Virus Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Virus Research

journal homepage: www.elsevier.com/locate/virusres

Plant viruses and viroids in the United Kingdom: An analysis of first detections and novel discoveries from 1980 to 2014

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ARTICLE INFO

Keywords:
Novel discovery
Detection
Diagnostics
Commodity
Virus,

ABSTRACT

This review covers 35 years (1980–2014) representing a period of changing land use and agricultural practices in the United Kingdom (UK), which have also witnessed a marked change in the availability and application of new diagnostic technologies. During this period there have been 53 first records of viruses and viroids, of which 36 were first UK findings and a further 17 previously undescribed viruses. Given the challenges in detection and diagnosis of plant viruses, the field of plant virology has been an early adopter of new diagnostic technologies and these data highlight the transition from a reliance on biological, morphological, and serological based identification to the increased application of nucleic acid based detection methods and latterly the emergence of Next-Generation Sequencing.

This review presents a comprehensive record of these findings and an analysis of how the potential drivers of change such as commodity based research, trade, as well as the application of diagnostic technology, could have influenced the frequency and type of findings.

1. Introduction

In order to control the spread of plant disease, the first critical step is to understand its aetiology. This is especially important for diseases caused by viral pathogens, as more generic, chemical control options are simply not available. For this reason the accurate identification and characterisation of plant viral pathogens have been a key challenge since the early history of plant virology. While the discipline of plant virology can be traced back to the late 19th Century, it was not until the 1930s that significant progress in determining the true nature of viral diseases was made (Hull, 2002). At this time a major step forward was the development of methods for characterising and differentiating viral pathogens; effectively the earliest virus diagnostics (Smith, 1933). Using these relatively simple approaches, based upon symptomatology and virus transmission, the first attempts to catalogue the world's viruses were made. In K.M. Smith's seminal 'A Textbook of Plant Virus Diseases', published 80 years ago, he described 51 viruses and virus diseases (Smith, 1937). By the release of the second edition of this text, two decades later, this number had risen to over 300 (Smith, 1957). Over 50 years later, the ninth report of the ICTV listed 1325 different plant virus species (King et al., 2011) and the tenth report listed in excess of 1400 species (ICTV, 2017). This review overlaps and enhances a previous review by Jones and Baker (2007) which covered all plant pathogenic taxa and focussed on the plant health biosecurity aspects of the findings. A limited number of similar reviews for specific geographic regions have been produced but these have focussed on regions such as the Pacific Island Territories (Davis and Ruabete, 2010) and New Zealand (Pearson et al., 2006; Veerakone et al., 2015), where the prevailing climate and agro-environment are markedly different to that in the UK and Northern Europe. Diagnostics are briefly discussed by Davis and Ruabete (2010), however these discussions concentrate on the validity of diagnostic methods reported, rather than exploring the comparative impact of different techniques over time.

The UK has historically had an important role in global trade, and has maintained the capability in terms of the skills and necessary technologies to monitor for both emerging and novel plant viruses. The UK has a demonstrable track record in plant health virology and has been at the forefront of applying many of the virus diagnostic techniques now commonly used around the globe, such as plate ELISA (Clark and Adams, 1977), real-time RT-PCR (Mumford et al., 2000), and more recently Next-Generation Sequencing (Adams et al., 2009). This development of new diagnostic technology has driven much of the surge in identifying new species. In this review we present a comprehensive list of the new viruses identified within the UK over a thirty five-year period and set this against the role that developing diagnostic technology has had, as well as exploring some of the key trends and drivers that have influenced the patterns and changes that we observe.

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http://dx.doi.org/10.1016/j.virusres.2017.06.029
Received 31 January 2017; Received in revised form 30 June 2017; Accepted 30 June 2017

2. Overview of records

As this study covers viruses, viroids and virus-like agents, the term 'virus' is used as a generic descriptor to cover all taxonomic entities, unless specific species are being discussed. First reports can be categorised as either 'novel discoveries' i.e. those viruses not previously described in the literature; or 'first UK detections' where a characterised virus has not been previously reported as occurring in the UK; thus separating out virus detection from virus discovery. Where possible, all these records have been published, either in scientific journals or on other plant health reporting platforms (e.g. EPPO Reporting Service; https://www.eppo.int/PUBLICATIONS/reporting/reporting_service.htm). For the purposes of this study a record is defined in accordance with the criteria required in the journal *New Disease Reports* (NDR; BSPP, 2017). If a virus had been reported subsequently in further host species, only the first finding was included in these data. Likewise if a report in the literature arose from an interception, i.e. a sample taken from a plant in trade which had been collected during phytosanitary border inspection, then these were also excluded from these data.

In reporting the technology used for virus detection and identification, all methods reported up to identification of the virus have been included. Where subsequent methods have been used to further characterise novel viruses, these have been excluded from the data. Methods are clustered into 'technology groups', for instance: ISEM, microprecipitin and ELISA have all been included as 'serology' methods; SDS-PAGE, Return Page and Genus level RT-PCR would be classed as 'molecular'.

For the purposes of further analysis, the date of first finding has been used and not the date of publication. This approach has been applied, as there is often a lag between the date of first finding and the report appearing in the literature. Where references are given in the text such as to a commodity group or the use of a diagnostic method these are meant to be illustrative and not exhaustive lists. For analysis of 'commodity groups', sugar beet (*Beta vulgaris*) has been included in the category 'arable' as this crop is common in arable rotations. Potatoes (*Solanum tuberosum*) have been included with field vegetables and leafy herbs, such as parsley (*Petroselinum crispum*), have been included in salad crops on the basis of sharing production system i.e. protected cropping.

