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Management of Viruses and Viral Diseases of Pepper (*Capsicum* spp.) in Africa

Olawale Arogundade, Titilayo Ajose, Itinu Osijo, Hilary Onyeanus, Joshua Matthew and Taye H. Aliyu

Abstract

Increasing outbreaks of virus species infecting pepper (*Capsicum* spp.) is a major problem for growers in Africa due to a combination of factors, including expansion of pepper cultivation, abundance of insect vectors and climate change. More than 45 viruses have been identified to infect pepper crops causing economic loss in terms of reduced quality and marketable yield, sometimes up to 100%. The *Pepper veinal mottle virus* (PVMV), *Potato virus Y* (PVY) and *Cucumber mosaic virus* (CMV) are endemic in many countries including Uganda, Mali, Cameroon, Morocco and Nigeria. Current management options for virus infection in *Capsicum* spp. is by the integration of several approaches. More importantly, eradication of infected plants, cultivation of disease resistant varieties, improved cultural practices and judicious use of insecticides especially when plants are young and easily colonized by vectors. In recent years, eco-friendly control measures are needful to reduce occurrence of virus diseases in *Capsicum* spp.

Keywords: climate change, economic loss, outbreaks, management options, virus infection

1. Introduction

Peppers (*Capsicum* spp.) are one of the most important spices and vegetable crops in the economic and social life of people living worldwide [1]. Viruses are among the most important factors threatening *Capsicum* spp. production in several regions like Australia [2], Europe [3], Asia [4] and Africa [5]. They cause diseases that not only reduce yield and quality of fruits, but also increase the cost of preventive measures and cost of producing clean planting materials. In addition, the high genetic diversity of virus strains and their accumulation in propagation materials makes them easily spread into unaffected areas [6].

In Africa, more than 45 viruses (grouped into eight genera namely, *Potyvirus*, *Tospovirus*, *Begomovirus*, *Cucumovirus*, *Tobamovirus*, *Polerovirus*, *Alfamovirus* and *Potexvirus*) have been identified to infect pepper crops causing reduced quality and marketable yield, sometimes up to 100% [7]. The major viruses of *Capsicum* spp. include *Pepper veinal mottle virus* (PVMV), *Chilli veinal mottle virus* (ChiVMV), *Potato virus Y* (PVY), *Tobacco etch virus* (TEV), *Tobacco mosaic virus* (TMV), *Tomato mosaic virus* (ToMV), *Pepper mild mottle virus* (PMMoV), *Pepper leaf curl virus*

(PepLCV), *Tomato yellow leaf curl virus* (TYLCV), *Cucumber mosaic virus* (CMV), *Alfalfa mosaic virus* (AMV) and *Tomato spotted wilt virus* (TSWV) while other viruses of minor importance include *Pepper vein yellows virus* (PeVYV) and *Potato virus X* (PVX) [8]. These viruses are mainly vectored by aphids, whitefly or thrips during feeding probes. However, mechanical transmission and seed transmission are efficient means for the spread of infection. Typical symptoms induced by viruses infecting *Capsicum* spp. include stunting, curling and mottling of foliage and fruits. Symptoms can vary significantly with cultivar, plant age, virus isolate and environmental condition. In recent years, co-infection of previously non-existent virus strains is most devastating [7].

The increasing outbreaks of virus species infecting *Capsicum* spp. have become a major problem for growers in many countries including Ghana, Uganda, Mali, Cameroon, Morocco and Nigeria [9, 10]. This is due to a combination of factors, including expansion and intensification of pepper cultivation, availability of volunteer hosts, abundance of insect vectors and climate change [6, 11]. Many techniques are used to minimize viral infections in *Capsicum* spp., but are successful when they begin prior to planting of the crop. Current management options for virus infection in *Capsicum* spp. is by the integration of several approaches. These include use of protected nurseries, cultivation of disease resistant varieties and ensuring adequate phyto-sanitary conditions after transplanting.

Generally, eco-friendly management measures are needful to reduce occurrence of virus diseases in *Capsicum* spp. and decrease the rate of spread of same into unaffected regions. This is important because of the need for increased international movement and exchange of pepper germplasm. This will also facilitate the selection and breeding for improved *Capsicum* spp. adapted to local conditions and uses. Therefore, there is need for a review of viruses infecting *Capsicum* spp., their symptoms, mode of transmission and management options.

