

Diversity and economic importance of viral diseases of pepper (*Capsicum* spp.) in Eastern Africa

B.W. Waweru^{1,2*}, D.C. Kilalo², D.W. Miano², J.W. Kimenju² and P. Rukundo¹

¹Rwanda Agriculture and Animal Resources Development Board, P.O. Box 5016, Kigali, Rwanda. ²Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-0625 Kangemi, Nairobi, Kenya. *E-mail: bancywaweru@gmail.com

Abstract

Pepper (*Capsicum* spp.) is an important vegetable crop in the Eastern Africa region where it is grown mainly by small-scale farmers. However, productivity of the crop is limited by many abiotic and biotic constraints. The abiotic constraints include high cost of seeds and inputs, shortage of improved varieties, drought, low soil fertility and lack of technical knowhow among others, while biotic constraints are dominated by diseases and insect pests. Numerous diseases especially those that are caused by viruses pose serious threats in pepper production. Currently, over 68 viruses are known to affect pepper on a worldwide scale and have serious impact on the quantity and quality of pepper produced. Out of the 68 viruses, 12 belonging to seven genera namely *Potyvirus*, *Cucumovirus*, *Tobamovirus*, *Polerovirus*, *Tospovirus*, *Alfavirus* and *Potexvirus* have been reported in Eastern Africa. *Pepper veinal mottle virus*, *Potato virus Y* and *Cucumber mosaic virus* are the most widespread and damaging viruses in the region. Yield losses ranging from 10 to 100% in pepper production have been reported for various viruses namely; *Pepper veinal mottle virus*, *Potato virus Y*, *Chilli veinal mottle virus*, *Ethiopian pepper mottle virus*, *Cucumber mosaic virus*, *Pepper mild mottle virus*, *Tobacco mosaic virus*, *Pepper vein yellows virus*, *Tomato spotted wilt virus*, *Alfaalfa mosaic virus* and *Potato virus X*. This article provides an overview of the important pepper viruses occurring in Eastern Africa with reference to their geographic distribution, yield-losses, symptoms, transmission, management methods and research gaps that need to be addressed. It can be concluded that viruses are a major constraint to pepper production in the target region.

Key words: *Cucumber mosaic virus*, distribution, pepper viruses, *Pepper veinal mottle virus*, *Potato virus Y*, yield-losses

Introduction

Pepper (*Capsicum* spp.), sweet or pungent, belongs to the *Solanaceae* family and is an important vegetable crop in the world. The worldwide production of green and dry peppers in 2016 was estimated at 38,415,621 tons, out of which Africa supplied 4,349,415 tons (FAOSTAT, 2016). Eastern Africa ranked 3rd after Western and Northern regions of Africa with production of 453,592, 1,703,612 and 2,035,462 tons, respectively. The top six pepper-producing countries in Eastern Africa in 2016 were Ethiopia, Tanzania, South Sudan, Kenya, Malawi and Rwanda as shown in Table 1 (FAOSTAT, 2016). In East Africa, pepper is mainly grown as a cash crop and contributes to the economy in various ways; as a source of income and employment generation especially to the rural population and foreign income earner.

In view of the significance of pepper as a cash crop in Eastern Africa and in the world, the constraints to its production should be regularly reviewed with the ultimate goal of addressing them. Among these constraints include; high cost of seeds, lack of proper and adequate inputs, shortage of improved varieties, drought stress, low soil fertility, lack of storage facilities, fluctuations of prices, non-availability of credit, lack of technical knowhow at the farm level and severe attack by diseases and insect pests (Mohammed *et al.*, 2016; Orobiyi *et al.*, 2013; Tesfaw, 2013). Fungal, bacterial and viral diseases are reported as the most serious threats in pepper production (Dagnoko *et al.*, 2013). Viral

diseases cause significant economic losses by reducing both fruit quality and quantity (Abdalla *et al.*, 1991). This paper reviews the important pepper viruses in Eastern Africa, their distribution, symptoms, management and future research needs.

Table 1. Pepper production in different countries in Eastern Africa

Country	Green pepper production (Tons)	Dry pepper production (Tons)	Total Production (Tons)
Ethiopia	61,794	329,804	391,598
Tanzania	16,470	7,860	24,330
South Sudan	-	8,037	8,037
Kenya	2,840	4,140	6,980
Malawi	-	5,886	5,886
Rwanda	4,460	-	4,460
Uganda	3472	-	3472
Zimbabwe	2186	219	2405
Madagascar	351	2050	2401
Mauritius	1903	-	1903
Reunion	-	878	878
Zambia	-	652	652
Djibouti	11	579	590

Source of data: FAOSTAT, 2016.

Pepper viruses in Eastern Africa: Currently, 68 viruses have been reported to affect pepper in the world (Pernezny *et al.*, 2003).

Table 2a. Characteristics and distribution of viruses reported infecting pepper in Eastern Africa

