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Economic Impact and Management of Plant Viral Disease: Review

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Abstract
Plant viral diseases in food crops pose a serious constraint to the productivity and profitability of a wide range of crops that affecting food production globally and cause enormous economic losses. Plant virus infections are emerging from time to time as major concerns in improving agricultural productivity. Rapidly-expanding global climatic change creates favorable conditions for development and increased spread of plant virus diseases due to direct or indirect impacts on population dynamics of virus-transmitting insect vectors. Plant virus disease management is the selection and use of appropriate technologies and practices to suppress disease to a tolerable level. Plant virus diseases are basically difficult to manage directly by use of chemical pesticides; however, integrated management methods which include cultural practices such as removal of infection sources, field sanitation, removal of alternative hosts, use of healthy seed (virus free seeds); chemical pesticides to control insect vectors indirectly through seed treatment and foliar spray are the most possible management measures of plant viral diseases.
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1. Introduction

Virus pathogens are obligate intracellular parasites and not have molecular machinery making them incapable to replicate without a living host cell. Virus particles are very small, their shape and size can be seen only with an electron microscope. Based on the assembly of capsids, plant viruses have been divided into two morphological groups rod-shaped and spiral shaped. Rod shaped viruses are more prevalent and differ in diameter (3-25 nm), length (150-2000 nm), packaging of subunits, pitch of the helix, and flexibility of the particle (Randles and Ogle, 1997).

Virus particles are immovable outside the diseased host; relying on other pathogens or the environment for their spreading. These are metastable macro-molecular assemblies of a nucleic acid core (5-40%) bounded within a protein coat known as a capsid (60-95%). The coat proteins of the viral play a vital role closely in every step of its infection cycle, such as virus distribution into the plant cell, disassembly of virus particles, viral RNA translation, viral genome replication, assembly of progeny virus, movement in the plant, activation or suppression of host defense and transmission of the virus to healthy plants (Lal, *et al.*, 2015).

Plant viruses cause systemic infections and the virus translocation from the point of inoculation depends on the cell-to-cell movement of its particles after the viral replication and establishment (Salaudeen and Aguguom, 2014). The cell-to-cell movement is accomplished through plasmodesmata (Heinlein, 2015), and at the primary infection location, the movement from cell-to-cell results in the development of local infection, after reaching the vascular system, viruses move long-distance and become infecting roots and young leaves and this leading to further infection and spread (Revers *et al*., 1999; Garcia- Ruiz, 2018), and causes significant plant/crop yield losses.

2. Emerging plant viral disease and their Economic Impact

The disease caused by viruses in food crops pose a serious constraint to the production and productivity of varied crops that affecting food production globally and cause enormous economic losses. The main impact happens with the emerging of viral diseases, as a result of their fast increase in disease incidence, rapid distribution into wide geographical areas. The main driving factors for the emergence of plant viruses (Anderson *et al*., 2004; Jones, 2009; Elena *et al*., 2014) include:

i) The monocropping agricultural systems based with low genetic diversity, which are more susceptible to viral pathogens;
ii) The global trade system of plant material that moves viruses, hosts, and vectors to new geographical location and regions;
iii) The climate change from time to time affecting the distribution area of hosts and vectors and
iv) The capability of the viruses for quick evolution and adaptation

Its consequences leading in loss by limiting plant produce quality and quantity (Thresh, 2006; Van der Vlugt, 2006; Mumford *et al*., 2016) and have an estimated economic impact of more than $30 billion per year (Sastry and Zitter, 2014). Plant virus infections are emerging from time to time as major concerns in improving agricultural productivity. In recent years, large numbers of plant viruses have already appeared and sprouted in various agroecological locations (Abraham, 2019).

