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Citrus Tristeza Virus in Pakistan: Unraveling its Emergence, Evolution, and Impact on the Citrus Industry

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Abstract

Due to their extensive cultivation, citrus fruits are among the most widely grown fruits in the world. CTV, a virus that infects and damages citrus plants, is one of the biggest economic and viral pathogen threats to the citrus industry. Aphid circulation and the use of infected bud wood are the primary causes of its spread. The pathogen's high genetic diversity causes a variety of infection-related symptoms. One of these symptoms is a slow and fast decline in the health of the plant. Other symptoms include seedling yellowing, vein clearing, stem pitting, and stunted growth. Many strategies have been developed and put into practice to mitigate the financial effects of CTV. There are a number of effective strategies to prevent the spread of this illness. These consist of quarantine protocols, budwood certification processes, eradication campaigns, and the application of mild strain cross-protection techniques. By implementing such strategies, the risk of disease transmission can be significantly reduced, protecting the health of individuals and the community. Advances in molecular biology and genetic engineering have produced novel strategies that have the potential to transform numerous scientific fields and real-world applications. The creation of transgenic plants has made it feasible to include features that provide disease resistance.

Keywords: Citrus tristeza virus, Citrus, Aphid transmission, Stem pitting, Cross-protection, Transgenic plants, Disease resistance.

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1 Introduction

One of the most popular fruit varieties, citrus, is widely grown both in Pakistan and around the world. This crop is grown across 199,000 hectares in Pakistan, contributing significantly to the nation's total fruit production. According to (Atta et al., 2017), About 40% of Pakistan's total fruit production comes from CTV. The most harmful disease in the citrus industry is generally agreed to be CTV, a serious pathogen that impacts citrus plants. (Folimonova, 2020). The viral entity is categorized under the genus Closterovirus, which is a member of the taxonomic family Closteroviridae. Worldwide, citrus trees have been extensively destroyed as a result of the phenomenon under discussion, as substantiated by the research of Liu et al. (2021). Aphids and infected bud wood are the main causes of the disease's spread. Two particular vectors *Toxoptera citricida*, also called brown citrus aphids, and *Aphis gossypii*, also called cotton aphids help spread the disease (Mubeen et al., 2015a). Because it can cause severe symptoms, CTV is a serious threat to many citrus species, cultivars, and hybrids. Numerous citrus plants are afflicted by this virus, rendering them vulnerable to its harmful consequences (Mubeen et al., 2024a, Mubeen et al., 2024b). Infection can also occur in a variety of sweet orange and citrus cultivars that have been grafted onto rootstock that originated from sour oranges and additionally, susceptible are grapefruit, lemon, and lime.

1.1. Significance of CTV in the Citrus Industry

The word "tristeza" is important in the Spanish language, meaning "sadness" or "melancholy" and in expressing linguistic concepts, it has had deep ramifications in many countries and caused huge losses. Moreover, it is important to mention the word "tristeza" is linked to many signs of diseases. According to (Afechtal, 2013) CTV has surpassed previously acknowledged viruses and virus-like diseases as a key harmful viral pathogen in the citrus industry (Mubeen et al., 2015b). The rapid decline of CTV has had a considerable global impact on the global tree population, resulting in a loss of more than 100 million trees. This includes regions such as California, Spain, Brazil, Argentina, and other areas around the world (Benítez-Galeano et al., 2017). Two distinct types of CTV infections primarily impact citrus production. The first type is characterized by a Quick decline and death of phloem cells, which are located under the bud union of trees grafted onto different rootstocks of citrus cultivars. Significant stem pitting symptoms and subsequent decline of the trees have been documented in numerous cultivars, irrespective of the rootstock used. This decline reduces the annual production and damages the quality of the fruit (Shalabi, 2017). The initial occurrences of citrus epidemics caused by CTV were documented during the early 20th century in South Africa, then in Brazil, and Argentina in the 1930s (Contreras-Maya et al., 2022). According to (Kumi et al., 2016) The decline induced by CTV resulted in the loss of almost 100 million trees in Argentina, Brazil, and the USA. According to (Moreno et al., 2022). The initial occurrence of CTV disease in Spain was documented in 1975. This outbreak resulted in a significant reduction of around 40 million sweet orange (*C. sinensis*) and mandarin (*C. reticulate*) that had been grafted onto the rootstock of sour orange.