Genus	Virus name	Common symptoms	Transimission	Genome type	Country reported	Reference
<i>Potyvirus</i>	<i>Potato virus Y</i> (PVY)	Leaf mosaic or mottling, vein-clearing, dark green vein-banding, small and deformed fruit	Aphids, Mechanical	ssRNA	Ethiopia, Uganda, Tanzania, Kenya, Zambia, Zimbabwe, Malawi, Madagascar	Dafalla, 2001; Haskias <i>et al.</i> , 1999; Karavina <i>et al.</i> , 2016 ; Ndunguru and Kapooria, 1999;
<i>Potyvirus</i>	<i>Pepper veinall mottle virus</i> (PVMV)	Leaf mosaic or mottling, vein banding, leaf yellowing, leaf deformation	Aphids, Mechanical	ssRNA	Ethiopia, Uganda, Tanzania, Kenya, Rwanda	Agranovsky, 1993; Dafalla, 2001; IPM CRSP, 2008; Skelton <i>et al.</i> , 2018
<i>Potyvirus</i>	<i>Chilli veinall mottle virus</i> (ChiVMV)	Mottling and dark green vein-banding	Aphids, Mechanical	ssRNA	Tanzania, Uganda, Ethiopia	Dafalla, 2001; IPM CRSP, 2008
<i>Potyvirus</i>	<i>Ethiopian pepper mottle virus</i> (EPMV)	Veinal chlorosis, leaf deformation and leaf crinkling	Aphids, Mechanical	ssRNA	Ethiopia	Agranovsky, 1993; Haskias <i>et al.</i> , 1999
<i>Tobamovirus</i>	<i>Pepper mild mottle virus</i> (PMMoV)	Mottling, puckering, malformed leaves, small and deformed fruit marked by off-coloured sunken areas, stunted growth	Seed, Mechanical	ssRNA	Zambia, Tanzania, Uganda	Dafalla, 2001; Ndunguru and Kapooria, 1999; IPM CRSP, 2008
<i>Tobamovirus</i>	<i>Tobacco mosaic virus</i> (TMV)	Leaf mosaic, leaf curling and stunted growth	Seed, Mechanical	ssRNA	Zambia, Tanzania, Sudan	Dafalla, 2001; Ndunguru and Kapooria, 1999; IPM CRSP, 2008
<i>Tobamovirus</i>	<i>Tomato mosaic virus</i> (ToMV)	Leaf mosaic, leaf curling and stunted growth	Seed, Mechanical	ssRNA	Ethiopia, Zambia	Dafalla, 2001; Haskias <i>et al.</i> , 1999; IPM CRSP, 2008

ssRNA - single stranded ribonucleic acid

Table 2b. Characteristics and distribution of viruses reported infecting pepper in Eastern Africa

Genus	Virus name	Common symptoms	Transimission	Genome type	Country reported	Reference
<i>Cucumovirus</i>	<i>Cucumber mosaic virus</i> (CMV)	Mild mosaic , dull-coloured leaves, mottling, shoe string and fern leaf, vein banding, vein clearing, leaf deformation, stunted growth	Aphids, Seed, Mechanical	ssRNA	Ethiopia, Zambia, Zimbabwe, Kenya, Tanzania, Sudan, Malawi, Uganda, Madagascar, Rwanda	Agranovsky, 1993; Dafalla, 2001; Ndunguru and Kapooria, 1999; IPM CRSP, 2008; Skelton <i>et al.</i> , 2018
<i>Polerovirus</i>	<i>Pepper vein yellows virus</i> (PeVYV)	Leaf curling, deformation, reduced leaf size, puckering, interveinal yellowing, vein clearing, or yellow patches on leaves	Aphids	ssRNA	Rwanda, Sudan	Alfaro-Fernández <i>et al.</i> , 2014; Skelton <i>et al.</i> , 2018
<i>Tospovirus</i>	<i>Tomato spotted wilt virus</i> (TSWV)	Yellowing/browning of leaves, chlorotic or necrotic ringspots on leaves and fruits, necrotic streaks on stems/terminal shoots/fruits	Thrips	ssRNA	Zimbabwe	Nyamupingidza and Machakaire, 2001
<i>Alfavirus</i>	<i>Alfaalfa mosaic virus</i> (AMV)	Bright yellow or blotchy white mosaic on pepper leaves	Aphids, Seed, Mechanical	ssRNA	Zambia	Kaitisha, 2001
<i>Potexvirus</i>	<i>Potato virus X</i> (PVX)	Mottling, severe necrosis of leaves and stems	Mechanical	ssRNA	Ethiopia, Zimbabwe, Zambia	Kaitisha, 2001; Nyamupingidza and Machakaire, 2001

ssRNA - single stranded ribonucleic acid

Among these viruses, 19 of them are found in Africa (Aliyu, 2014; Njukeng *et al.*, 2013) out of which 12 belonging to seven genera of *Potyvirus*, *Cucumovirus*, *Tobamovirus*, *Polerovirus*, *Tospovirus*, *Alfavirus* and *Potexvirus* are documented in Eastern Africa (Table 2a, b).

Potato virus Y (PVY) is a single-stranded RNA virus belonging to the genus *Potyvirus* and family *Potyviridae*. The virus is known to occur on pepper in Zimbabwe, Zambia, Kenya, Tanzania, Malawi, Madagascar and Ethiopia, East Africa (Dafalla, 2001; Haskias *et al.*, 1999; Karavina *et al.*, 2016; Ndunguru and Kapooria, 1999). It is among the most widespread viruses in the region. In spite of this, PVY as a virus infecting pepper has not

received much attention in region and other parts of Africa and much of the research done has focused on PVY strains infecting potato. Therefore, more work is needed on strains of the virus that attack pepper. According to Singh *et al.* (2008), isolates of PVY from pepper do not infect potato and vice versa. Since the virus is causing substantial losses on pepper, in the Eastern Africa region (Dafalla, 2001), in-depth studies to identify the pathotypes present, incidence, losses associated with PVY and management within pepper fields are absolute necessity.

According to Avilla *et al.* (1997), PVY caused yield reductions of 20 to 70% in pepper production. Plant stunting, systemic vein-clearing, leaf mosaic or mottling, dark green vein-banding of the leaves and smaller deformed fruit with a mosaic pattern are

some of the symptoms associated with PVY infection on pepper (AVRDC, 2004). The virus is spread non-persistently by several species of aphids and also by mechanical means as demonstrated by Schramm *et al.* (2011). *Potato virus Y* has a wide host range and some of the hosts include potato (*Solanum tuberosum* L.), tobacco (*Nicotiana* spp.), pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* Mill.) and several species of weeds. Intercropping of maize with pepper was found to be effective in management of potyviruses in pepper fields according to Mitiku *et al.* (2013), and hence the approach was recommended.