2. Viruses of pepper

2.1 Genus: *Potyvirus*

The genus *Potyvirus* consists of a large group of plant viruses that are widespread, infecting economically important crops like tomato, potato, eggplant and pepper [12]. Members of this genus have non-enveloped flexuous filamentous single-stranded RNA (ssRNA) particles about 680–900 nm long and 11–15 nm wide [13]. The symptoms induced by potyviruses include mottling, mosaic, curling, vein banding or clearing, chlorosis, blistering and severe stunting of the whole plant. Severity of these symptoms depends on the *Capsicum* variety, virus strain and presence of other viruses. The major potyviruses infecting *Capsicum* spp. in Africa include PVMV, ChiVMV, PepMoV, PVY and TEV [12].

2.1.1 Pepper veinal mottle virus (PVMV)

Pepper veinal mottle virus (PVMV) was first reported in Ghana in 1971 and has since then spread to other regions in Africa including Ethiopia, Kenya, Tanzania, Uganda and Rwanda [14] causing yield loss ranging from 70 to 100 % [15]. Infection of PVMV also occurs in other solanaceous crops, including eggplant and tomato [16]. Eight species of aphids have been shown to transmit the virus in a non-persistent manner, of which *Myzus persicae*, *Aphis craccivora*, *A. gossypii* and *A. spiraeicola* are rated as efficient vectors [17]. Mechanical transmission also occurs through contact with infected sap, but not via seeds. Several symptoms associated with

PVMV include leaf mottle, leaf mosaic, leaf curl, vein banding, leaf ring spots, leaf deformation, leaf chlorosis, blistering and severe stunting of the whole plant [18].

2.1.1.1 Management of PVMV

Plastic mulches have been reported to reduce insect infestation and the concurrent damage associated with the insect transmission of viruses [10]. Intercropping *Capsicum spp.* with maize can also reduce the incidence of the disease compared to sole cropping [17]. The use of resistant varieties, raising of seedlings in insect-proof nursery and roguing of infected plants once detected are also crucial to reduce PVMV incidence and spread in the field. These are recommended as integrated ways for managing PVMV infection in the field [7].

2.1.2 Chilli veinal mottle virus (*ChiVMV*)

Chilli veinal mottle virus (*ChiVMV*) has been reported in various countries of West and East Africa including Ethiopia, Uganda and Tanzania [19]. The virus is not transmitted through seeds but is acquired mechanically and is transmitted by several species of aphids in a non-persistent manner. These vectors (*Myzus persicae*, *Aphis gossypii*, *Aphis craccivora*, *Aphis spiraecola*, *Rhopalosiphum maidis*, *Toxoptera citricida* and *Hysteroneura setariae*) retain the virus for not more than 1 hour after virus acquisition [20]. The winged aphids are generally the most efficient vectors to transmit the virus from field to field and are the most difficult to control [21]. Typical symptoms caused by *ChiVMV* include leaf mottle and dark green vein-banding.

2.1.2.1 Management of *ChiVMV*

The effective management strategies for *ChiVMV* include early identification and timely disposal of infected seedlings, application of mineral oil-based insecticides in controlling aphid populations early enough during planting, careful handling of diseased-free seedlings and use of resistant varieties. In addition, removal of solanaceous weeds, which serve as alternate hosts, can reduce incidence of *ChiVMV* in pepper gardens [21].

2.1.3 Potato virus Y (*PVY*)

Potato virus Y (*PVY*) is common among solanaceous crops including pepper, potato, tomato, tobacco and many weeds [22]. It has been reported in many African countries including Zimbabwe, Zambia, Kenya, Tanzania, Malawi, Madagascar, Ethiopia and Nigeria [23]. Isolates of *PVY* from pepper do not infect potato and vice versa [24]. Strains of *PVY* infecting sweet pepper are classified by their ability to overcome resistance genes based on differential host reactions. They cause yield reductions of 20–70% in pepper production [25]. The virus is transmitted in a non-persistent manner through several species of aphids, but the green peach aphid (*Myzus persicae*) is considered generally to be the most important vector. Infection of *PVY* can spread during grafting, handling of plant and use of unsterilized farming equipment. The symptoms of *PVY* include stunting or dwarfing of plant, systemic vein clearing and banding, leaf mosaic and small deformed fruit with a mosaic pattern making them unmarketable [26].

2.1.3.1 Management of *PVY*

Management of *PVY* is successful through the use of resistant varieties, elimination of solanaceous weeds and adjoining volunteer host plants, scheduling the time

of planting to conform with period of least aphid population, careful handling of plant seedlings especially during nursery and farming operations. Early detection and roguing of infected plants are the effective measures to reduce incidence of PVY. Additionally, intercropping pepper with maize has been found helpful in the management of potyviruses in pepper fields [27].

