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A REVIEW PAPER ON POTATO MOP-TOP VIRUS (PMTV): OCCURRENCE, PROPERTIES AND MANAGEMENT

[a]Aqleem Abbas* and [b] Meysam Madadi
Department of Plant Pathology, the University of Agriculture, Peshawar Pakistan,
College of Plant Science and Technology, Huazhong Agriculture University, Wuhan, China.
*Corresponding email address: aqlpath@gmail.com

ABSTRACT

Potato mop-top virus (PMTV) is a plant pathogenic virus that affects potatoes. The virus was initially reported from Germany but now it has spread throughout Europe, Asia, South America and North America. It is responsible for spraing symptoms (brown arcs/lines, blemishes, and rings) on potato tubers and yellow chevrons or mopping (Shortened internodes) in the leaves and stems of plants grown from infected potato tubers. PMTV causes huge economic losses due to poor tuber quality. It is an important disease in the potato growing areas of the world. PMTV is tubular rod shape and has a single stranded positive sense RNA (+ssRNA) tripartite genome. RNA 1 encodes RdRp (viral RNA-dependent RNA polymerase). Coat protein (20kDa) and a larger protein (91kDa) is encoded by RNA2. RNA2 encodes larger protein (91 kDa) by read through (RT) of the amber termination codon of the coat protein. There are three conserved moldular sets of genes known as triple gene block (TGB) which are coded by RNA3. These TGBs are involved in cell to cell or long distance movement of PMTV. In nature, PMTV is vectored and transmitted by a soil born pathogen (Plasmodiophorid (*Spongosporasubterraneanf.sp.* subterranean abbreviated as 'Sss') that itself causes the powdery scab disease on tubers. The disease caused by PMTV and *Sss* are favored by cool and damp conditions. PMTV remain in spore balls of *Sss* for several years even if the potato is not grown in the field. There are no efficient means to manage the virus nor its vector in an infested field, therefore, preventive measures are essential. Since PMTV along with its vector is causing important disease of potato, so understanding its molecular, biological, physical properties and management strategies is very important.

Key word: PMTV, genome, distribution, detection, management.

INTRODUCTION

*Potato mop-top virus (*PMTV*)* belongs to family *Virgaviridaae* and genus *Pomovirus*.PMTV is known as type species of the genus *Pomovirus*. PMTV is affecting tuber quality and reducing the yield of potato (*Solanum tuberosum* L.) (Van de Graaf *et al.*, 2007; Kalischuk *et al.*, 2016). Qualitative losses are much more than quantitative yield losses of potato tubers and can lead to total crop rejection by processors and supermarkets (Mumford *et al.*, 2000).

PMTV has been reported from North and South America, Asia, northern and central Europe and some parts of Africa (Domfeh *et al.*, 2015). PMTV has straight, tubular, rigid particles of about 100-300 nm in length and 18-20nm in diameter (Plchova *et al.*, 2011). As mentioned in Abstract of this review paper the genome of PMTV is composed of three positive sense single stranded RNA molecules viz.,RNA1, RNA 2 and .RNA3. The size of RNA 1, RNA 2 and RNA3 is about 6, 3.2. and 2.5 kb respectively (Hélias *et al.*, 2003).

Spongospora subterranean f.sp. subterranean (Sss) a soil born pathogen is causing powdery scab disease and also a vector for the transmission of PMTV to potato cultivars (Arif *et al.*, 1995). PMTV persists for a longer period of time in the resting spores of Sss and remain infective for 18 years without potato crop (Calvert, 1968). The resting spores of *Sss* also have potential to remain alive for a long period of time without the presence of potato crop. Prolonged or normal periods of crop rotations may not eliminate PMTV easily. PMTV in contrast to *Sss* has a narrower host range, infecting members of families *Solanaceae*, *Tetragoniaceae*, and *Chenopodiaceae,*(Andersen *et al.*, 2002). Cool and humid soils are favorable to both PMTV and its vector. Symptoms induced by PMTV typically depends on potato cultivars and environmental conditions. Typical symptoms caused by PMTV are somewhat raised lines or slightly raised brown or rust colored lines or rings on the surface of potato tubers or arcs, technically called spraing symptoms in the flesh of potato tubers of the susceptible potato cultivars. These are actually current season infection, so called primary infection. Among various factors, the most important factors are the cultivar and environmental conditions greatly influence symptoms caused by PMTV(Harrison and Reavy, 1974). In the case of secondary infections, tubers exhibit deep cracks or reticulations or, freckled or blotchy surface markings (elephant hide blemishes) or distortions (Harrison and Jones, 1971). The same symptoms are also induced by Tobacco rattle virus (TRV) both of which make the tubers unacceptable for consumption or processing. Foliar symptoms consist of mild to severe symptoms. Yellow blotches, rings and chevrons on the leaves are mild symptoms whereas the shortening of internodes resulting in a dwarfed appearance so called mop-top is known as severe symptoms (Calvert, 1968). The leaves are showing different shades of yellow markings resembles symptoms caused by Alfalfas mosaics virus and Potatos acuba. Virus. Foliar symptoms described above are severely