Pepper veinal mottle virus (PVMV) (genus *Potyvirus* and family *Potyviridae*) is the most widespread and damaging disease affecting pepper in Africa (Dafalla, 2001). This virus was first reported in Ghana in 1971 from *C. annuum* and *C. frutescens* (Brunt and Kenten, 1971) and since then, the virus has increasingly spread to other regions in Africa. In East Africa, PVMV has been reported in Ethiopia, Kenya, Tanzania, Uganda and Rwanda (Agranovsky, 1993; Dafalla, 2001; IPM CRSP, 2008; Skelton *et al.*, 2018). Information on incidence, symptoms, yield losses and management of PVMV disease in this region is scanty.

Unlike in the Eastern Africa region, extensive research work on this virus has been done in West Africa especially in Nigeria and Ghana on strain characterization, incidence, yield losses, vectors, host range and management techniques. For instance, yield losses of 54.5–64.3% and disease incidence as high as 100% was observed in hot pepper fields in Nigeria (Alegbejo and Abo, 2002; Fajinmi *et al.*, 2012). Several symptoms are associated with PVMV on infected pepper plants; mottle, mosaic, curling, vein banding, ringspots, various types of necrosis, deformation, leaf yellowing, blistering and severe stunting of the whole plant (Fajinmi *et al.*, 1998; Tsai *et al.*, 2010). Eight species of aphids have been shown to spread PVMV in a non-persistent way, of which *Myzus persicae*, *Aphis craccivora*, *A. gossypii* and *A. spiraecola* are rated as efficient vectors in nature (Fajinmi *et al.*, 2011; Pernezny *et al.*, 2003). Mechanical transmission has also been demonstrated by Moury *et al.* (2004) but the virus is not known to be transmitted through seed. Intercropping pepper with tall companion crops revealed a reduced PVMV disease incidence (<17%) and severity (15%) compared with the sole pepper cropping that recorded a disease incidence and severity as high as 75% and 72%, respectively (Fajinmi and Odebode, 2010). Intercropping can therefore be recommended as a component of integrated strategies of managing *Pepper veinal mottle virus*.

Cucumber mosaic virus (CMV) (genus *Cucumovirus* and family *Bromoviridae*) occurs globally mainly in temperate, tropic and sub-tropic regions of the world (Arogundade *et al.*, 2012). It is among the most widespread viruses in the region and was identified in Uganda, Zambia, Ethiopia, Zimbabwe, Kenya, Tanzania, Malawi, Madagascar, Sudan and Rwanda (Agranovsky, 1993; Dafalla, 2001; Ndunguru and Kapooria, 1999; IPM CRSP, 2008; Skelton *et al.*, 2018). The virus has also been reported in other parts of Africa (Afouda, *et al.*, 2013; Appiah *et al.*, 2014). Rahman *et al.* (2016a) observed 10.56 to 36.96% reduction on yield as a result of CMV infections on pepper plants. Symptoms of naturally affected pepper plants vary widely and most prominent ones are mild mosaic and dull-coloured leaves, mottling, shoe string, fern leaf, vein banding, vein clearing, leaf deformation, stunted growth and reduced fruit size (Kapoor *et al.*, 2018; Zitikaite and Samuitien, 2009).

More than 80 species of aphids transmit CMV in a non-persistent way; *Aphis. gossypii*, and *M. persicae* are the most efficient in transmitting CMV (Palukaitis, *et al.*, 1992). According to Ali and Kobayashi (2010), CMV is also seed-transmitted in pepper. The virus infects over 1200 plant species from both monocotyledons and dicotyledons (Zitter and Murphy, 2009). Resistant pepper genotypes to CMV have been identified. For example, Rahman *et al.* (2016b) observed genotype CA23 (Noakhali) as resistant, while CA12 (Comilla-2) as moderately resistant to CMV both in natural and inoculated conditions.

Pepper mild mottle virus (PMMoV) (genus *Tobamovirus* and family *Virgaviridae*) was first described in USA in 1952 (McKinney, 1952) and since then it has spread worldwide. PMMoV was reported in East Africa countries such as Zambia, Uganda and Tanzania (Dafalla, 2001; IPM CRSP, 2008; Ndunguru and Kapooria, 1999). PMMoV is also present in West Africa (Appiah *et al.*, 2014; Olawale *et al.*, 2015). This viral disease causes considerable yield losses and significant damage on quality of fruits. For instance, Martínez-Ochoa (2003) observed that disease incidence of 20 to 80% on pepper plants, resulted in 50 to 100% yield loss. Similar studies by Guldur and Caglar (2006) reported disease incidence of 60 to 95% resulted in 75 to 95% yield loss. Details of symptoms associated with this disease, yield losses and its management approaches are scanty in East Africa.

Various symptoms have been associated with PMMoV disease elsewhere and includes; stunted growth, mottling, puckering, malformed leaves, small and deformed fruits, marked by off-coloured sunken areas (Guldur and Caglar, 2006; Nikolay, 2014). The symptoms are far more pronounced in younger infected plants compared with old infected plants (Sevik, 2011). The spread is through seed and soil in the fields, and not transmitted by insects (Genda *et al.*, 2005). PMMoV persists in soil, on infected debris which serve as a primary source of inoculum for subsequent crops (Ikegashira *et al.*, 2004; Lamb *et al.*, 2001). Major host of this virus is *Capsicum* spp., however, it has been shown to infect up-to 24 species belonging to Solanaceae family and other species in Chenopodiaceae, Cucurbitaceae, Labiatae and Plantaginaceae through experiments (Wetter, 1984). Treatment of PMMoV infected *Capsicum* seeds with 10% trisodium phosphate for 2.5 hours significantly reduced the incidence of the virus. However, this approach was not able to completely eliminate the virus from the seeds (Jarret *et al.*, 2008).