For instance, the outbreak of maize complex virus known as maize lethal necrosis (MLN)in East Africa, China and Ecuador caused a serious impact on maize plant production and grain yields in the region (De Groote *et al*., 2016; Marenya *et al*., 2018). MLN is caused by double infection of *Maize chlorotic mottle virus* and one of any cereal potyvirus. In East Africa the emergence of MLN was first reported in 2011 in Kenya (Wangai *et al*. 2012). Since its occurrence in Kenya, MLN has been extensively disseminated in neighboring countries and caused from low to complete maize yield loss in Uganda, Tanzania, Ethiopia and Rwanda (Mahuku *et al*., 2015). The economic loss caused by MLN to smallholder maize growers across Kenya, Tanzania, Rwanda, Uganda and Ethiopia were estimated between 291 and 339 million US$ (Pratt *et al*., 2017). It was stated in Uganda in 2013 with yield loss of 50.5% (Kagoda *et al*., 2016) and in Rwanda in 2013 (Adams *et al*., 2013) with up to 100% crop loss. In Kenya, 23-100% yield reduction was occurred in severely affected areas, about 0.5 million tons with a value of US$ 180 million (De Groote *et al*., 2016). In Ethiopia, MLN is widespread and has caused from low to complete crop failure (Guadie *et al*., 2018; Regassa *et al*., 2020) and estimated losses amounting to US$261 million (Marenya *et al*., 2018). In the production year 2015-2016 in Ecuador, MLN disease caused yield reduction of 25–40% (Vega and Beillard, 2016). Also, the economic losses caused by this disease in China were about 2 billion USD (Rao *et al*., 2010).

Rapidly-expanding global climatic change creates favorable conditions for development and increased spread of plant virus diseases due to direct or indirect impacts on population dynamics of virus-transmitting insect vectors (Pautasso *et al*., 2012; Geering and Randles, 2012). Approximately 80% of the plant viruses depend on insect vectors for transmission, and plant viruses demonstrate a high level of specificity for the group of insects that may transmit them (Froissart *et al.,* 2002; Hull, 2002).

The need for the achievement of overall global food security is becoming increasingly urgent as the world population continues to grow up. The rising climate change from time to time made problems associated with controlling devastating plant virus diseases threatening food crops create a crucially important concern for humankind to resolve. Therefore, attaining effective management of virus disease epidemics that harm staple food crops is the most important goal. Epidemics of existing plant virus diseases and newly emerged of novel plant virus diseases have become a serious threat to both subsistence and commercial agriculture (Abraham, 2019, Regassa *et al*., 2020). The losses and the resulting financial damage caused by plant virus diseases can be reduced by controlling epidemics through methods that minimize virus infection sources or decrease its geographical distribution.

3. Plant Virus Disease Management

Disease management is the selection and use of appropriate technologies and techniques (practices) to suppress disease to a tolerable level. The goal of plant disease management is to reduce the economic and aesthetic damage caused by plant diseases. Proper disease management is achieved when the causation and the effect (damage) that the disease could cause are known. The main approach for plant virus management is prevention or delaying virus infection. Various means have been used to achieve these aims, including reduction of initial inoculum, reducing the rate of infection, management of insect vectors insecticides or other means and deployment of resistant or tolerant varieties.

3.1. Reduction of initial inoculums

3.1.1. Quarantine

Quarantine and sanitary certification of virus free seeds and asexual propagative planting materials are the primary procedures to avoid the introduction of new viruses in to previously virus free geographical areas. Plant quarantine is a national service and is organized within the framework of Food and Agriculture Organization (Kumar *et al*., 2004). It is considered as one of the best procedures of controlling movement of seed transmitted viruses (Adams *et al*., 2014). In various countries and territories, legislation at this time in force to prevent introduction of important seed-transmitted diseases and pests involves the following quarantine regulations (Khetarpal and Gupta, 2006; Munkvold, 2009):

(i) Embargo and import permit (restriction placed on the *import* or export of goods, services by government)
(ii) Inspection (field check and laboratory testing) in the exporting country before shipment of the consignment,
(iii) Seed treatment for diseases and pests that can be eliminated by disinfection or fumigation with reasonable certainty,
(iv) Post-entry growth inspection by the importing country in closed quarantine and
(v) Certification

Most countries differentiate between the seed imported for scientific purposes and those imported for sowing or commercial purposes. Since more than 231 viruses are seed transmitted (Sastry, 2013), there is a high risk of introducing the virus diseases, which are not known to occur in a country if proper testing is not carried out. Even minute quantities of soil and plant debris contaminating true seeds can introduce the virus/vector, or both. Thus, man is the direct or indirect cause of most epidemic imbalances that known about, and the high virulence and extreme susceptibility of an epidemic situation is an unnatural imbalance usually brought about by human disturbance (Jones, 2000).

