



Sustainable ways of controlling virus diseases in plants: A review

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Abstract

Virus diseases in plants pose significant challenges to global agriculture, impacting crop yield, food security, and economic stability. This review examines sustainable methods for managing plant virus diseases, focusing on environmentally friendly strategies that minimize negative impacts on ecosystems and human health. Various approaches, including microbial agents, botanical extracts, and advanced biotechnological tools, are explored for their efficacy in controlling plant viruses while maintaining agricultural sustainability. Microbes such as fungi, bacteria, and their derivatives have demonstrated promising antiviral properties through mechanisms such as induced systemic resistance and direct inhibition of viral activity. Additionally, botanical extracts derived from plants have shown effectiveness in controlling a wide range of plant viruses, offering potential alternatives to chemical pesticides. Furthermore, advanced biotechnological approaches, including technology based on Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR/Cas) and genetic resistance, provide innovative avenues for developing virus-resistant crop plants with enhanced sustainability. This review provides a comprehensive overview of work done by different phytopathologists toward the collective understanding of sustainable strategies for managing plant virus diseases.

Keywords: Plant virus disease, sustainable strategies, genetic resistance, antiviral activity, etc

Introduction

At the global level, plant virus diseases are a significant cause of biological disasters in agriculture ^[1]. Plant viruses are accountable for roughly 47% of global plant disease epidemics ^[2], significantly impacting economies through the destruction of vital crops. This results in an estimated 15% reduction in global yield ^[3].

Managing and preventing plant viral diseases presents great challenges due to their complex transmission mechanisms and infection processes. These diseases, often rank as the second largest plant diseases after fungal infections ^[4], resulting in substantial loss to agricultural production.

Chemotherapeutics have been a primary means of virus control, alongside screening for anti-disease organisms. However, the proliferation of pesticides has sparked worries, given their detrimental impact on agricultural fertility and the emergence of problems like heightened drug resistance in plant pathogens and excessive pesticide residues. As a result, biopesticides have garnered heightened interest due to their eco-friendly properties, specificity, and lower likelihood of fostering drug resistance ^[5].

Given the obligate intracellular nature of plant viruses, curative methods are often ineffective. Therefore, disease management strategies must prioritize risk reduction and prevention, taking into account the dynamic and evolvable nature of plant viruses.

Active principles of plants can be extracted using water or any other solvent and these constituents show variable degrees of control over the virus either by controlling of vector, inhibiting virus amplification, or altering any biosynthetic pathway via upregulating or downregulating expression of some genes. For sustainable control of different plant virus diseases, the antiviral activity of some of the plant extracts, fungi, and bacteria or their originated compounds including a few advanced approaches have been mentioned in this paper.

Microbes for control of plant viruses

Certain microbes such as many groups of bacteria including plant-growth-promoting rhizobacteria (PGPR), endophytic bacteria, actinomycetes, and many fungi possess the ability to combat viral infections in plants. They achieve this through techniques such as cross-protection, induced systemic resistance, and by synthesis of biochemicals including lipopeptides and phenolic compounds; various enzymes related to activating defense mechanisms, proteolytic enzymes and nuclease, especially RNase (as most of the plant viruses having RNA as genetic material) found to be effective for controlling many plant viruses ^[6].

Bacteria or bacterial-origin compounds as antiviral agents

Harnessing microbe-derived organic agents for controlling plant viruses by enhancing disease resistivity may prove a useful tool for sustainable and environmentally appropriate agriculture. Abdelkhalek *et al.* ^[7], currently studied the efficacy of *Bacillus amyloliquefaciens* strain TBorg1 in protecting tomatoes from *Tobacco mosaic virus* (TMV) infection. Application of spray of culture filtrate of this bacterial strain on tomato leaves before and after infection showed improved growth by reducing disease severity, and TMV accumulation in infected leaves. Treated plants also showed increased levels of carbohydrates, proteins, and ascorbic acid, along with reduced enzyme activities involved in scavenging reactive oxygen species.

Similarly, other bacteria like *Bacillus licheniformis* strain POT1 have shown substantial control over Alfalfa mosaic virus (AMV) infection in potatoes by inducing systemic resistance through secondary metabolites, specifically polyphenolics ^[8]. *Streptomyces* isolates have also demonstrated antiviral effects, with culture filtrates inhibiting Cucumber mosaic virus (CMV) in *Chenopodium amaranticolor* ^[9]. Moreover, *Streptomyces* strains, such as

RFS-23, have been reported to positively regulate plant growth, reduce disease severity, and diminish Tomato yellow leaf curl virus (TYLCV) DNA accumulation [10].

Additionally, foliar application of *Streptomyces* spp culture filtrate has shown significant reductions in Potato virus Y (PVY) in potatoes [11]. Induced systemic resistance mediated by plant growth-inducing bacteria has yielded satisfactory results in controlling various viruses of plants, including tomato mottle virus (ToMV) and PVY in tomatoes, cucumbers, and potatoes, respectively [12, 13, 14].