affected by environmental conditions such as temperature, light, and rainfall. The severity of symptoms sometimes decreases in warm and dry weather (Carnegie *et al.*, 2010). The techniques used to detect PMTV are; a. Reverse transcription polymerases chain reactions (RT-PCR) b. Real time Polymerase chain reactions (RT-PCR) c. qualitative amplifications based specific hybridizations, microplate hybridization RT-PCR and ELISA (enzyme-linked immunosorbent assay (Domfeh *et al.*, 2015). As PMTV survives in resting spores of *Sss* for a long period of time. Therefore, it becomes very difficult to control both the vector and PMTV. The vector can also be treated with chemicals, but chemicals cause cytotoxicity in plants and also other environmental problems. Genetic resistance in potato cultivar against PMTV remains the best option to manage the disease (Sandgren *et al.*, 2002). The disease can also be managed by avoiding that is to grow certified seeds and use of Sss free soil (Sandgren, 1995). The primary objective of this review paper is to demonstrate the geographical distributions, biological and physical properties and management of PMTV and its vector.

Occurrence and Distribution: Among other potato viruses like PVY (Abbas *et al.*, 2012; Abbas *et al.*, 2013; Abbas *et al.*, 2014; Hussain *et al.*, 2016) and PLRV (Abbas *et al.*, 2016) PMTV is one of the significant problems of potato growing areas of the world (Harrison and Jones, 1971; Harrison and Reavy, 1974). PMTV is present in almost all potato producing countries of the world. The environmental factor in particular precipitation is related to the occurrence of PMTV. If the amount of precipitation is less than 760 mm then infection of PMTV will be low. The prevalence of PMTV will be increased with the increase in the amount of precipitation from 760 to 1140 mm or higher (Cooper and Harrison, 1973). The origin center of PMTV is the Andean region of South American (Tenorio *et al.*, 2006) and then the virus spread to the United States and Canada. Later PMTV was detected in potato tubers of England, Scotland and Ireland (Calvert and Harrison, 1966). In Asia, PMTV was detected in Hokkaido islands of Japan (Nakayama *et al.*, 2010) and in China. PMTV has been detected from the Czech Republic and Switzerland (Schwärzel, 2002). PMTV has also been detected from potato tubers of Nordic countries such as Norway, Sweden, Denmark and Finland (Santala *et al.*, 2010). The occurrence of PMTV was also reported from potato cultivars of Malakand and Hazara divisions of Pakistan. The highest disease incidence of PMTV was reported from Hazara division. In Hazara division potato cultivars in Abbottabad (19%) were severely infected by PMTV followed by Manshera (15%). In the case of Malakand division lower incidence (5-12%) was observed (Arif *et al.*, 2013). PMTV was also reported from the countries around the Baltic Sea in 2005, in particular, Latvia where PMTV was detected from the tubers by double sandwich enzyme linked immunosorbent assay (DAS-ELISA) and further confirmed by RT-PCR(Santala *et al.*, 2010). PMTV was also reported from the potato tubers of the central Poland in 2008 and 2009 (Budziszewska *et al.*, 2010).