Tobacco mosaic virus (TMV) (genus *Tobamovirus* and family *Virgaviridae*) is the first ever virus to be identified (Scholthof, 2008). The virus was reported to infect pepper in Uganda, Tanzania, Zimbabwe, Sudan and Zambia (Dafalla, 2001; IPM CRSP, 2008; Ndunguru and Kapooria, 1999) in East Africa. It is also reported in other parts of Africa (Appiah *et al.*, 2014; Olawale *et al.*, 2015). Heavy yield losses due to this virus have been worldwide reported in tobacco, tomato and pepper. According to Chitra *et al.* (2002) the yield losses of up-to 90% have been recorded in bell pepper as a result of TMV infection. Generally, infected pepper plants are stunted, deformed and show chlorotic areas in the leaves (Pazarlar *et al.*, 2013). Leaf mosaic, leaf curling and stunted growth are other symptoms observed by Kumar *et al.* (2011).

Like other tobamoviruses, TMV survives on infected plant

materials for months or years (Moury and Verdin, 2012). It is spread mainly through contact between plants and seed, mechanical means, but not by insect-vectors. TMV infects at least 125 crop species which include tobacco, tomato, pepper, cucumber among others (Kumar *et al.*, 2011). Use of resistant cultivars to TMV infection has been demonstrated in Nigeria by Igwegbe and Ogungbade (1985).

Tomato mosaic virus (ToMV) (genus *Tobamovirus* and family *Virgaviridae*) is a single-stranded RNA virus present globally and was reported in Uganda, Zambia and Ethiopia (Dafalla, 2001; Hiskias *et al.*, 1999; IPM CRSP, 2008). Symptoms of ToMV in most cases resemble those of TMV. Kumar *et al.* (2011) observed leaf mosaic, leaf curling and stunted growth on pepper plants infected with ToMV. It is known to infect more than 150 economically important crop species, including vegetables and ornamental flowers. It occurs more frequently on tomato and pepper than TMV. The mode of spread is by contact, though it is also transmitted mechanically (Kenyon *et al.*, 2014).

Pepper vein yellows virus (PeVYV) (genus *Polerovirus* and family *Luteoviridae*) was first isolated in Israel by Dombrovsky *et al.* (2010). In East Africa, it was first identified in Sudan (Alfaro-Fernández *et al.*, 2014) and more recently in Rwanda (Skelton *et al.*, 2018). PeVYV was also reported in Benin (Afouda *et al.*, 2013), Tunisia (Buzkan *et al.*, 2013) and Mali (Knierim *et al.*, 2013). Infection rates of up-to 100% have been reported (Tomassoli *et al.*, 2016). However, little has been done to determine the diversity, management and current levels of damage caused by the disease in the recent years in East Africa region. Leaf curling, deformation, reduced leaf size, puckering, interveinal yellowing, vein clearing, or yellow patches on leaves are among the commonly observed symptoms on cultivated pepper plants (Alfaro-Fernández *et al.*, 2014; Murakami and Kawano, 2017). This virus is spread in circulative and non-propagative manner by *A. gossypii* and *M. persicae* (Dombrovsky *et al.*, 2010; Murakami and Kawano, 2017). Host plants include *Capsicum* spp. (Alabi *et al.*, 2015) and *Solanum nigrum* (Knierim *et al.*, 2013).

Chilli veinal mottle virus (ChiVMV) (genus *Potyvirus* and family *Potyviridae*), is reported to affect pepper in Ethiopia, Uganda, Tanzania (Dafalla, 2001; IPM CRSP, 2008). Disease incidence range of 50 % that reduce yield by 50 % worldwide has been documented (Shah *et al.*, 2008). Typical symptoms caused by this virus includes leaf mottle and dark green vein-banding. ChiVMV is transmitted by several species of aphids and also by mechanically, but not through seed (Shah *et al.*, 2008). Information on symptoms associated with this disease, yield losses and its management approaches are scanty in East Africa.

Alfalfa mosaic virus (AMV) belongs to the genus *Alfamovirus* and family *Bromoviridae*. AMV is distributed worldwide and in East Africa, it is most prevalent and widespread virus in Zambia (Kaitisha, 2001). Disease incidence of 80-100% was observed in pepper fields by Ndunguru and Kapooria (1999). Common symptoms associated with this virus on pepper is bright yellow or blotchy white mosaic on pepper leaves (Kenyon *et al.*, 2014). Stunted growth with misshapen and blotchy fruits are also observed especially if plants are infected with the virus at young stage. AMV has wide host range and is transmitted through

mechanical and in a non-persistent manner by numerous aphid species. It can also be transmitted through pepper seed (AVRDC, 2004).

Ethiopian pepper mottle virus (EPMV) (genus *Potyvirus* and family *Potyviridae*), is endemic and important diseases of pepper in Ethiopia (Agranovsky, 1993). Common symptoms associated with EPMV infection include; veinal chlorosis, leaf deformation and leaf crinkling (Alemu, 2004). This virus is transmitted in a non-persistent manner by several species of aphids of which *Aphis gossypii*, *Myzus persicae*, *Lipaphis erysimi*, *Macrosiphum euphorbiae*, *Huperomyzus lactucae* and *Uroleucon compositae* have been shown to successfully transmit this virus (Atsebeha *et al.*, 2009). EPMV is also mechanically-transmitted but not spread through seeds (Alemu, 2004). According to Mitiku *et al.* (2013) intercropping of maize with pepper lead to lower incidence of potyviruses and unmarketable yields; and higher total and marketable yields in pepper fields compared to mono-cropping. Resistant genotypes to EPMV have been identified in Ethiopia by (Alemu, 2004).

Tomato spotted wilt virus (TSWV) (genus *Tospovirus* and family *Bunyaviridae*), is the most widespread of the tospoviruses. This virus was reported to affect pepper in Zimbabwe (Nyamupingidza and Machakaire, 2001). Typical symptoms associated with TSWV in pepper are yellowing/browning of leaves, chlorotic or necrotic ringspots on leaves and fruits and, necrotic streaks on stems, terminal shoots and fruits (Kenyon *et al.*, 2014). The virus is transmitted in a persistent and propagative manner by several species of thrips, among which Western flower thrips, *Frankliniella occidentalis* is the most efficient (Gallitelli *et al.*, 2012). *Tomato spotted wilt virus* infects more than 1000 different plant species from more than 80 botanical families. Some of the main hosts of TSWV are pepper, lettuce, tobacco, tomato, and various ornamental crops. Information on incidence, yield losses and management of this virus in pepper is scanty.