1.2. Symptoms and Effects of CTV Infection

The symptoms displayed by Citrus Tristeza Virus are based upon the particular union of rootstock and scion, and viral strain. The CTV symptoms in the form of slow and quick decline, seedling yellowing, vein clearing, stunting, stem pitting, and stunting exemplify the range of genetic and biological variance (Shafique et al., 2024a). However, the extent of the symptoms experienced will vary according to the time of infection, surrounding environmental conditions, cultivar, and specific viral isolates. The decline of trees is another prominent sign of Tristeza disease. Weakness and yellowing of leaves and defoliation are the dieback symptoms visible on the diseased portions of the trees. Depending on the specific strain of the virus involved, the decline could occur slowly or be accelerated (Shafique et al., 2024b). If the decline is slow, the process can continue for months to years after the first symptoms are noted. In addition, an observable outgrowth is present on the infected tree just above the graft union. An observable outgrowth is also evident on the infected tree just above the grafting point. This reduction is also characterized by a decline in production. With a quick decline, the tree that is infected usually dies within a few months after the symptoms appear (Dandlen et al., 2023). The rapid decline of a tree may be the result of girdling the rootstock, which eliminates starch reserves and leads to the tree's starvation and eventual death. Stem pitting is a common symptom of Citrus Tristeza Virus (CTV) in different hosts, including citrus trees grafted to sour orange rootstock. Pitting occurs in the stems and trunk of the infected trees and results in loss of tree vigor and lower yield of the fruits. Stem pitting is largely caused by highly pathogenic strains of CTV. The Tristeza virus strain and specific citrus species will determine the level of symptom severity (Iftikhar et al., 2021). The presence of stem pitting isolates is associated with undersized fruit and reduced citrus production. Viral infections can manifest in different forms such as Stem Pitting, Slow and Quick Decline, leaf corking, Stunning, and vein clearing. Additionally, symptom development can also be caused by the rootstock and scion combination (Lbida et al., 2005).

2. Management Strategies for CTV

CTV causes considerable economic losses. Since the losses attributable to CTV are quite substantial, several control strategies have been developed to alleviate these losses. CTV causes considerable economic losses. Different strategies have been developed for controlling losses associated with CTV (Fareed et al., 2026; Farooq et al., 2025). Depending on the presence or absence of CTV, different techniques can be employed in different citrus-growing regions (Ghosh et al., 2022). The utilization of different methods for implementing eradication programs and quarantine measures to prevent the spread of the virus, the use of certification protocols for bud wood to prevent the entry of CTV, the application of MSCP practices, the use of CTV-tolerant rootstocks, participation in breeding programs to develop CTV tolerance, the use of modern Biotechnological methods, as well as genetic engineering (see Figure 1) can be classified into distinct strategies (Sharma, 2023).

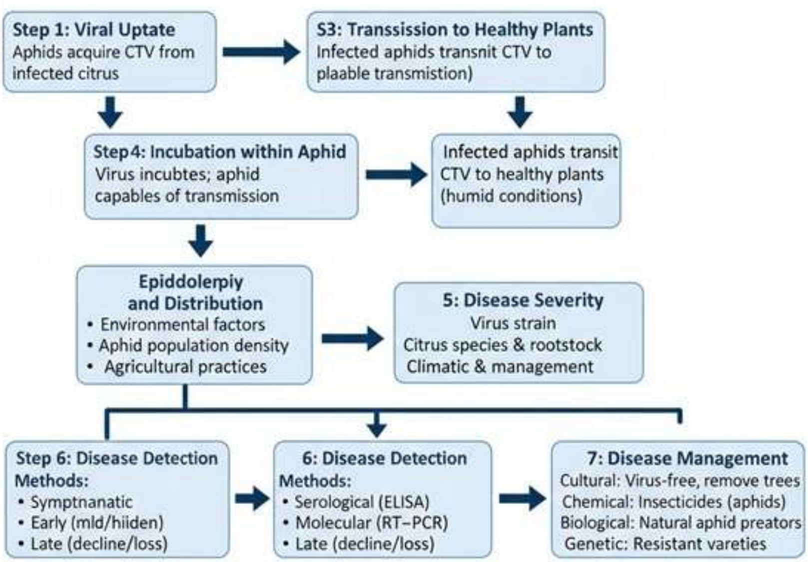

Figure 1: Citrus Tristeza Virus (CTV) infection managements strategies

2.1. Cross Protection and Disease Management

Cross-protection is when a plant, having been infected beforehand with a less aggressive variant of a given virus, exhibits some form of resistance to further attacks of more aggressive forms of the same virus. (Syller & Grupa, 2016). Assessing the presence of mild strains of the CTV isolates requires preliminary testing across different temperature regimes and varied field site conditions. The well-established MSCP technique has been adopted as a management strategy in several countries, including Brazil, South Africa, India, Japan, and Australia (Chen et al., 2023). Given the difficulties the stem-pitting strain of CTV presents, the technique's application is integral to the sustainability of grapefruit production in South Africa (Cook et al., 2020). Analysis of cross-protection and its empirical findings in Florida indicate that, in cross-protection's efficacy, it only assists in a reduction of the impact of stem pitting disease (Iftikhar et al., 2024).