Biological Properties: When plants are grown from infected tuber foliar symptoms usually develops and symptom development depends on temperature. The foliar symptoms appear on potato crops when grown at the temperature below twenty degree centigrade (<20°C)(Carnegie *et al.*, 2010). The common symptoms induced by PMTV are known as accuba patterns. These patterns are actually bright yellow lines or blotches or rings usually visible on the leaflets of upper leaves and with the passage of time these patterns converts into a mosaic. The other symptoms produced by PMTV which are not more common are V shaped chlorotic or pale chevrons. The most prominent symptoms are mop-top which consist of extreme shortening of internodes in combination with the bunching or crowding of the foliage. In tubers, Potato mop top virus (PMTV) is responsible for causing spraing disease. This disease is characterized by formation of arcs (necrotic) and rings on the surface of the potato tubers. These symptoms degrade the quality and consequently the market value of potato tubers(Harrison and Jones, 1971; Kurppa, 1989). Brownish arc and circles will be formed in the tuber flesh of susceptible potato cultivars if grown in infested soil. These symptoms are technically called primary symptoms (Sandgren, 1995). When infected tubers are grown, secondary symptoms are developed. Secondary symptoms include chevron or yellow blotches and bunched upper leaves with rolled and wavy margins. (Kurppa, 1989). Cracks, blotchy marking on the surface of potato tubers as well as distortion in infected tubers are also parts of secondary symptoms caused by PMTV (Harrison and Jones, 1971).

In additions to potato, the other hosts of PMTV (Jones and Harrison, 1972) are weeds as well as crop species belong to families such as *Solanaceae*, *Chenopodiaceae* and *Tetragoniaceae*(Jones and Harrison, 1972; Andersen *et al*., 2002*)*. Large no of other host plants such as *Chenopodium amaranticolor, Nicotiana debneyi* and *N. tabacum* have been identified by artificial inoculation for in vitro (Harrison and Reavy, 1974). There are no reports of PMTV presence in sugar beet and spinach belonging to the family *Chenopodiacea*(Jones and Harrison, 1972). Tomato (*Lycopersicon esculentum*Mill.) also known to obtain PMTV through vector transmission. The black nightshade (*Solanum nigrum*L.) is a common weed found throughout the world and it is a major reservoir for PMTV during the years when the potato is not cultivated (Andersen *et al.*, 2002).

The occurrence of the vector (Sss) of PMTV (Arif *et al.*, 1995)has been reported from all potato growing regions of the world (Kirk, 2008). Transmission of PMTV by powdery scab is dependent on temperature. If temperature ranges are at 12-20^{0}C then transmission of PMTV will occur with the greatest success and above 24^{0}C little or no transmission will take place (Carnegie *et al.*, 2010).Life cycle of PMTV vector (Sss) has two stages. The formation of cystosori which are dormant or resting spores is the first stage. Then cystosori will germinate and release zoospores that called secondary stage. The zoospores then infect roots, stolons and tubers. During infection zoospores also transmit PMTV into host

plant (Merz *et al.*, 2005; Kirk, 2008). Aphids being the important vectors of other plant viruses cannot transmit PMTV to host plant. PMTV may also be transmitted to some host by grafting or mechanical inoculations. The capability of PMTV to stay on spores balls of Sss for several years in soil has made its management challenging (Kirk, 2008).

Physical and Molecular Properties: The genus *Pomovirus* contains PMTV along with other plant viruses (family *Virgaviridae*). PMTV particles are linear, tubular and rigid in shape measuring 18-20nm in diameter and 100-300nm in length (Jones and Harrison, 1972; Harrison and Reavy, 1974). Being a systemic pathogen PMTV prefers to reside in host cell cytosol (Tidona and Darai, 2002). It's usually found in low concentration and in uneven distribution in infected host tissues (Hélias *et al.*, 2003). The genome of PMTV consists of three molecules of positive sense RNA species (+ssRNA) (Harrison and Reavy, 1974)(Fig 1).

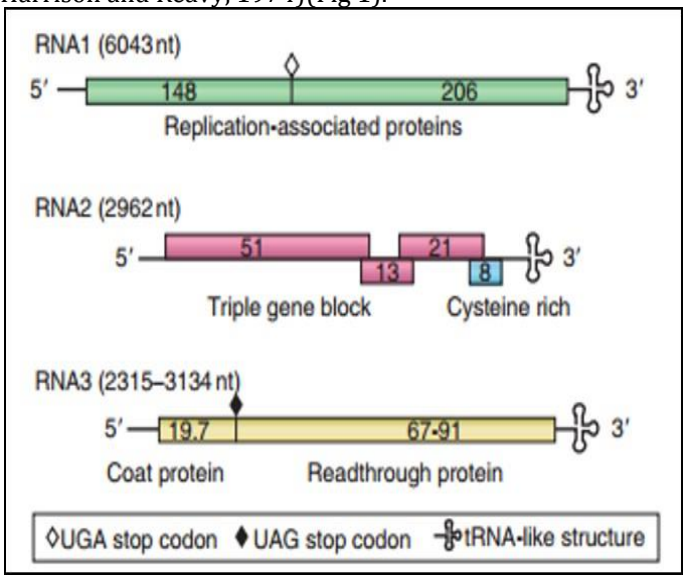

Fig 1. Genome organization of PMTV (Abou-Elnasr *et al.*, 1985).