3.1.2 Use of virus free-planting materials

The use of virus-free planting materials for all new plantings is a basic approach to control that is beneficial for several reasons:

1) virus-free plant material establishes more readily and is more productive than infected
2) if virus-free planting material is applied there are no initial source of viral inoculum within crops from the outset.
3) plants not infected until a late stage of crop growth stage are affected less severely than those infected at early growth stage.
4) infected propagules are particularly a risky source of inoculum since they tend to be disseminated randomly within crops. This facilitates virus spread from infected to neighboring healthy plants, whether this is by contact or by vectors. For these reasons, much attention has been given in developed/technologically innovative countries to producing virus-free stocks of seed and of tubers, cuttings or other propagules of crops that are propagated vegetatively (Thresh, 2003).

3.2. Pathogen eradication

Viral pathogen eradication comprises sanitation, which includes cleaning of agricultural tools used in infected fields, elimination/removal of infected plant debris that can act as source of inoculum in the next cropping season, rouging of diseased plants (Mawishe and Chacha, 2013), eradicating weeds in and around the crop fields, and extra alternative hosts, which aid as reservoir for viruses' inoculum (Webster *et al*., 2004; Trigiano *et al*., 2008).

3.2.1. Sanitation

Epidemiologically many instances of the threats by the remains of previous crops, and by re-growth from the tubers, roots, stems, growth of 'self-sown' seedling (volunteers) or other plant residue and debris left in the ground at harvest. This enables the survival of viruses and their vectors, and can provide a 'green bridge' between consecutive crop growing seasons. Hence the removal and destruction of these crops deny the virus and its vector a survival opportunity and reduce the disease intensity in the subsequent cropping seasons (Thresh, 2003).

3.2.2. Removal of weeds or wild hosts

Many viruses have weeds or wild hosts that act as foci of infection from which there is spread into or within crops. Weed and volunteer plants being major components of the agroecosystem not only compete with crop plants for water and nutrients but also serve as sources of virus inoculum for both the crop and the vector. In some of the weed hosts, the virus is seed transmitted, and the infected seeds survive in the soil for long periods. In certain cases, the presence of weeds in the field becomes more dangerous as they are symptomless virus carriers and consequently are difficult to assess (Thresh, 1981; Sastry, 1984; Sastry, 2013). Therefore, the removal of weeds and wild hosts will support in the management of virus diseases.

3.2.3. Roguing

The removal of virus infected/symptomatic plants is known as roguing. It is widely used to remove initial sources of virus infection within crops from which further spread can occur. Crop in the fields necessarily inspected regularly and plants that look infected removed instantly. Rouging of virus infected plants can be more effective when the virus disease incidence is very low that could help in minimizing the spread of virus (Thresh, 1988; Sastry, 2013).

3.2.4. Crop Rotation

Crop rotation has historically been a major means of disease control in production of annual and biennial crops. It helps to avoid infection sources consisting of volunteer crop that may have become infected through seed or have survived from previous crops. Encouraging results are available wherein the soil borne diseases are minimized by crop rotation with non-susceptible hosts of virus/vector. For example**,** *Tobacco mosaic virus* remains infectious even after 2 years in the old infected root debris and crop rotation is one of the ways of freeing the soil from *Tobacco mosaic virus* satisfactorily (Sastry, 2013; Uyemoto, 1983).