2.1.4 Tobacco etch virus (TEV)

Tobacco etch virus (TEV) naturally occurs in co-infection with PVY [13]. In Africa, TEV is endemic and widespread in Madagascar and occasionally in South Africa. The virus is transmitted by several species of aphids in a non-persistent manner. Infected plants are lighter in colour and have mosaic patterns on their leaves, sometimes with dark-green banding along the leaf veins. Plants may also be stunted, showing leaf curl and fruit distortion.

2.1.4.1 Management of TEV

The use of cultivars with PVY resistance helps manage TEV because resistance to the two viruses is closely-linked. Additionally, pepper seedlings should be produced in protected culture system equipped with nets or screens to exclude aphids. Scheduling planting dates to avoid periods of high aphid activity early in the season and controlling weeds, volunteer host plants in and around seedlings will lower the amount of virus inoculum introduced into the crop. Application of mineral oil has been reported to reduce incidence of TEV in pepper [10].

2.2 Genus: *Tobamovirus*

The viruses in the genus *Tobamovirus* are especially important because they do not require biological vectors for transmission. Members of this genus have flexuous filamentous ssRNA particles approximately 300 nm in length and 18 nm in diameter that can persist for years and survive many adverse environmental conditions because of their strong structural coat protein. Due to their high stability, tobamoviruses remain infectious in contaminated plant debris, compost, soil and irrigation water. Viruses in this genus include TMV, ToMV and PMMoV [13].

2.2.1 Tobacco mosaic virus (TMV)

Tobacco mosaic virus (TMV) is the first ever virus to be identified. The virus infects more than 350 plant species, including at least 125 crop species such as tobacco, tomato, pepper, eggplant, potato and cucumber [28]. *Tobacco mosaic virus* has been found to infect pepper in Uganda, Tanzania, Zimbabwe, Sudan, Zambia (East Africa) and (Nigeria, Ghana) West Africa [29, 30]. The virus survives in infected plant materials for months or years and multiplies in living plant tissue but can remain dormant in dead plant tissue, retaining its infectiveness [31]. Tobacco mosaic virus spreads mainly through contact between plants, infected seeds and by mechanical means but not insect vectors. Typical symptoms of TMV infection include chlorotic leaves, mosaic patterns on leaves, leaf distortion and stunted growth usually associated with reduced fruit size [32].

2.2.1.1 Management of TMV

Management of TMV can be achieved through careful handling of plants, disinfection of farm tools, eradication of infected plants and treatment of seeds with 10% trisodium phosphate (TSP). The use of resistant cultivar to TMV infection has

been demonstrated in Nigeria [33]. Also, healthy seed-testing and 2-year minimum crop rotation is advisable. *Capsicum* spp. should not be planted alongside other susceptible crops such as tomato and potato.

2.2.2 Tomato mosaic virus (ToMV)

Tomato mosaic virus (ToMV) has a worldwide distribution and is often endemic in African countries such as Uganda, Zambia and Cameroon [29]. The virus is one of the most resilient viruses in terms of its ability to survive outside plant cells and dead tissues. *Tomato mosaic virus* is known to infect more than 150 economically important crop species, including vegetables and ornamental plants. Natural mode of spread of ToMV is by contact with infected sap but it is also being transmitted mechanically during farming operations [6]. The occurrence of ToMV is more predominant in pepper than TMV even though both virus species produce similar symptoms on pepper. Typical symptoms include severe stunting of plants with chlorotic mosaic patterns on leaves and fruits [34]. Additional symptoms may vary depending on the plant age, virus strain and environmental condition. These include distorted leaves, which often occur with premature defoliation and necrotic (brown) patches on leaves and fruits [35].

2.2.2.1 Management of ToMV

Management options for ToMV include rotation to non-host plants after an infection outbreak. The use of resistant varieties coupled with improved cultural practices can help to improve production especially in endemic areas. Disinfection of screen-house soils, planting tools and containers ensures clean planting materials in the nursery. After transplanting, careful handling of healthy seedlings while removing symptomatic ones can reduce spread of the virus. Sterilizing seeds with 10% TSP can help remove ToMV present on the seed coat [36].