The source data, the infected host, and taxonomic assignments for all viruses, viroids and virus-like agents discussed throughout the review are presented in Table 1. During the 35-year period covered by this review from 1980 to 2014 (inclusive) a total of 53 first detections were recorded in the UK, which equates to a mean frequency of discovery of 1.5 detections per year. However, as can be seen in Fig. 1, when plotted against time, the frequency of discovery is non-linear. While in 29 of the years the number of first detections was between 0 and 2, in 6 years the frequency of discovery was at least double the mean (1983, 1999, 2002, 2003, 2007, 2013); most notably in 2013 where eight viruses were discovered, five of which were from a NGS-based study of a single carrot crop (Adams et al., 2014). Two of the three first detections in 2007 were of pospiviroids: *Columnea latent viroid* detected from tomato (Nixon et al., 2009) and *Tomato chlorotic dwarf viroid* from petunia (James et al., 2008). There were no clear trends discernible from the other years with high numbers of detections, where the viruses, viroids and virus-like agents detected appear to be from a range of host plants and geographic sources. Looking at the cumulative data over 35 years, it is also possible to identify that the frequency of discovery is greater after the late 1990s; with 20 discoveries over the 19-year period from 1980 to 98, compared to the 33 new detections made over the 16 years from 1999 to 2014. There were no clear patterns evident in the detection and discovery of different viral taxa. Excluding unassigned species, there were 26 different viral genera reported. The most commonly reported genera over the period were potyviruses (8 records) and potexviruses (7 records).

As the number of detections per year fluctuates this is presented per 5 year period with a summary of these data is given in Fig. 2. Of the 53 reports reviewed, there were 36 first UK detections and 17, which were discoveries of novel viruses. In the early 1980's there were slight peaks in both these categories. However, the key period for detection of first UK detections was during the period from 1995 to 2004 whereas the peak for novel discovery is the period from 2010 to 2014, where novel discoveries were 50% greater than in any other period.

2.1. Detections with respect to host commodity group

Data for detections by host commodity group over time are given in Fig. 3. This shows that during the review period, just over 37% of first detections are from ornamental species (20 out of 53), with equal numbers of detections from both arable rotation and field vegetable crops (7 out of 53 for each, equal to 13%). Small numbers of detections were identified across the protected edibles, fruit and salad crops (5, 5, and 4 respectively). Over the review period only 4 detections (8%) were from uncultivated species including weeds and trees. During the first half of the study period around a third of first detections were from crops in arable crop rotations, i.e. cereals and Sugar beet. This period includes the first detections of Rhizomania (*Beet necrotic yellow vein virus*) (Hill and Torrance, 1989) and the novel discovery of *Beet soil-borne virus* in Sugar beet (Henry et al., 1986), as well as *Barley yellow mosaic virus* (Hill and Evans, 1980), *Barley mild mosaic virus* (Hill and Evans, 1980; Huth and Adams, 1990) and *Oat chlorotic stunt virus* (Catherall, 1986) in cereals. There were also significant detections in salad crops including *Beet pseudo-yellows virus* in lettuce (Coffin and Coutts, 1990) and the discovery of the novel virus *Watercress yellow spot virus* (Walsh et al., 1989). During the 1990's there is an apparent rise in the prominence of detections in ornamental species, including *Impatiens necrotic spot virus* in Cineraria (Weekes et al., 1998) and *Canna yellow mottle virus* in Canna (Wright, 1999). This decade also witnessed the first UK finding of *Pepino mosaic virus* in Tomato (Wright and Mumford, 1999). The 2000's are again dominated by detections in ornamentals with notable detections of the tospoviruses *Chrysanthemum stem necrosis virus* in Chrysanthemum (Mumford et al., 2003) and *Iris yellow spot virus* in Lisianthus (Mumford et al., 2008). There were significant novel discoveries in fruit crops including *Blackberry chlorotic ringspot virus* (Jones et al., 2006), *Rubus chlorotic mottle virus* (McGavin and MacFarlane, 2009) and *Raspberry leaf blotch virus* (McGavin et al., 2012). This period also includes the first detections of pospiviroids in the UK, with outbreaks of *Potato spindle tuber viroid* and *Columnea latent viroid* in tomato (Mumford et al., 2004; Nixon et al., 2009) and the detection of *Tomato chlorotic dwarf viroid* in Petunia (James et al., 2008). The marked rise in novel discoveries of viruses in field vegetables is due to detections from a single NGS study of carrot viruses (Adams et al., 2014).

2.2. Detections with respect to diagnostic technologies

The development and application of diagnostic technologies have an influence on the ability to detect and diagnose viruses. Summary data of techniques reported in diagnosing first virus detections are presented in Fig. 4, recording where techniques have been successfully applied to the detection or diagnosis of a finding. Due to the limited rate of development of new diagnostic methods these data are presented in 5-year periods. As the diagnostic process is complex and multiphasic, in the majority of reports there are at least two methods applied in the initial detection and identification of a novel or unusual virus. The period covered by the review saw the emergence of many techniques implemented for the first time in laboratories and in turn these have helped in the detection and diagnosis of novel or unusual viruses. Some of these techniques have developed to become routinely used in the laboratory such as microplate ELISA, first reported by Clark and Adams (1977), the first record of this technique being used in the detection of a first finding in the UK was in the detection of *Potato virus V* (Jones and