Actinomycetes, such as *Streptomyces* species, have also demonstrated antiviral activity against TMV infection in tobacco through various ways, such as triggering plant defense pathways and generating signaling molecules [7].

Actinomycetes occurring in the ocean, known for their unique bioactive compounds, have been investigated for their antiviral potential against viruses like Cucumber mosaic virus (CMV) [15]. Furthermore, *Enterobacter asburiae* has been shown to activate resistance against TYLCV in tomatoes, reducing disease rates even up to 45 days post-infection [16].

In a recent study, the utilization of nanoencapsulated *Bacillus* consortia presents a promising and innovative approach for combatting Groundnut bud necrosis orthotospovirus (GBNV) in both cowpeas and tomatoes. The encapsulation of *Bacillus* spp within nano silica enhances their shelf life and facilitates improved water retention on tomato leaf surfaces, consequently enhancing their antiviral efficacy. This study demonstrates significant reductions in GBNV lesions and virus titers in both cowpea and tomato plants, highlighting the potential of nano-encapsulated *Bacillus* consortia as an effective solution for GBNV management in vegetable crops [17].

Fungi or fungal-origin compounds as antiviral agents

Various fungi and fungal-origin compounds have demonstrated potent antiviral properties against a range of plant viruses. For instance, *Trichoderma pseudokoningii* [18], *Coriolus versicolor* [6], *Alternaria tenuissima* [19], *Flammulina velutipes* [20, 21], and *Lentinus edodes* [22] have been effectively employed to combat Tobacco mosaic virus (TMV) infections in *Nicotiana tabacum* L.

Hypocera lixii has been identified as capable of controlling Iris yellow spot virus infections in *Allium cepa* L. [23]. Additionally, *Beauveria bassiana*, an endophytic fungus, has shown promise in managing Zucchini yellow mosaic virus (ZYMV) in *Cucubita pepo* L. [24], while *Neotyphodium uncinatum*, another endophytic fungus, has been effective against Barley yellow dwarf virus infections in *Lolium pratensis* [25].

The interplay between fungi and viruses may be influenced by fungal secondary metabolites synthesized through endophytic associations. Notably, alkaloids produced by fungal endophytes have demonstrated antiviral properties [26].

Furthermore, the use of fungi that promote plant growth has demonstrated potential in managing viral infections. For instance, *Penicillium simplicissimum* (GP17-2) has been employed to control Cucumber mosaic virus (CMV) infections in *Arabidopsis thaliana* L. and *Nicotiana tabacum* L. [27], while *Trichoderma harzianum* has been effective against CMV in *Solanum lycopersicum* L. [28]. Additionally, *Trichoderma harzianum* has also been used to combat the Sugarcane mosaic virus in *Zea mays* L. [29].

The desiccated mycelium of *Penicillium chrysogenum* (PDMP) can trigger the initiation of callose deposition around the Tobacco Mosaic Virus (TMV), which effectively limits its spread. The production of ABA (abscisic acid) is a key role player in this callose priming process induced by PDMP, thus significantly bolstering the plant's defense mechanisms against TMV. [30].

Another study investigated the efficacy of a basidiomycetous fungus *Ganoderma lucidum* culture filtrate in managing Groundnut bud necrosis virus (GBNV) in tomato plants. Co-inoculation spraying of *G. lucidum* filtrate at 0.1% concentration significantly reduced lesion numbers and inhibited virus population build-up by up to 77.83% in cowpea, an indicator host. Quantitative assays revealed a substantial decrease in virus titer and copy numbers in treated tomato plants compared to untreated controls. Additionally, the analysis identified the triterpenoid compound Squalene in *G. lucidum*, marking a significant advancement in understanding its antiviral activity against plant viruses, particularly GBNV [31].

These examples illustrate just a portion of the extensive research into the antiviral capabilities of fungi and fungal compounds. The list is extensive and indicative, but by no means exhaustive or concluded here.

Botanicals for control of plant viruses

The identification of antiviral properties in pokeberry juice in 1914 marked a pivotal moment, catalyzing further investigations into the antiviral potential of various herbs and plants [32]. Extracts from entire plants or specific plant components like shoots, leaves, roots, bulbs, and fruits have demonstrated effectiveness against the Tobacco mosaic virus (TMV) [33].

Azadirachta indica leaf extract has emerged as a potent solution for managing cotton leaf curl virus (CLCuV) disease by effectively targeting its vector, the whitefly (*Bemisia tabaci* L.). Abbas *et al.* [34] demonstrated its efficacy by inhibiting both the egg hatchability and adult emergence of the whitefly. In a previous study, *Azadirachta indica* crude leaf extract was found significantly effective against bean-common mosaic virus infections under field conditions [35]. In another study, Elsharkawy and El-Sawy [36] found *Azadirachta indica* extracts effective against the Bean common mosaic virus along with four other plant extracts namely *Plectranthus tenuiflorus*, *Clerodendrum inerme*, *Schinus terebinthifolius*, and *Mirabilis jalapa* by reducing local lesions produced by the virus in bean plants. Elbeshehy [37] also reported the inhibitory activity of *Azadirachta indica* including four other medicinal plants viz. *Nigella sativa* L., *Thuja orientalis*, and *Bougainvillea spectabilis* against Zucchini yellow mosaic virus (ZYMV) in *Citrullus lanatus* plants. *In vitro* studies, *Bougainvillea spectabilis* extracts showed promising results against Tobacco Mosaic Virus (TMV) and Tomato Mosaic tobamovirus (ToMV) by 62% and 59% reduction in local lesions produced in *Nicotiana glutinosa* [38].