The size of RNA1, RNA2 and RNA3 is 6kb, 3.2kb and 2.5kb respectively (Savenkov *et al.*, 1999; Zamyatnin Jr *et al.*, 2004). The enzymes such as viral RNA dependent RNA polymerase (RdRp), helicase and a methyltransferase is encoded by RNA1 molecule. The other special proteins i.e. coat protein (CP) and read through (RT) proteins are encoded by RNA 2 molecule. However, RNA 3 molecule encodes a cysteine rich protein (of unknown functions), triple gene block (TGB) and an 8k protein (Nielsen and Nicolaisen, 2003). Currently these RNA molecules have been renamed; RNA-Rep (former RNA 1), RNA-CP (former RNA2 or RNA 3) and RNA-TGB (former RNA2 or RNA 3) (Lukhovitskaya *et al.*, 2013). PMTV moves from cell to cell via RNA-TGB Molecule which encodes a triple gene block movement protein and also mini cysteine rich 8kD zinc finger protein. Coat protein (RNA-CP) is found to highly conserved among various isolates of PMTV(Hélias *et al.*, 2003). For clearer picture, Genomic components of PMTV are shown in Table 1.

Genomic components	Functions
RNA-Rep RNA-CP RNA-TGB	• RNA-dependent RNA Polymerase • Coat Protein • Four open reading frames (ORF); These ORF encodes TGB Proteins i.e. TGBp1 (51K), TGBp2 (13K), and TGBp3 (21K) • Also having an 8K cysteine-rich protein • Involved in virus movement

Table 1. Genomic components of PMTV and their functions

Detection of PMTV: Symptoms caused by PMTV are not preferred for reliable detection of PMTV virus. The distribution of PMTV even in tubers is uneven so sampling is also the most critical step in its detection(Sokmen *et al.*, 1998). If sampling is done from the stolon of the tuber or from tissues having spraing symptoms, then still detection becomes complicated because the virus is not always present in high titers or confined to either tissue(Germundsson *et al.*, 2002). Tubers are also checked for the presence of PMTV by planting them in the soil and when leaves emerge sampling is done unluckily this method is also not appropriate for detection of PMTV, as the virus is rarely present in the leaves grown from infected tubers (Carnegie *et al.*, 2010). The occurrence of Soil samples can also be studied for the detection of PMTV, but the problem is neither the virus nor its vector found to be evenly distributed in the field (Jones and Harrison, 1972).

Therefore, for detection of PMTV, virus-specific methods such as PMTV coat protein (CP) specific antibodies, DAS-ELISA, immune capture reverse transcription polymerase chain reaction (IC-RT-PCR) or RT-PCR using PMTV specific primers techniques are used (Sandgren *et al.,* 2001). Modern methods such as RT-PCR micro-plates hybridization and fluorescent amplification based specific hybridization (FLASH-PCR) have also been applied to improve PMTV detection ((Nakayama *et al.*, 2010) Enzyme linked immunusorbent Assay (ELISA) is reported by several researchers as a best option for detection PMTV (Sokmen *et al.*, 1998). RT-PCR having fluorescent assays have increased accuracy in diagnosis of PMTV (Mumford *et al.*, 2000). Recently in Colombia PMTV has been detected along with a new pomo-like virus. The genome of that new virus is found to be closely related to the genome of PMTV. That new virus was called Colombian potato soil borne virus (CPSbV). Similarly, in the Narino region of Columbia another virus 'soil born virus 2' (SbV2) was detected along with the PMTV (Gil *et al.*, 2016). RT-PCR along with the baiting methods to trapped Sss have proven effective in the detection of PMTV (Nakayama *et al.*, 2010). For successful detection of PMTV from the soil and plant samples a combination of infectivity assays, ELISA and RT-PCR has recently been reported by a researcher (Arif *et al.*,