2.2.3 Pepper mild mottle virus (PMMoV)

Pepper mild mottle virus (PMMoV) has been widely reported in some African countries including Uganda, Zambia, Tanzania, Nigeria and Ghana. It has been shown to infect up to 24 other plant species including *Solanaceae*, *Chenopodiaceae*, *Cucurbitaceae*, *Labiatae* and *Plantaginaceae* [29, 23]. In cultivated pepper plants, PMMoV can be transmitted through seed and contact with infected plant sap [37]. Seedlings can also be infected by mechanical contamination during transplanting or other cultural routine. *Pepper mild mottle virus* persists in soil and on infected debris, which serve as primary source of inoculum for subsequent planting. Symptoms of PMMoV include various degrees of leaf mottling, leaf mosaic, leaf chlorosis, necrosis, leaf curl and growth decline. These symptoms are more pronounced in young plants than in older plants [38].

2.2.3.1 Management of PMMoV

Treatment of *Capsicum* spp. seeds with 10% TSP for 2.5 hours (h) reduces the incidence of PMMoV. Other management options include sterilization of soil before planting, especially in screen-houses and ensuring good field hygiene after transplanting [13].

2.3 Genus: *Begomovirus*

The genus *Begomovirus* comprises monopartite or bipartite plant viruses that infect a wide range of crops throughout the world. Viruses in this genus are

exclusively transmitted by the whitefly (*Bemisia tabaci*) in a persistent and circulative manner. These virus species have circular single-stranded DNA (ssDNAs) particles approximately 30 nm in length and 18 nm in diameter. Examples of important begomoviruses affecting pepper include PepLCV and TYLCV.

2.3.1 Pepper leaf curl virus (*PepLCV*)

Pepper leaf curl virus (PepLCV) has been found in different countries of Africa and is responsible for several epidemics causing severe economic losses. Transmission of PepLCV is most damaging when plants are infected at early growth stage preventing the proper formation of flowers resulting in low fruit production. Symptoms of PepLCV include severe stunting, flower bud abscission, reduced pollen production, upward curling of leaves, leaf chlorosis and elimination of fruit production. Yield losses may be between 90 and 100% [39].

2.3.1.1 Management of *PepLCV*

The most widely used treatments include use of insecticides and other cultural methods to control vector population. Other methods to control the spread of PepLCV include planting resistant or tolerant plants, crop rotation and border planting, and plastic mulching [40].

2.3.2 Tomato yellow leaf curl virus (*TYLCV*)

Tomato yellow leaf curl virus (TYLCV) is one of the most destructive viruses affecting a wide host range of vegetable crops, including Okra (*Abelmoschus esculentus*), tomato (*Solanum lycopersicum*), sweet and chilli pepper (*Capsicum* spp.), tobacco (*Nicotiana tabacum*), common bean (*Phaseolus vulgaris*) and some weeds [41]. The virus has been reported in *C. annuum* in Tunisia [42]. However, its distribution spreads across East, West and Central Africa. Movement of infected plants or virus-carrying whiteflies aids the spread of the virus. Typical symptoms of TYLCV in infected pepper plants include interveinal yellowing, leaf curling and stunting which cause critical production losses.

2.3.2.1 Management of *TYLCV*

Plastic mulching has been effective in the control of whitefly populations in pepper fields. Other strategies for managing TYLCV include raising of seedlings in pest-proof nurseries, adoption of crop rotation, use of insecticides, selection of resistant varieties for planting, improved cultural practices to remove weeds and alternative host plants [43].

2.4 Genus: *Cucumovirus*

The genus *Cucumovirus* comprises tripartite ssRNAs encapsidated in small icosahedral particles approximately 29 nm in diameter. Viruses in this genus infect over 1200 plant species worldwide [44], including weeds and wild species.

2.4.1 Cucumber mosaic virus (*CMV*)

Cucumber mosaic virus (CMV) is an important viral disease of pepper with a worldwide distribution. In Africa, the virus has been reported in Uganda, Zambia,

Tanzania, Ethiopia, Zimbabwe, Kenya, Malawi, Madagascar, Sudan, Rwanda, Ghana and Nigeria [14, 45]. Although the virus exists as a number of strains, all are apparently capable of infecting pepper and differ only in their symptom expression. The age of a plant at the time of infection strongly influences what type of symptoms will be manifested. Symptoms of naturally affected pepper plants vary 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 [46, 47]. More than 80 species of aphids transmit the virus in a non-persistent way but *Aphis gossypii* and *Myzus persicae* are the most efficient [48]. Additionally, transmission can be through seeds, parasitic weeds and mechanically [26, 49].