Potato virus X (PVX) (genus *Potexvirus* and family *Alphaflexiviridae*) is reported in Ethiopia, Zambia, Zimbabwe (Alemu, 2004; Kaitisha, 2001; Nyamupingidza and Machakaire, 2001). The virus causes mottling, severe necrosis of leaves and stems and, sometime defoliation of some cultivars. It is transmitted mechanically but not by seed (Alemu *et al.*, 2002). *Potato virus X* is of minor importance in pepper production as reported by Alemu (2004) and much of the work done is only on its detection on pepper.

Other pepper viruses reported in Africa include: *Pepper mottle virus* (PepMoV) reported in Central Africa (Njukeng *et al.*, 2013); *Tobacco etch virus* (TEV) in West Africa (Olawale *et al.*, 2015); *Cowpea aphid borne mosaic virus* (CABMV) and *Blackeye cowpea mosaic virus* (BICMV) in West Africa (Aliyu, 2014). All these viruses belong to the genus *potyvirus*, family *Potyviridae*. *Tomato yellow leaf curl virus* (TYLCV) has been reported in West and Central regions (Leke *et al.*, 2015) while, *Pepper yellow vein Mali virus* (PepYVMLV) has been reported in West Africa (Séka *et al.*, 2017; Tiendrébéogo *et al.*, 2008). Belonging to the genus *begomovirus*, family *geminiviridae*. *Tobacco mild green mosaic virus* (TMGMV) belong to the genus *tobamovirus* and family *virgaviridae*, was reported in North Africa (Cordoba *et al.*, 2009).

Viruses infecting pepper are diverse, new species and strains

continue to be identified, posing a threat to resistance that may have been developed in cultivars against particular viral diseases. In the Eastern Africa region, 12 viruses are reported to infect pepper of which the *Pepper vein mottle virus* (PVMV), *Potato virus Y* (PVY) and *Cucumber mosaic virus* (CMV) are the most damaging and widespread. This review, has revealed that there is scanty information concerning viral diseases of pepper in the target region. This may be due to poor documentation which makes it difficult to capture all information on what has been done or lack of funds leading to little or no research conducted. Thus, there is need for more investigations to generate valuable information on various aspects related to these viral diseases in pepper. The research may include: characterization of the isolates from the East Africa region and comparing their relationships with isolates from other parts of the world, yield-loss assessment, finding new sources of resistance or tolerance among germplasm collections, studies on transmission and host range, interactions of vector-transmitted viruses with their vectors, effects of these viruses on different phenological stages of pepper varieties and development of more effective control strategies. This important information will be valuable in the formulation of strategies of reducing the huge losses incurred in pepper production due to plant virus' infections in Eastern Africa region.

Acknowledgements

This review forms part of the first author's PhD studies and is funded by the United States Agency for International Development, as part of the Feed the Future initiative, under the CGIAR Fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013; with additional support from Rwanda Agriculture and Animal Resources Development Board (RAB).

Statement of Competing Interests: The authors have no competing interests.