3. Current Status of CTV in Pakistan

The chronological progression of research conducted to assess the prevalence and distribution of Citrus Tristeza Virus (CTV) across various citrus-growing regions of Pakistan (Table 1). Catara et al. (1991) confirms CTV, ELISA and electron microscopy were used to diagnose the virus on several varieties of sweet oranges in Punjab, with Mosambi being found to be the most vulnerable. Anwar and Mirza (1992) afterwards, in a survey of every citrus district revealed that Sahiwal was the most impacted. Significant infection rates were recorded in Punjab and Northwest Pakistan in the 2000s, especially according to of Arif et al. (2005, 2015). This indicated a slow yet sustained rise in the prevalence of CTV. Following the work of Naseem et al. (2016) and Liu et al. (2016), and other spatial and molecular studies, much has been learned about the geographic and molecular distribution of the virus. Khan and others, in their 2022 study revealed that Sargodha district had the highest infection rates, especially for the early varieties of Mosambi and Feutral, highlighting the devastating threat that CTV poses to Pakistan's citrus sector. The cumulative work shows that CTV is becoming more widely distributed, with the provinces of Punjab and Khyber Pakhtunkhwa having the highest concentration. This underscores the necessity of focused, integrated management strategies in these regions.

Table 1. Chronological progression to assess the prevalence and distribution of CTV in citrus-growing regions of Pakistan.

Year / Period	Region / Districts Covered	Detection Method(s)	CTV Incidence / Findings	Reference
1991	Punjab	ELISA, Electron Microscopy	Mosambi showed the highest receptivity (7/35 cases). Greening organism observed in phloem; *Diaphorina citri* prevalent.	Catara et al. (1991)
1992	Sahiwal, Sargodha, Faisalabad, Lahore, Sheikhupura	ELISA	Highest infection in Sahiwal (18.8%), Sargodha (13.2%), Faisalabad (13.13%), none in Lahore.	Anwar & Mirza (1992)
2005–2007	Punjab, Bhalwal, Mardan (NWFP)	ELISA, Mechanical Inoculation, Grafting	Punjab (48.6%), Bhalwal (44.6%), Mardan (37.39%), NWFP (40.86%).	Arif et al. (2005)
2002–2010	Northwest Pakistan (Haripur, Swat, others)	ELISA	Gradual increase from 24% (2004) → 39% (2010). Haripur (27.5%), Swat (+26%). Avg. 43% (sour orange), 37% (rough lemon).	Arif et al. (2015)
1992–2013	Punjab & Khyber Pakhtunkhwa	GIS Mapping, ELISA	CTV widespread. Sargodha highest (67%), and Mardan lowest (39%). Correlated with temperature and rainfall.	Naseem et al. (2016)
2009–2011	Punjab (Sweet orange orchards)	ELISA	Infection rate increased to ~50%.	Iftikhar et al. (2009)
2012	—	RT-PCR	Molecular confirmation of CTV presence in Pakistan.	Liu et al. (2016)
2022	Sargodha district (Kot Momin, Bhalwal, Sargodha)	ELISA	Mosambi (90%), Feutral's early (74%), Kinnow (57%). Severity highest in Kot Momin (62%).	Khan et al. (2022)

4. Conclusion and Future Prospectus

Although 80 years have gone by since the first CTV infection, the Tristeza epidemic is still on the rise, including places such as Pakistan. The likely impact of the current decrease in tristeza is the probability of increased future loss, which is a serious risk for the citrus sector in a number of countries. The spread of Tristeza-induced diseases has led to the situation where sweet orange cultivars have vanished. Tristeza-induced diseases are proliferating at an alarming rate and could endanger the citrus industry in Pakistan and in its neighboring countries. There are several approaches dealing with the situation Reviving citrus production is possible. Among these strategies are the replacement of old trees with new tristeza rootstock trees, trees with tristeza resistant genes, trees using cross-protection, and the determination of pathogenicity of different disease syndromes. The scientific and professional approach in nurseries would improve the production of Citrus. The resolution of the issue arising from the CTV necessitates the establishment of accredited citrus nurseries. There is a need to enhance the comprehension of the interplay between vectors, host plants, and CTV isolates, as this information remains significantly limited in Pakistan. Using certified Budwood programs with the Mild Strain Cross Protection techniques is undoubtedly an effective control measure to manage CTV.

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