2.4.1.1 Management of CMV

Strategies to delay early infection can be used to enhance yield. Isolation of pepper from weedy border areas or growing them next to taller border plants such as maize, which can function as a non-susceptible host, use of certified seeds and plants, screening and disinfection of infected mother stock, washing and disinfecting of hands and tools, and planting of resistant pepper genotypes constitute the effective means of managing CMV [47].

2.5 Genus: *Alfamovirus*

The genus *Alfamovirus* consists of ssRNA viral particles. A typical member of this genus is *Alfalfa mosaic virus* (AMV) having natural host range including over 250 plant species and is closely related to CMV [13].

2.5.1 Alfalfa mosaic virus (AMV)

Alfalfa mosaic virus (AMV) is distributed worldwide, having a wide host range. In Africa, it has been reported in Zambia [50]. The virus is transmitted mechanically and in a non-persistent manner by numerous aphid species. Transmission of AMV also occurs through pepper seeds or pollen [9]. Typical symptoms associated with AMV in pepper include bright yellow or blotchy white mosaic patterns on pepper leaves [6]. Additional symptoms include stunted growth with deformed and blotchy fruits, especially if plants are infected at young stage. *Alfalfa mosaic virus* can cause important yield losses and increased susceptibility of pepper to other pathogens.

2.5.1.1 Management of AMV

Alfalfa mosaic virus can be successfully managed by reducing aphid population by use of insecticides. The use of resistant varieties and regular rouging of weeds from the fields are effective means to manage the virus [51].

2.6 Genus: *Tospovirus*

The genus *Tospovirus* consists of important species of plant viruses that cause great losses in many economically important crops. Members of this genus have tripartite ssRNA particles about 80–120 nm in size [42, 52]. The major virus species in the genus *Tospovirus* is *Tomato spotted wilt virus* (TSWV), which infects various *Capsicum spp.* in Africa [13].

2.6.1 Tomato spotted wilt virus (TSWV)

Tomato spotted wilt virus (TSWV) causes serious crop losses in many economically important crops, including vegetables and ornamental crops. It has been reported to affect pepper in Zimbabwe in Africa [53]. The virus is transmitted in a persistent and propagative manner by several species of thrips. The western flower thrip (*Frankliniella occidentalis*) is the most efficient [54]. However, only the adult thrips that feed on infected plants transmit the virus after inoculation period of less than 48 h. *Tomato spotted wilt virus* is known to infect more than 1000 different plant species from about 80 botanical families. Symptoms of the virus can be very host-specific. Typical symptoms observed in pepper include yellowing or browning of leaves, chlorotic or necrotic ringspots on leaves and fruits, necrotic streaks on stems with terminated shoots and fruits [6].

2.6.1.1 Management of TSWV

Early detection and roguing of infected plants is important for reducing TSWV incidence in the field. Intercropping pepper with companion crops like ginger (*Zingiber officinale*) can reduce the vector from reaching its host. Additionally, use of insecticide is a critical measure in management of TSWV [9].

2.7 Genus: *Polerovirus*

2.7.1 Pepper vein yellows virus (PeVYV)

Pepper vein yellows virus (PeVYV) has been reported in Ivory Coast, Mali, Republic of Benin, Sudan and Tunisia in Africa with infection rates of up to 100%. The virus is spread in circulative and non-propagative manner by *A. gossypii* and *M. persicae* [55]. Major host plants include *Capsicum* spp. and *Solanum nigrum* [56]; however, some alternate hosts such as *Chenopodium amaranticolor*, *Curcubrita pepo*, *Datura stramonium*, *Gomphrena globose* and *Nicotiana* spp. have been reported [56]. Symptoms on cultivated pepper plants include leaf curling, deformation, reduced leaf size, puckering, interveinal yellowing, vein clearing and yellow patches on leaves [57].

2.7.1.1 Management of PeVYV

The most effective means of controlling PeVYV is preventing its introduction. Careful sourcing of plants, keeping aphid population low, raising awareness of its symptoms will assist in preventing the establishment of the virus [56].

2.8 Genus: *Potexvirus*

2.8.1 Potato virus X (PVX)

Potato virus X (PVX) has been reported in Ethiopia, Zambia and Zimbabwe to infect a wide range of solanaceous crops including pepper, tomato, potato and tobacco. The virus causes a range of symptoms including mottling, severe necrosis of leaves and stems and sometimes, defoliation of some cultivars. Symptoms of PVX are worsened in co-infection with other viruses, especially *Potato virus Y* [58, 59]. *Potato virus X* is transmitted mechanically and by contact between plants, but not through seeds [60]. PVX is of minor importance in pepper production [60].