References

- Abdalla, O.A., P.R. Desjardins and J.A. Dodds, 1991. Identification, disease incidence, and distribution of viruses infecting peppers in California. *Plant Disease*, 75: 1019-1023.
- Afouda, L.A.C., R. Kotchofa, R. Sare, V. Zinsou and S. Winter, 2013. Occurrence and distribution of viruses infecting tomato and pepper in Ahbori in Northern Benin. *Phytoparasitica*, 41: 271-276.
- Agranovsky, A.A. 1993. Virus diseases of pepper (*Capsicum annuum* L.) in Ethiopia. *Journal of phytopathology*, 138(2): 89-97.
- Alabi, O.J., M. Al Rwahnin, J.L. Jifon, L. Gregg, K.M. Crosby and T. Mirkov, 2015. First report of *Pepper vein yellows virus* infecting pepper (*Capsicum* spp.) in the United States. *Plant Disease*, 99(11): 1656.
- Alegbejo, M.D. and M.E. Abo, 2002. Ecology, epidemiology and control of *Pepper vein mottle virus* (PVMV) genus *Potyvirus*, in West Africa. *Journal Sustainable Agriculture*, 20(2): 5-16.
- Alemu, T., J. Hamacher and H.W. Dehne, 2002. The role of some weeds as hosts of *Capsicum* viruses in the rift valley parts of Ethiopia. 54th International Symposium on Crop Protection, Part I. 7 May, 2002, Gent, Belgium, 67(2): 283-289.
- Alemu, T. 2004. Characterisation of viruses of pepper (*Capsicum* spp.) and sweet potato (*Ipomoea batatas*) from Ethiopia. ISBN 3865370489, 9783865370488, Cuvillier Verlag, pp 126.
- Alfaro-Fernández, A., E.E. ElShafie, M.A. Ali, O.O.A. El Bashir, M.C. Córdoba-Sellés and M.I. Font San Ambrosio, 2014. First report of *pepper vein yellows virus* infecting hot pepper in Sudan. *Plant Disease*, 98(10): 1446.
- Ali, A. and M. Kobayashi, 2010. Seed transmission of *Cucumber mosaic virus* in pepper. *Journal of Virological Methods*, 163(2): 234-237.
- Aliyu, T.H. 2014. The incidence, severity and occurrence of four viruses infecting pepper (*Capsicum* spp.) in the Southern Guinea Savannah Agro-ecological Zone of Nigeria. *Agriculturae Conspectus Scientificus*, 79: 233-237.
- Appiah, A.S., E.K. Quartey, H.M. Amoatey, W. Nunekpeku, M. Owusu-Ansah and S. Ofori, 2014. Response of nine cultivars of pepper (*Capsicum* spp.) to infection by four viruses under natural field conditions in the coastal savanna zone of Ghana. *Research Journal of Applied Sciences, Engineering and Technology*, 7(5): 903-907.
- Arogundade, O., O.S. Balogun and K.T. Kareem, 2012. Occurrence and distribution of *pepper vein mottle virus* and *cucumber mosaic virus* in pepper in Ibadan, Nigeria. *Virology Journal*, 9: 79.
- Atsebeha, S., T. Alemu and F. Azerefgne, 2009. Diversity of aphids in the central rift valley of Ethiopia and their potential as vectors for *Ethiopian Pepper Mottle Virus* (EPMV). *Journal of Entomology and Nematology*, 1(1): 001-006.
- Avilla, C., J.L. Collar, M. Duque and A. Fereres, 1997. Yield of bell pepper (*Capsicum annuum*) inoculated with CMV and/or PVY at different time intervals. *Journal of Plant Diseases and Protection*, 104(1): 1-8.
- AVRDC. 2004. *Alfalfa mosaic virus*. Fact Sheet. AVRDC Publication 04-590. http://203.64.245.61/web_crops/pepper/AMV.pdf. Accessed 2nd May 2018.
- AVRDC. 2004. *Potato virus Y*. Fact Sheet. AVRDC Publication 04-587. http://203.64.245.61/web_crops/pepper/PVY.pdf. Accessed 2nd May 2018.
- Brunt, A.A. and R.H. Kenten, 1971. *Pepper vein mottle virus* a new member of the potato virus Y group from peppers (*Capsicum annuum* L. and *C. frutescens* L.) in Ghana. *Annals of Applied Biology*, 69: 235-243.
- Buzkan, N., B.B. Arpacı, V. Simon, H. Fakhfakh and B. Moury, 2013. High prevalence of poleroviruses in field-grown pepper in Turkey and Tunisia. *Archives Virology*, 158(4): 881-885.
- Chitra, T.R., H.S. Prakash, S.E. Albrechtsen, H.S. Shetty and S.B. Mathur, 2002. Indexing of leaf and seed samples of tomato and bell pepper for tobamoviruses. *Indian Phytopathology*, 55: 84-86.
- Cordoba, M.C., M.C. Cebrián, J. Herrera Vasquez, A. Alfaro-Fernández, A. Boubaker, I. Soltani and C. Jordá, 2009. First Report of *Tobacco mild green mosaic virus* infecting *Capsicum annuum* in Tunisia. *Plant Disease*, 93: 761-761.
- Dafalla, G.A. 2001. Situation of tomato and pepper viruses in Africa. *Proceedings of International Institute of Tropical Agriculture Conference on Plant Virology in Sub Saharan Africa* (J. d'A Hughes, and B.O. Odu, eds.). 4-8 June 2001, Ibadan, Nigeria, pp. 18-24.
- Dagnoko, S., N. Yaro-Diarisso, P.N. Sanogo, O. Adetula, A. Dolo-Nantoumé, K. Gamby-Touré, A. Traoré-Théra, S. Katilé and D. Diallo-Ba, 2013. Overview of pepper (*Capsicum* spp.) breeding in West Africa. *African Journal of Agricultural Research*, 8: 1108-1114.
- Dombrovsky, A., E. Glanz, M. Pearlsman, O. Lachman and Y. Antignus, 2010. Characterization of *Pepper yellow leaf curl virus*, a tentative new Polerovirus species causing a yellowing disease of pepper. *Phytoparasitica*, 38: 477-486.
- Fajinmi, A.A. and C.A. Odebo, 2010. Evaluation of maize/pepper intercropping model in the management of *Pepper vein mottle virus*, genus *Potyvirus*, family *Potyviridae* on cultivated pepper (*Capsicum annuum* L.) in Nigeria. *Archives of Phytopathology and Plant Protection*, 43(15): 1524-1533.
- Fajinmi, A.A., A.O. Oladiran and S.A. Shoyinka, 1998. Relative susceptibility of pepper varieties to *Pepper vein mottle virus*. *International Journal of Tropical Plant Diseases*, 16: 41-48.