These studies highlight the great potential of *Azadirachta indica* due to its well-known insecticidal properties extending its effectiveness to either indirectly control plant virus diseases by controlling disease-spreading vector population or directly inhibit virus effectivity.

Furthermore, plant extracts have exhibited remarkable antiviral activity against a range of viruses. Narusaka [39] reported the high antiviral activity of aqueous extracts from

the *Alpinia zerumbet* plant in controlling tobacco and tomato mosaic viruses. *Mirabilis jalapa* root extract has shown effectiveness against Potato Spindle Tuber Viroid, Potato Leaf Roll Virus, and Potato Virus X & Y [40] while *Tanacetum vulgare* extract was found effective against PVY and CMV infections in tomatoes [41].

Similarly, Sharma *et al.* [42] evaluated the leaf extracts of Brahmi (*Centella asiatica*) and *Vitex negundo* to control the Turnip mosaic virus (TuMV) of radish. *Mirabilis jalapa* Leaf extract was found effective in controlling the Cucumber mosaic virus of Brinjal [43].

Hamidson *et al.* [44] studied the efficacy of *Datura stramonium* and *Annona muricata* extracts against cucumber mosaic virus in chili and found them effective in overcoming disease severity.

In another study, the antiviral potential of *Clerodendrum aculeatum* extracts was reported against the Soybean mosaic virus in *Glycine max* by Verma *et al.* [45].

Additionally, plant-derived biocides have demonstrated significant antiviral properties. Helal [46] investigated the efficacy of biocides derived from essential oils of various plants for controlling Tobacco necrosis virus (TNV) and Cucumber mosaic virus (CMV), showcasing substantial growth inhibition and defense enhancement against viral infections. Furthermore, essential oils obtained from tea trees, ginger, lemon, and many other plants have demonstrated significant inhibition (50%) of TMV [47]. Similarly in another study, a novel acetone extract from cottonseed oil sludge demonstrated potent antiviral activity against plant viruses such as Tobacco mosaic virus (TMV), Rice stripe virus (RSV), and Southern rice black-streaked dwarf virus (SRBSDV). It outperformed the commercial agent Ningnanmycin in field trials, showing broad-spectrum antiviral activity without phytotoxic effects, suggesting potential for environment-friendly plant virus control [48].

Not only higher Angiosperms but lower plants such as Bryophytes extracts have also been found to contain proteins that have the potential to inactivate TMV, suggesting a broad spectrum of antiviral mechanisms across plant species [49].

Advanced approaches

Significant advancements have been made in the current decade inducing resistance against viruses in plants, particularly DNA viruses, through the application of CRISPR/Cas technology [50]. This revolutionary approach involves the manipulation of either the viral genome itself or the host genes, ultimately rendering plants resistant to the target virus.

In crop plants, utilization of genetic level resistance has become a potent and favoured approach for controlling virus diseases. A wide array of resistance genes has been deployed for this purpose. Additionally, many technologies based on RNA like double-stranded RNA (dsRNA) and small interfering (siRNA) based RNA interference, microRNA, and CRISPR/Cas9 have recently emerged, offering both transgenic and non-transgenic routes for creating virus-resistant crop plants [51].

Conclusion and the way forward

In conclusion, plant viruses present notable challenges to worldwide agriculture, resulting in considerable economic

damage and impeding efforts toward ensuring food security. With approximately half of emerging and re-emerging plant disease epidemics attributed to viruses and around 30% of crop diseases caused by them, effective management strategies are imperative. Despite the challenges posed by the complex transmission mechanisms and infection processes of plant viruses, advancements in antiviral research offer promising solutions.

Various microbial agents, including fungi, bacteria, and their derived compounds, have demonstrated remarkable antiviral properties, either directly inhibiting viral activity or inducing systemic resistance in plants. Additionally, botanical extracts have shown efficacy in controlling a wide range of plant viruses, highlighting the potential of natural biocontrol agents in sustainable agriculture.

Furthermore, advanced approaches such as CRISPR/Cas technology and genetic resistance offer innovative avenues for developing virus-resistant crop plants, providing long-term solutions to virus-related agricultural challenges.

Moving forward, collaborative efforts among researchers, policymakers, and agricultural stakeholders are essential to further explore and implement these strategies. Integrating traditional knowledge with modern technologies and promoting environmentally friendly practices will be crucial in mitigating the impact of plant viruses and ensuring global food security. Additionally, continued research into novel antiviral agents and innovative approaches will be necessary to stay ahead of evolving virus strains and emerging plant disease threats. By embracing these interdisciplinary approaches, we can pave the way for a resilient and sustainable agricultural future.

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