2.8.1.1 Management of PVX

Planting resistant cultivar is the most economic and effective way of managing the virus [61].

3. Conclusion

Viruses remain a primary constraint to production of high-quality *Capsicum* spp. worldwide, especially in the developing regions [1]. In Africa, weeds often become reservoir hosts for vectors and virus species that attack pepper in the field [47]. Currently, virus species in the genus *Potyvirus*, *Cucumovirus*, *Begomovirus* and *Tobamovirus* are major concern for many growers because of their effects on yield [7, 62]. The severity of infection depends on environmental conditions, host varieties and individual virus infection (**Figure 1**). Generally, these virus infections cannot be totally eradicated in many plantations where they occurred [10]. However, prompt action against the damage caused by viruses is with the use of resistant varieties and ensuring adequate phyto-sanitary conditions within the field. Therefore, awareness of local farmers on the impact of field hygiene must be improved as adjunct to using tolerant varieties. Additionally, screening of young seedlings for infection before they ever reach the field is crucial to reduce virus occurrence. Ultimately, the development of eco-friendly ways of virus disease management will help to improve yield in the pepper industry.

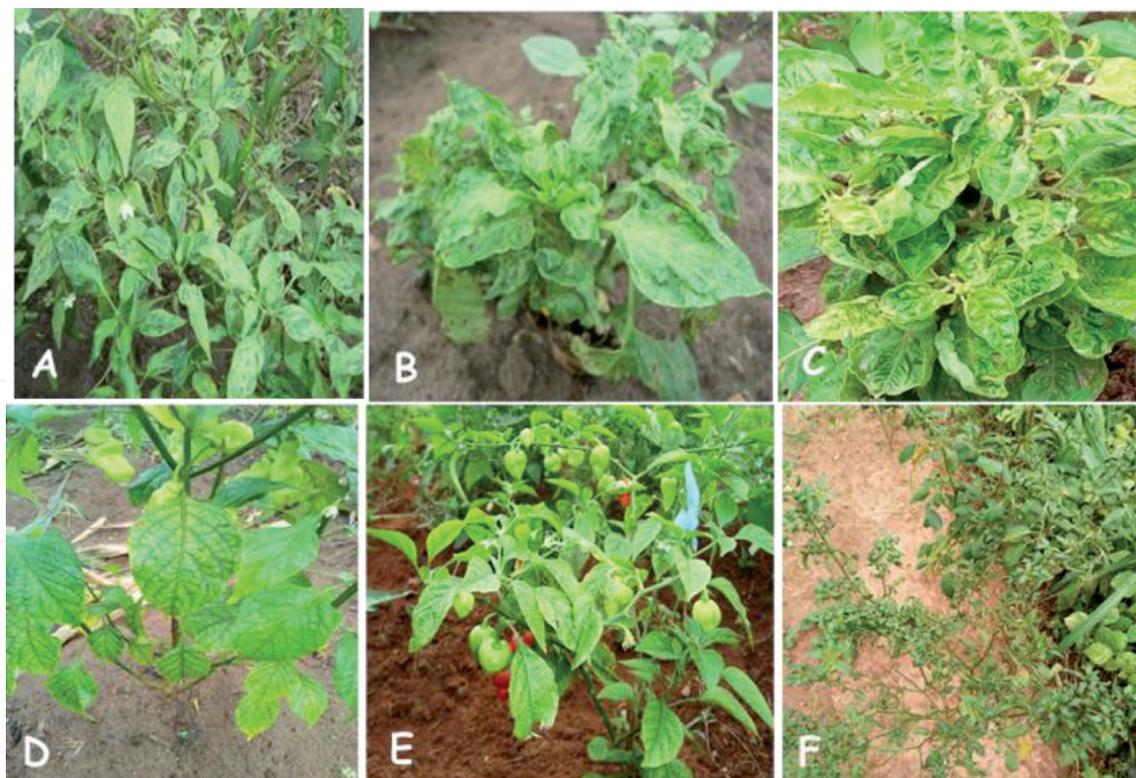


Figure 1. Possible symptoms that can be observe on pepper in the field. (A) Mosaic pattern on leaves, (B) leaf mottling, (C) leaf curl, (D) vein banding, (E) vein yellowing and (F) leaf reduction.

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