- Fajinmi, A.A., C.A. Odebode and O.B. Fajinmi, 2011. Incidence and distribution of aphid vectors of *Pepper vein mottle virus* on bell pepper. *International Journal of Entomology*, 1 (1): 1-12.
- Fajinmi, A.A., A.R. Popoola and O.B. Fajinmi, 2012. Incidence and epidemiology of *Pepper vein mottle virus* (PVMV), a Potyvirus disease of pepper. *Archives of Phytopathology and Plant Protection*, <http://dx.doi.org/10.1080/03235408.2012.694250>
- FAOSTAT, 2016. FAO Statistics Division, <http://www.fao.org/faostat/en/#data/QC> 13 June 2018.
- Font, M.I., M.C. Córdoba-Sellés, M.C. Cebrián, J.A. Herrera-Vásquez, A. Alfaro-Fernández, A. Boubaker, I. Soltani and C. Jordá, 2009. First Report of *Tobacco mild green mosaic virus* infecting *Capsicum annuum* in Tunisia. *Plant disease*, 93(7): 761.
- Gallitelli, D., T. Mascia and G.P. Martelli, 2012. Viruses in Artichoke. *Advances in Virus Research*, 84: 289-324.
- Genda, Y., K. Sato, O. Nunomura, T. Hirabayashi, J. Ohnishi and S. Tsuda, 2005. Immunolocalization of *Pepper mild mottle virus* in *Capsicum annuum* seeds. *Journal of General Plant Pathology*, 71: 238-242.
- Guldur, M.E. and B.K. Caglar, 2006. Outbreaks of *Pepper mild mottle virus* in greenhouses in Sanliurfa, Turkey. *Journal of Plant Pathology*, 88(3): 339-342.
- Hiskias, Y., D.E. Lesemann and H.J. Vetten, 1999. Occurrence, distribution and relative importance of viruses infecting hot pepper and tomato in the major growing areas of Ethiopia. *Journal of Phytopathology*, 147(1): 5-11.
- Igwegbe, E.C.K. and K. Ogungbade, 1985. Evaluation of pepper cultivars under greenhouse conditions for resistance to a defoliation strain of *Tobacco mosaic virus*. *Plant Disease*, 69: 899-900.
- Ikegashira, Y., T. Ohki, U. Ichiki, T. Higashi, K. Hagiwara, T. Omura, Y. Honda and S. Tsuda, 2004. An immunological system for the detection of *Pepper mild mottle virus* in soil from green pepper fields. *Plant Disease*, 88: 650-656.
- IPM CRSP, 2008. Annual report, Integrated Pest Management Collaborative Research Support Program. USAID, Virginia Tech, pp 190.
- Jarret, R.L., A.G. Gillaspie, N.A. Barkley and D.L. Pinnow, 2008. The Occurrence and Control of *Pepper mild mottle virus* (PMMoV) in the USDA/ARS *Capsicum* Germplasm Collection. *Seed Technology*, 30(1): 26-36.
- Kaitisha, G.C. 2001. Some virus diseases of crop plants in Zambia. *Proceedings of International Institute of Tropical Agriculture Conference on Plant Virology in Sub Saharan Africa* (J. d'A Hughes, and B.O. Odu, eds.). 4-8 June 2001, Ibadan, Nigeria, pp. 317-333.
- Kapoor, S., A. Sharma and A. Handa, 2018. Correlation between symptoms and ELISA for the detection of *Cucumber Mosaic Virus* in bell Pepper. *International Journal of Current Microbiology and Applied Sciences*, 7(6): 400-406.
- Karavina, C., S. Ximba, J.D. Ibaba and A. Gubba, 2016. First Report of a Mixed Infection of *Potato virus Y* and *Tomato spotted wilt virus* on Pepper (*Capsicum annuum*) in Zimbabwe. *Plant disease*, 100 (7): 1513.
- Kenyon, L., S. Kumar, H. Wen-ShiTsai Jacqueline d'A, 2014. Virus diseases of peppers (*Capsicum* spp.) and their control. *Advances in Virus Research*, 90: 297-354.
- Knierim, D., W. Tsai and L. Kenyon, 2013. Analysis of sequences from field samples reveals the presence of the recently described *Pepper vein yellows virus* (genus *Polerovirus*) in six additional countries. *Archives of Virology*, 158(6): 1337-1341.
- Kumar, S., A.C. Udaya Shankar, S.C. Nayaka, O.S. Lund and H.S. Prakash, 2011. Detection of *Tobacco mosaic virus* and *Tomato mosaic virus* in pepper and tomato by multiplex RT-PCR. *Letters in Applied Microbiology*, 53: 359-363.
- Lamb, E.M., S. Atkins, K.D. Schuler and P.D. Roberts, 2001. *Pepper Mild Mottle Virus*. University of Florida Extension Bulletin.
- Leke, W.N., D.B. Mignouna, J.K. Brown and A. Kvarnheden, 2015. *Begomovirus* disease complex: emerging threat to vegetable production systems of West and Central Africa. *Agriculture and Food Security*, 4:1. <https://doi.org/10.1186/s40066-014-0020-2>. Accessed on 14/11/2017.
- Martínez-Ochoa, N., D.B. Langston, S.W. Mullis and J.T. Flanders, 2003. First Report of *Pepper mild mottle virus* in jalapeno pepper in Georgia. Online. Plant Health Progress doi:10.1094/PHP-2003-1223-01-HN. <https://www.plantmanagementnetwork.org/pub/php/brief/2003/pepper/>
- McKinney, H.H. 1952. Two strains of *tobacco mosaic virus*, one of which is seed-borne in an etch-immune pungent pepper. *Plant Disease*, 36: 184-187.
- Mitiku, A., A. Chala and Y. Beyene, 2013. The effect of intercropping pepper with maize and sweet potato on infection of pepper (*Capsicum Annuum* L.) by potyviruses and yield of pepper in, Southern Ethiopia. *International Journal of technology Enhancements and Emerging Engineering Research*, 1(4): 68-73.
- Mohammed, B. 2016. Analysis of Income and Constraints to chilli pepper production in Kaduna State, Nigeria. *Journal of Scientific Research and Reports*, 9(3): 1-7.
- Moury, B. and E. Verdin, 2012. Viruses of Pepper Crops in the Mediterranean Basin: A Remarkable Stasis. *Advances in Virus Research*, 84: 127-162.
- Moury, B., C. Morel, E. Johansen, L. Guilbaud, S. Souche, V. Ayme, C. Caranta, A. Palloix and M. Jacquemond, 2004. Mutations in *Potato virus Y* genome-linked protein determine virulence towards recessive resistances in *Capsicum annuum* and *Lycopersicon hirsutum*. *Molecular Plant Microbe Interact*, 17: 322-329.
- Murakami, R. and S. Kawano, 2017. A natural host and diversity of *Pepper vein yellows virus* in Japan. *JARQ*, 51(1): 59-68.
- Ndunguru, J. and R.G. Kapooria, 1999. Identification and incidence of virus diseases of *Capsicum annuum* in the Lusaka Province of Zambia. *EPPA Bulletin*, 29, 2: 183-189.
- Nikolay, P. 2014. Effect of *Pepper mild mottle virus* infection on pepper and tomato plants. *Science and Technologies*, 5: 61-64.
- Njukeng, P.A., W.N. Ngwakum and G.A. Mbong, 2013. Relative prevalence, incidence and severity of two viruses infecting cultivated pepper in the Western Highlands of Cameroon. *Agricultural Science Research Journals*, 3(8): 261-266.
- Nyamupingidza, T.N. and V. Machakaire, 2001. Virus diseases of important vegetables in Zimbabwe. *Proceedings of International Institute of Tropical Agriculture Conference on Plant Virology in Sub Saharan Africa* (J. d'A Hughes, and B.O. Odu, eds.). 4-8 June 2001, Ibadan, Nigeria, pp. 397-405.
- Olawale, A., B.O. Balogun Olusegun Samuel, A.S.O. Solomon and P.L. Kumar, 2015. Surveys of virus diseases on pepper (*Capsicum* spp.) in South-west Nigeria. *African Journal of Biotechnology*, 14(48): 3198-3205.
- Orobiyi, A., A. Dansi, P. Assogba, L.Y. Loko, M. Dansi, R. Vodouhè, A. Akouègninou and A. Sanni, 2013. Chili (*Capsicum annuum* L.) in southern Benin: production constraints, varietal diversity, preference criteria and participatory evaluation. *International Research Journal of Agricultural Science and Soil Science*, 3(4): 107-120.
- Palukaitis, P., M.J. Roossinck, R.G. Dietzgen and R.I.B. Francki, 1992. *Cucumber mosaic virus*. *Advances in Virus Research*, 41: 281-349.
- Pazarlar, S., M. Gumus and G.B. Oztekin, 2013. The effects of *Tobacco mosaic virus* infection on growth and physiological parameters in some pepper varieties (*Capsicum annuum* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 41(2): 427-433.
- Pernezny, K., P.D. Robert, J.F. Murphy and N.P. Goldberg, 2003. Compendium of pepper diseases. The American Phytopathological society 1: 24-25. *Plant disease*, 68: 597-599.
- Rahman, M.S., M.S. Akhter, M.M. Alam, N. Pervin and A.M. Akanda, 2016a. Prevalence of *Cucumber Mosaic Virus* and its impact on growth and yield of different chili cultivar. *Bulletin of the Institute of Tropical Agriculture, Kyushu University*, 39: 65-74.

