Management of viruses and virus-like agents affecting apple production

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1 Introduction

In the context of this chapter, the term 'virus' will include virus-like agents that share certain characteristics such as persistence in the tree and graft transmissibility. Therefore, the comments to follow apply to viruses, viroids and phytoplasma, as well as agents of graft-transmissible diseases that have yet to be identified. Many viruses and virus-like agents that infect apple do not elicit acutely obvious symptoms. Consequently, they are frequently and inadvertently propagated and dispersed, creating a negative impact on production and the economic sustainability of the industry from the nursery to the consumer. Unlike many insect or microbial infections, viruses persist within infected tissues, and thus, exert their effects throughout the life of an orchard tree, which may span 20 years or more. Most viruses encountered in apple production do not have insect vectors known to transmit the pathogen – perhaps the long history of vegetative propagation has allowed the viruses to evolve without the need to associate with insect or other vectors other than humankind. For this reason, many diseases caused by virus-like agents can be managed most effectively by planting trees that are tested and found free of pathogens. The effectiveness of this strategy was demonstrated in the 1950s with fruit tree and grape programmes and is currently reinforced by a system of clean plant programmes operating throughout the world (Gergerich et al., 2015). Planting stock that is tested and found free of virus-like agents based on prescribed protocols is referred to by one of several terms, including foundation, nuclear or G1 stock. The strategy of building the industry on nuclear stock is particularly critical in the face of rapid globalization of fruit tree production, increased global competitiveness and the exchange of large volumes of planting and breeding material in the search for new and desirable product characteristics.

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The quest to obtain new genetic material from other growing regions and countries is tempered by the desire to prevent the introduction of disease agents, or potentially more damaging isolates of existing agents, into a particular growing region. A substantial barrier to rapid access to virus-tested material is the absence of knowledge of aetiological agents associated with many graft-transmissible diseases. The North American Plant Protection Organization currently lists 39 graft-transmissible apple diseases for which the associated pathogen is not known (NAPPO, 2009). To strengthen assurances that these agents and other pathogens are absent from propagation material, a complex system of testing has developed. These procedures are used in whole or in part (tailored to regional disease pressures) in foundation and certification programmes in many countries. In the past 20 years, molecular and serological assays have been increasingly incorporated into these programmes because of their rapidity and dependability. However, for the diseases with no known pathogen(s), biological assay procedures remain the current standard. The introduction of high-throughput sequencing has the potential to dramatically impact this model, and the technology is being introduced into several testing facilities. From the research perspective, this technology provides a tool that will allow scientists to determine the identity of aetiological agents associated with many of these diseases. However, this powerful technique is also revealing previously unrecognized viruses in plants that are not expressing overt symptoms, thus raising the question as to whether these agents should be considered pathogens.

2 Reducing the economic impact of virus-like agents

Quantifying crop losses attributable to infection by virus-like agents is one of the most difficult parameters to assess in crop production (Posnette, 1989; Waterworth and Hadidi, 1998; Hadidi and Barba, 2011). Yet, the presence of virus-like agents can be a determining factor in the economical sustainability of the apple industry. The impacts of viruses begin in the nursery where infection significantly reduced tree growth over their two-year residency in the nursery (Maxim et al., 2004). The impact carries forward through the production of trees and fruit, and into the marketplace. One analysis reported that the use of virus-free trees for apple production would avoid losses to growers in the United States of $63M annually (Cembali et al., 2003). The same study suggested that uniform adoption of virus-free planting stock would be reflected in substantial cost benefits to consumers in the United States.

The economic impact of viruses on production can be viewed at the individual grower level. A 14-year study determined the impact on the production of 'Golden Delicious' apples from trees infected with three common 'latent viruses' of apple: *Apple chlorotic leafspot virus* (ACLSV) (genus *Trichovirus*), *Apple stem pitting virus* (ASPV) (genus *Foveavirus*) and *Apple stem grooving virus* (ASGV) (genus *Capillovirus*) (van Oosten et al., 1983). The combination of these viruses resulted in a 17% reduction in yield over the course of the study. This reduced growth triggered a reduction in pruning costs and harvest costs that only partially compensated for reduced yield. The application of these reported yield and cost reductions to a balance sheet for the establishment and maintenance of a 'Red Delicious' apple orchard in Washington State (planted at 900 trees per acre) (Gallardo and Galinato, 2012) provides a gauge for the value of anticipated losses. It would require a price of $421.50 per 850-pound bin for the orchard planted with infected trees to match the economic return from an orchard planted with virus-free trees receiving only $400.00 per bin. This disparity is imposed throughout the 30-year life expectancy of the orchard and dramatically reduces the economic sustainability of the orchard operation. Moreover, the study of the 'Golden Delicious' block (van Oosten et al., 1983) also noted an increased rate of blemished fruit that would further reduce the profit margin from the virus-infected orchard. A similar 12-year study on 'McIntosh' grown on a variety of rootstocks confirmed these basic trends (Warner et al., 1984). Virus-infected trees not only produced lower crop yield, but the grade of the fruit produced was also reduced, resulting in lower profitability of orchards. In spite of the apparent economic impact of these 'latent viruses', the absence of easily recognizable symptoms has led to their widespread distribution in the industry.

The production and distribution of virus-tested propagation material is key to reducing the burden of virus diseases in commercial production (Gergerich et al., 2015). Clean plant programmes provide propagation material that is free of known economically important virus and virus-like agents, and are essential elements in any holistic approach to manage the diseases caused by these pathogens, and to improve economic sustainability. The constant flow of virus-tested material into commercial production displaces virus-infected trees and, over time, improves the overall phytosanitary status of the industry. Many of the diseases reported in the mid-twentieth century and caused by graft-transmissible agents can no longer be found in commercial production orchards. Also, clean plant programmes provide a means to safely access foreign cultivars for both new market development and new cultivar development, critically important to future viability of the industry.

Producers who are able access new varieties within the first three years of availability gain higher returns from their planting than growers who enter the market at a later time in the cycle of new variety development. Therefore, a central issue in the management of viral diseases in sustainable apple production is the balance between the need to establish new apple clones in orchards of commercial growers as quickly as possible, and the need for biosecurity (Foster and Hadidi, 1998). Since trees that are tested in the various quarantine and certification programmes will be expanded to thousands or millions of trees, these programmes are circumspect in their efforts to ensure that trees are free of harmful pathogens that could impact the broader industry.

The heart of clean plant programmes is the production of foundation planting material. Clean plant programmes represent substantial commitment and economic investment because of extensive testing and quarantine requirements, particularly for material from foreign sources. These programmes are the first line of defence in the effort to exclude new pathogens or genetic variants of pathogens from an area. For example, the Clean Plant Center Northwest located at Washington State University – IAREC in Prosser, Washington, reports that 40% of the propagation material submitted to the programme is infected with one or more virus-like agents. Similar programmes dedicated to the exchange of foundation level material exist throughout the world, and they facilitate the domestic and foreign exchange of commercial cultivars and germplasm (Gergerich et al., 2015). The nuclear stock sourced from these centres becomes the foundation from which large numbers of trees are expanded by nurseries and growers. In the United States, state-operated certification programmes offer a mechanism by which the released foundation material is propagated in such a manner as to minimize the risk of reintroduction of virus-like agents. The regulations for certification are generally based on the risk of re-infection imposed by regional conditions; consequently, testing requirements can vary between states.