2014).**PMTV and Vector:** *S. subterraneaf. sp. subterranean* (*Sss*) besides being a pathogen is also a vector of PMTV (Arif *et al.*, 1995). It is confined to areas with a cool and humid climate i.e. Northern Europe, Northern America, China, Japan and the Andes region. Powdery scab the vector of PMTV is widely distributed, but PMTV has a narrower distribution. Powdery scab infects various families of plants, but PMTV only infects *Solanaceae* and *Chenopodiaceae*(Jones and Harrison, 1972; Andersen *et al.*, 2002). PMTV resides in zoospores and is transmitted by zoospores during infection. Powdery scab isolates which are free of PMTV will be viruliferous upon attacking PMTV-infected host plants. After penetration the zoospores of Powdery scab forms multinucleate plasmodia that plasmodia forms either secondary zoospores or resting spores (Merz *et al.*, 2005; Kirk, 2008). The spore balls of powdery scab persist in the soil for long period of time. PMTV infection has been obtained from 18 years old spore balls. The plants may also be infected with PMTV through sap inoculation. The isolates lose the vector transmissibility by a deletion in the CP encoding RNA subunits when kept in the laboratory for many generations(Jones and Harrison, 1972; Kirk, 2008).

Few members of the families *Chenopodiaceae* and *Aizoaceae* are found to be infected with PMTV via sap inoculation, but they are not infected with powdery scab transmission, for example common weed plant white goosefoot (*Chenopodium album* L.) (Andersen *et al.*, 2002). PMTV can be transmitted both to zoosporangia and to resting spores. Powdery scab is a vector of PMTV but no correlation is existed between the resistance to powdery scab on tubers and the virus titers in the tubers (Arif *et al.*, 1995).

The incidence and amount of powdery scab DNA are recorded highest on potato tubers grown in moistened soil as compared to soil having been fluctuating by moisture (Van de Graaf *et al.*, 2007). Highest severity of foliar symptoms was recorded on plants grown at 12˚C, less at 16˚C, few at 20˚C and none at 24˚C. The temperature range (12-24 ˚C) had no any profound effect on the transmission of PMTV from infected seed tubers, but the transmission of PMTV by *Sss* was found to be minimum at 24˚C. The infection of tubers by powdery scab was recorded highest at 12 and 16˚C and least at 20 and 24˚C (Carnegie *et al.*, 2010). Most of the root infections at 12 ˚C and all root infections in 9 were found to be symptomless. The amount of DNA detected at these temperatures was very low at 9˚C (Van de Graaf *et al.*, 2007). Tuber infections by PMTV or powdery scab seem to be more severe when the low temperature combined with damp soil. The PMTV infection rate also increases when damp and cool conditions prevail from tuber initiation to harvesting(Cooper and Harrison, 1973; Sandgren *et al.*, 2002).

PMTV infection in the fields usually occurs by its viruliferous vector (Sss), but the poor correlation has been reported between the incidence of PMTV in potato tubers and susceptibility to powdery scab (Sandgren *et al.*, 2002; Tenorio *et al.*, 2006).

Management of PMTV: Potato mop top virus (PMTV) cannot manage easily because no resistant potato cultivars are available, which would be completely immune to S. subterranean (Sss) (Arif *et al.*, 2014). The potatoes once infected by viruses, they will remain infected for the remainder of their lives. Preventive measures are preferable options. This consists of avoidance, breeding for resistant cultivars, vector management and crop sanitation (Beuch *et al.*, 2015). Breeding for resistance could be considered as the best option. Regrettably, new cultivars have been proven largely unsuccessful for PMTV. This is because plants must have immunity in all its parts from its tubers, roots to stolons to become resistant to vector and virus. However, A few breeding lines have been developed which have exhibited minimum incidence of PMTV (Sandgren *et al.*, 2002). Currently the genetic stability of the potato cultivars to PMTV is under study. As PMTV depends on Sss for its transmission, so control of Sss will eventually minimize PMTV infection. Chemical treatments of seeds and soil fumigations are the most commonly used methods to manage Sss. However, chemical treatments are not acceptable because of their high toxicity and unfavorable environmental effect (Montero-Astúa *et al.*, 2008). The vector can also be managed by crop rotations with Brassica and Daturas, rotating with these plants has shown to produce low levels of Sss in the soil. Crop sanitation is also achieved by eliminating infected plants, leftovers and removing diseased plants and breeding of virus free potato genotypes (Beuch *et al.*, 2015).

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