- Rahman, S., A.M. Akanda, I.H. Mian, K.A. Bhuiyan and M. Hossain, 2016b. New sources of resistance to *Cucumber mosaic virus* in *Capsicum annuum*. *Journal of Crop Science and Biotechnology*, 19(3): 249-258.
- Scholthof, K-B.G. 2008. *Tobacco Mosaic Virus*: The Beginning of Plant Pathology. Online. APSnet Features. doi: 10.1094/APSnetFeatures-2008-0408
- Schramm, S., K. Frost, A. Charkowski, S. Gray, A. Crochford and R.L. Groves, 2011. Management of *Potato Virus Y* (PVY) in Wisconsin Seed Potato Production. A3951, 1-06-11.
- Séka, K., A. Ouattara, K.P. Assiri, K.D. Kra, M. Hoareau, P. Lefevre, H. Atta Diallo and J.M. Lett, 2017. First report of *Pepper yellow vein Mali virus* associated with pepper yellow vein disease in Cote d'Ivoire. *New Disease Reports*, 35: 11.
- Sevik, M.A. 2011. Occurrence of pepper mild mottle virus in greenhouse grown pepper (*Capsicum annuum* L.) in the West Mediterranean region of Turkey. *African Journal of Biotechnology*, 10(25): 4976-4979.
- Shah, H., T. Yasmin, M. Fahim, S. Hameed and M.I. Ul-Haque, 2008. Transmission and Host Range Studies of Pakistani Isolate of *Chilli Veinal Mottle Virus*. *Pakistan Journal of Botany*, 40: 2669-2681.
- Singh, R.P., J.P.T. Valkonen, S.M. Gray, N. Boonham, R.A.C. Jones, C. Kerlan and J. Schubert, 2008. The naming of *Potato Virus Y* strains infecting potato. *Archives of Virology*, 153: 1-13.
- Skelton, A., B. Uzayisenga, A. Fowkes, I. Adams, A. Buxton-Kirk, V. Harju, S. Forde, R. Ward, B. Ritchie, M. Rutherford, L. Offord, C. Umulisa, B. Waweru, B. Kagiraneza, P. Karangwa and A. Fox, 2018. First report of *Pepper veinal mottle virus*, *Pepper yellows virus* and a novel *enamovirus* in chilli pepper (*Capsicum* sp.) in Rwanda. *New Disease Reports*, 37: 5.
- Tesfaw, A. 2013. Benefit-Cost Analysis of growing pepper: A trial at West Gojjam, near the source of Blue Nile. *International Journal of Agriculture and Crop Sciences*, 6(17): 1203-1214.
- Tiendrebeogo, F., V.S. Edgar Traore, N. Barro, A.S. Traore, G. Konate and O. Traore, 2008. Characterization of *Pepper yellow vein mali virus* in *Capsicum* sp. in Burkina Faso. *Plant Pathology Journal*, 7: 155-161.
- Tomassoli, L., A. Manglli, A. Ahmad, A. Tiberini and M. Barba, 2016. First report of *Pepper vein yellows virus* infecting chilli pepper (*Capsicum* spp.) in Italy. *New Disease Reports*, 33: 22.
- Tsai, W.S., I.K. Abdourhamane and L. Kenyon, 2010. First report of *pepper veinal mottle virus* associated with mosaic and mottle diseases of tomato and pepper in Mali. *Plant Disease*, 94: 378-378.
- Wetter, C., M. Conti, D. Altschuh, R. Tabillion, M. Regenmortel and H. VVan, 1984. *Pepper mild mottle virus*, a tobamovirus infecting pepper cultivars in Sicily. *Phytopathology*, 74(4): 405-410.
- Zitikaite, I. and M. Samuitiene, 2009. Detection and characterization of *Cucumber mosaic virus* isolated from sweet peppers. *Scientific works of the Lithuanian Institute of Horticulture and Lithuanian University of Agriculture*, 28(3): 281-288.
- Zitter, T.A. and J.F. Murphy, 2009. *Cucumber mosaic*. The Plant Health Instructor. DOI: 10.1094/PHI-I-2009-0518-01.

Received: February, 2019; Revised: March, 2019; Accepted: March, 2019