3.3. Reducing the rate of infection

3.3.1. Chemical control

Many plant viruses have insect vectors that spread into, between and within crops. Arthropod such as aphids, whiteflies, and thrips are the most common virus vectors transmit plant virus from plant to plant and place to place. This has led to the use of pesticides to prevent such spread by decreasing vector populations or by impeding transmission (Satapathy, 1998; Perring *et al.*, 1999).

Numerous insecticides, formulated either as granules or spray applications can be used to manage vectors that transmit plant viruses. The introduction of the neonicotinoid class of insecticide seed treatments (imidacloprid, thiamethoxam and clothianidin) are used in a large improvement in insect control. Neonicotinoid insecticides possess a number of valuable attributes that have led to their increased adoption by growers (Hahn and Noleppa, 2013).

3.3.2. Host Tolerance and Resistance

The greatest economically feasible and environmentally sustainable approach to controlling plant virus diseases in crops is to deploy virus-resistant cultivars. Plants can fend off pathogens either by reducing or restricting pathogen growth (resistance) or by reducing or moderating pathogen effects (tolerance) (Boots, 2008; Roy and Kirchner, 2000).

Plants have developed resistance mechanisms to prevent and resist attacks from pathogens (Dangl and Jones, 2001). Use of resistant plant cultivars for disease management is an environmentally friendly and cost-effective measure compared to other methods such as chemical control methods (Kumar *et al*., 2004). This is because it is durable, reduces crop losses due to disease and no or little use of chemicals (pesticides) that could affect human and the environment. Resistance to plant viruses can be due to the inability to establish infection, inhibited or delayed viral multiplication, blockage of movement, resistance to the vector, and viral transmission from it (Jones, 1998), and resistance to symptom development, also known as tolerance. This indicated that plant defense mechanism against viruses could be mediated by resistance genes which are observed as complete resistance or extreme resistance and that the virus replication could be hindered or gone undetectable among the infected cells (Ingvardsen *et al*., 2010). Genetically, disease resistance in plants can be either qualitative/complete resistance conditioned by a single gene/major gene or quantitative/incomplete resistance conditioned by one-to-many genes/minor genes (Poland *et al*., 2009).

Qualitative resistance involves resistance genes (R-genes) with gene-for-gene action in which pathogen avilurence genes (Avr-gene) interact directly or indirectly with a plant resistance gene (R-gene) to activate resistance mechanism in the host plant. (Flor, 1971) found that each avilurence gene in the pathogen has a corresponding resistance gene in the host and the interaction between them initiates a hypersensitive reaction. Lack of compatibility between avirulence and resistance genes results a susceptible reaction (Hammond-Kosack and Jones, 1997). Qualitative resistance is specific for each race and strains of a pathogen. Each species has a large number of R-genes with receptors specific to different strains of pathogens (Ellis *et al*., 2000).

Quantitative disease resistance is conferred by multiple genes (quantitative trait loci) with minor effects. Such kind of resistance is known to be non-specific and controlled by environmental factors which make it difficult to know the mechanism underlying resistance by multiple genes. Due to high interaction with environment and incomplete gene effects, it is difficult to fine map and clone genes conferring quantitative disease resistance (Ali and Yan, 2012).

Conclusion

The emergence and rapid spread of plant virus disease can result in high epidemics and huge crop losses. When staple food crops suffer large-scale losses from destructive virus disease, it has key implications for people whose livelihoods depend directly or indirectly depend on these crops. It can lead to hunger and famine, especially in the world's poorer countries. Once plants have been infected by a virus, there is no feasible treatment to cure the diseased plants, unlike fungi or bacteria that can be treated with fungicide or bactericide respectively. The approach intended at plant virus disease management is largely directed at preventing virus infection by eradicating the source of infection to prevent the virus from reaching the crop, reducing the spread of the disease by controlling its vector, use of virus-free planting material, and incorporating host-plant resistance to the virus. The integrated management methods which include cultural practices such as removal of infection sources, field sanitation, removal of alternative hosts, use of healthy seed (virus free seeds); chemical pesticides to control insect vectors indirectly through seed treatment and foliar spray are the most possible management measures of plant viral diseases.

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