Emerging strawberry virus and virus-like diseases in the world

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As strawberry demand and production increases , so too do the virus diseases that affect them. In the last ten years there has been significant work towards the characterization and detection of graft-transmissible diseases and today the number of strawberry viruses has more than doubled compared to the number we knew of at the turn of the century (Martin and Tzanetakis, 2006). Another significant change in the last years is the presence of multiple virus infections that synergistically cause severe disease and losses in several strawberries-producing areas. This review aims to summarize the information on strawberry viruses and diseases that was accumulated during the first part of the 21st century.

The most important strawberry viruses are those transmitted by aphids. This virus group has always been a major problem wherever the strawberry aphid (*Chaetosiphon fragaefolii*) is present (Converse, 1987). There are now seven aphid transmitted viruses, Strawberry mild yellow edge (SMYEV), Strawberry vein banding (SVBV), Strawberry crinkle (SCV), Strawberry mottle (SMoV), Strawberry chlorotic fleck (SCFV), Strawberry pseudo-mild yellow edge (SPMYEV) and Strawberry latent C (SLCV).

SMYEV is an aphid-borne potexvirus (Jelkmann et al., 1992) and SVBV is a caulimovirus (Petrzik et al., 1998). In the last decade, a study with several SMYEV isolates revealed significant virus diversity and this information was used to develop primers that allow detection of all diverse isolates identified (Thompson and Jelkmann, 2004). This information has been invaluable in certification programs for elimination of the virus given its significance in strawberry production.

SCV, another major strawberry virus, was known to be a persistently transmitted *Cytorhabdovirus*, but now there is sequence information (Schoen et al., 2004) that has been used to develop new detection techniques that allow fast and sensitive detection (Posthuma et al., 2002; Klerks et al., 2004; Mumford et al., 2004). A major strawberry disease, mottle, now known to be caused by SMoV, a semi-persistent virus that is closely related to *Satsuma dwarf virus* and *Black raspberry necrosis virus* (Thompson et al., 2002). Several isolates have been characterized and this information has been used for the development of a robust detection method of the virus in certification programs and the field (Thompson and Jelkmann, 2003). SCFV, a closterovirus, was isolated and characterized from the only chlorotic fleck diseased plant known to exist, but the presence of several other viruses in this plant prevented the determinating whether CF is the sole cause of chlorotic fleck disease (Tzanetakis et al. 2007). Detection protocols for the virus have been employed in the North America and Europe and the virus was found in both continents in small number of plants (this meeting, Martin and Tzanetakis; Ratti, personal communication). This information indicates that the virus is probably not a major problem for strawberry production. The other two aphid-borne viruses, SPMYEV and SLCV are poorly characterized but there is information on their phylogenetic placement. SPMYEV is a carlavirus (Yoshikawa and Inouye, 1986) and SLCV a nucleorhabdovirus (Yoshikawa and Inouye, 1988). An antiserum has been developed for SPMYEV and there are efforts under way to characterize SPMYEV and SLCV at the molecular level.

A new group of viruses, members of the genus *Crinivirus* have emerged as a new threat to strawberry in areas where whiteflies, crinivirus vectors, are present. To date all criniviruses are transmitted by whiteflies in the genera *Trialeurodes* and *Bemisia*. There are four new criniviruses discovered in strawberry, *Strawberry pallidosis associated virus* (SPaV) (Tzanetakis et al., 2004), *Beet pseudo-yellows virus* (BPYV) (Tzanetakis et al., 2003) and strawberry criniviruses 3 and 4 (Tzanetakis and Martin, unpublished). SPaV and BPYV have been fully characterized, including their virus-vector relationships (Tzanetakis et al., 2006), whereas there is only limited sequence information available for strawberry criniviruses 3 and 4. SPaV and BPYV are the most common of the four and are present in both the New and Old World. SPaV has a limited host range but some of the alternative hosts are common strawberry field weeds (Tzanetakis et al., 2006). BPYV has a wide host range ranging from strawberry and blackberry to beet and spinach. Both viruses are transmitted semi-persistently by the greenhouse whitefly (*Trialeurodes vaporariorum*). Although there are both immunological and molecular (reverse transcription polymerase chain reaction/RT-PCR) tests available for SPaV and BPYV, the preferred detection method is RT-PCR against conserved polymerase sequences because of the low titer of the viruses and the genetic diversity observed between different isolates that can be lower than 80% in the nucleotide level.

The pollen-borne ilarviruses that infect strawberry include Strawberry necrotic shock (SNSV), Apple mosaic (ApMV), Tobacco streak (TSV) and Fragaria chiloensis latent (FClLV). SNSV is the predominant ilarvirus in the United States whereas FClLV has significant presence in Chile (this meeting, Martin and Tzanetakis). TSV is uncommon in strawberry in the United States (Tzanetakis et al., unpublished) and previous reports of the virus in the crop were probably actually due to SNSV (Tzanetakis et al., 2004). ApMV was first found naturally infecting strawberry a few years ago (Tzanetakis and Martin 2005), although it was known that the virus can replicate in strawberry through grafting experiments. The virus was found in the only known plant with strawberry leafroll disease, but as was the case with chlorotic fleck the plant was also infected with SPaV and BPYV that might have contributed to the observed symptomatology. Several hundred plants have been tested for ApMV infection in the United States and the infection percentage was miniscule. The high titer ilarviruses reach in strawberry, the great diversity observed with many ilarviruses (Petrzik and Lenz, 2002) and the excellent antisera available for these viruses make immunological detection methods, such as ELISA, the preferred detection method for these viruses.

Modern strawberry cultivation has minimized the impact of nematode-borne viruses but the reduced use of methyl bromide and other soil fumigants may lead to the re-emergence of this group of viruses in the future. There are five nematode transmitted viruses found in the crop, *Tomato ringspot* (ToRSV), *Strawberry latent ringspot* (SLRSV), *Arabis mosaic* (ArMV), *Raspberry ringspot* (RpRSV) and *Tomato black ring* (TBRV). All but ToRSV are primarily found in Europe. The major discovery concerning nematode-borne viruses in strawberry in the last decade was the discovery of SLRSV in the United States and Canada (Martin et al., 2004). Like ilarviruses ELISA is the preferred detection method for strawberry nematode-borne viruses.

Three other viruses have been found in strawberry, Tobacco necrosis, Fragaria chiloensis cryptic and Fragaria latent. They have not been reported to cause significant losses as is also true for the still uncharacterized agent that causes feather-leaf disease.

Tolerance of modern cultivars to single virus infections together with much of the cultivation now done on an annual system have minimized the effect of viruses in the crop. However, there have been cases of severe outbreaks that have caused losses in the tens of millions of dollars to growers. Such is the case of the virus-caused decline that occurred in the west coast of North America in the 2002-2003 seasons and led to losses that exceeded $50 million (Martin and Tzanetakis, 2006). The new information developed on strawberry viruses over the last decade is being applied to improve certification schemes, which are the cornerstone in controlling virus disease of perennial crops such as strawberry.

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