 28.2 ***
9	No symptoms	7/134	6/39	0/33	1/24	0/20	-	$\chi^2_{(4)}$ 4.3 ns

NA means statistical analysis was not applicable because there were too many zero values

ns not significant

** $0.01>P\geq0.001$

*** $P<0.001$

Discussion

Viruses causing mosaic symptoms are widely recognised as affecting crop vigour and yield, depending on the interaction of virus and cultivar and its effect on plant growth (Burton 1966). The yield of an infected plant is generally reduced in proportion to the severity of the symptom. However, in a crop, adjacent healthy plants can compensate, to some extent, for the reduced yield of virus-affected plants, provided that the incidence of infection is not too great. In certification schemes, e.g. United Nations Economic Commission for Europe Standard for Seed Potatoes (www.unece.org/trade/agr/standard/potatoes/pot_e.htm), the minimum tolerance for virus in the direct progeny (succeeding crop) of certified seed potatoes which are mainly intended to produce end-use crops is no more than 10% severe virus. Crop yield will be increasingly affected as the incidence of virus increases above this tolerance. Our results are, however, the first report to indicate that infection by the mosaic-causing viruses PVA, PVV and PVY^N may, in some circumstances, affect tuber quality by increasing the incidence of growth cracking (Tables 3 and 4), thus rendering the tubers unmarketable.

Growth cracking was much more prevalent on plants showing mosaic symptoms than on those symptomlessly infected or free of virus (Table 3). The data also indicates that, in cv. Estima, growth cracking was more frequent when PVA and PVV were both present in a plant with symptoms than when they were present alone (Table 4). Infection by more than one virus is likely to result in more severe

symptoms of mosaic than infection by a single virus, possibly resulting in a greater effect on tuber growth and hence growth cracking. In the sampled crops of cv. Estima, however, symptoms on plants infected with PVA and PVV were on the borderline between severe and mild mosaic, albeit symptoms were slightly more severe than with one virus alone. The association of growth cracking with mosaic symptoms did not seem to depend on any specific virus because it occurred with three viruses, PVA, PVV and PVY^N (Table 4). It is possible that this effect has been overlooked in the past because growth cracking has only been seen after destruction of foliage and been ascribed to growing conditions. It may also be associated with changes in strains of virus present in Scotland but unfortunately there is no data available on this. Further studies with a range of virus strains and cultivars are necessary to elucidate these findings.

The virus infection detected in apparently healthy plants of cv. Estima was probably the result of primary infection occurring within the crops in 2004 and 2007. The incidence of mosaic-affected plants in the sampled crops was very high, at least 20%, so there were numerous sources of virus within each growing crop for aphids to acquire and transmit virus. This conclusion is supported by the increased amount of infection detected in plants with no symptoms at the later dates of sampling in 2004 when a longer period will have been available for virus transmission by aphids carrying virus. Such infection seemed to be more common in the ware crops than in the two seed crops. This difference could be attributable to more effective aphid control measures in seed crops than in ware crops. Our results show that the incidence of growth cracking on tubers from plants with no symptoms was similar for infected and uninfected plants (Table 4). When plants showing no symptoms were infected by virus, particularly PVA and PVV together, the incidence of growth cracking was considerably less than for mosaic-affected plants infected by these viruses. Primary infection by these viruses did not, therefore, appear to enhance growth cracking of tubers. The very low occurrence of growth cracking in plants with no symptoms may reflect the physiological proneness of the crop to tuber cracking. The additional stress created by symptomatic infection of plants then enhanced this physiological disorder resulting in more prevalent growth cracking on tubers of mosaic-affected plants.

The finding of an association between mosaic symptoms and the development of tuber growth cracking clearly has potentially important implications for seed and ware producers. If mosaic-affected plants in a crop produced more tubers with growth cracks than plants with no symptoms then the incidence of such virus infection would have an effect on the marketable yield of a crop and thus relatively low levels of virus could have a financial impact on the profitability of a crop. The extent to which this type of enhancement occurs with cultivars other than Estima and Blue Tzar has yet to be fully investigated but evidence from SASA's collection of virus-infected samples covering over 25 UK commonly grown cultivars is that it may be very limited.

Acknowledgments We thank the staff in the Potato and Virology Sections at SASA and Rural Payments and Inspections Directorate of Scottish Government for assistance with this work. Thanks also go to the potato growers for allowing us to access their crops and to Mr Adrian Roberts, Biomathematics and Statistics Scotland for statistical advice.

References

Banttari EE, Ellis PJ, Khurana SMP (1993) Management of diseases caused by viruses and virus-like pathogens. In: Rowe RC (ed) Potato health management. The American Phytopathological Society, Minnesota, pp 127–133

Beczner L, Horvath J, Romhanyi I, Forster H (1984) Studies on the etiology of tuber necrotic ringspot disease in potato. Potato Res 27:339–651

Burton WG (1966) The potato. A survey of its history and of factors influencing its yield, nutritive value, quality and storage. Second edition (completely revised). H. Veenman and Zonen N.V., Wageningen, The Netherlands, 382pp

Fox A, Evans F, Browning I (2005) Direct tuber testing for Potato Y *potyvirus* by real-time RT-PCR and ELISA: reliable options for post-harvest testing? Bull EPPO 35:93–97

Hiller LK, Thornton RE (1993) Management of physiological disorders. In: Rowe RC (ed) Potato health management. The American Phytopathological Society, Minnesota, pp 87–94

Logan C (1986) Potato diseases. Department of Agriculture for Northern Ireland, Belfast

Piche LM, Singh RR, Nie X, Gudmestad NC (2004) Diversity among *Potato virus Y* isolates obtained from potatoes grown in the United States. Phytopathology 94:1368–1375