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Current Status of Tomato Chlorosis Virus and Whiteflies in Potato Crops of São Paulo State and Virus–Vector–Host Interactions

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ABSTRACT

Potato is a vital food source worldwide, but its production is frequently threatened by viral diseases. Tomato chlorosis virus (ToCV) primarily affects solanaceous crops, especially tomatoes. Although ToCV has been reported in potatoes, its relevance in this crop remains understudied in Brazil. This study evaluated the incidence of ToCV in major potato-producing regions of São Paulo state and identified the predominant whitefly species. Transmission efficiency of ToCV by *Bemisia tabaci* MEAM1 and MED, vertical transmission via tubers, and the latent and incubation periods in potato plants were also investigated. Field surveys (2022–2024) showed a low ToCV incidence in potato crops. MEAM1 was the predominant whitefly species, whereas MED was detected at a single location. MED transmitted ToCV to potato plants of cv. Agata with higher efficiency (36.6%) than MEAM1 (10%), but no significant difference was observed for plants of cv. Asterix. Vertical transmission rates via tubers were high, reaching 76.7% for cv. Agata and 88.1% for cv. Asterix. The mean latent period was 8 days, with symptom expression approximately 35 days post-inoculation. These findings suggest that ToCV is currently not widely distributed in potato crops in São Paulo state. However, the high vertical transmission rates and the demonstrated transmissibility by both MEAM1 and MED highlight the potential risks for future spread. Continued monitoring of potato fields and whitefly populations is crucial to mitigate the potential risk posed by ToCV in the region.

Gabriel Madoglio Favara and Caroline da Cruz Martines contributed equally to this work.

1 | Introduction

The potato (*Solanum tuberosum*) is among the most important crops within the family Solanaceae, alongside tomato (*Solanum lycopersicum*) and sweet pepper (*Capsicum annuum*). Its prominence is primarily due to its global significance in human nutrition, ranking as the third most consumed vegetable after rice (*Oryza* spp.) and wheat (*Triticum* spp.) (Devaux et al. 2014).

In 2023, Brazil produced 4.2 million tonnes of potatoes over 123 thousand hectares, with an average yield of 33.9 t/ha (Instituto Brasileiro de Geografia e Estatística [IBGE] 2025). Approximately 85% of Brazil's production is concentrated in the south and southeast regions, with Minas Gerais, Paraná and São Paulo being the leading producing states (IBGE 2025).

Potato crops are susceptible to various pathogens, including fungi, bacteria and viruses (Kreuze et al. 2020). Globally, over 50 viruses have been reported infecting potatoes, with potato virus Y (PVY) and potato leafroll virus (PLRV) being the most significant, causing substantial losses, especially in mixed infections with other viruses (Kreuze et al. 2020).

In Brazil, PLRV was the predominant virus in potato crops until the mid-1990s, when the introduction of $PVY^{N\text{-}Wi}$ and PVY^{NTN} strains via infected seed potatoes established this potyvirus as the primary virus threat (Kreuze et al. 2020). In 2011, the tomato chlorosis virus (ToCV) was first identified in potato crops in Brazil, in a commercial field in the state of Goiás (Freitas et al. 2012).

ToCV belongs to the family *Closteroviridae*, genus *Crinivirus*, and species *Crinivirus tomatichlorosis* (International Committee on Taxonomy of Viruses [ICTV] 2025). Its particles are elongated and flexuous, measuring 800–850 nm in length, with a genome consisting of two single-stranded, positive-sense RNA molecules (Fiallo-Olivé and Navas-Castillo 2023). ToCV is transmitted in a semipersistent manner by the cryptic species *Bemisia tabaci* Middle East–Asia Minor 1 (MEAM1) and Mediterranean (MED), as well as *Trialeurodes abutiloneus* and *T. vaporariorum* (Bello et al. 2019; Wintermantel and Wisler 2006).

Insect vectors play a fundamental role in the epidemiology of viral plant diseases. Currently, *B. tabaci* MEAM1 is the predominant whitefly species in Brazil (Fernandes et al. 2022). However, the introduction of *B. tabaci* MED has raised concerns about a potential shift in this scenario, with significant epidemiological implications. For example, in protected tomato crops in the state of São Paulo, ToCV incidences ranging from 26% to 86% were associated with *B. tabaci* MED (Nogueira et al. 2024). The predominance of *B. tabaci* MED has also been reported in some open-field tomato-growing regions (Lima Alvarez et al. 2024). However, there is currently no available information on the main whitefly species associated with potato crops or the incidence of ToCV in São Paulo's major potato production areas.

In addition to whitefly transmission, ToCV can be transmitted through infected tubers, as potatoes are vegetatively propagated. Vertical transmission via propagative material has significant epidemiological importance, allowing the pathogen to persist and spread within crops, affecting plant health from the start of the growth cycle and complicating effective management (Fortes and Navas-Castillo 2012). Understanding the rate of vertical transmission of ToCV in potato cultivars grown in Brazil is relevant for comprehending its importance in the epidemiology of this crinivirus.

This study aimed to survey the incidence of ToCV in São Paulo's main potato-growing regions and identify the associated whitefly species. It also evaluated ToCV transmission efficiency by *B. tabaci* MEAM1 and MED, the detection rate of ToCV in tubers produced by infected plants, and the vertical transmission of the virus to the next generation of plants. Furthermore, the study assessed the latent and incubation periods of this crinivirus in infected potato plants. The findings contribute to a deeper understanding of ToCV epidemiology in potato crops and virus–vector–host interaction.

2 | Materials and Methods

2.1 | Plant Material, ToCV Isolate and *B. tabaci* MEAM1 and MED Colonies

Potato plants of the cultivars Agata and Asterix, two of the most widely grown cultivars in Brazil, were used in this study. Virus-free mini-tubers, kindly provided by Soleil Papa Tecnologia (Vargem Grande do Sul, Brazil), were used as the starting material. To stimulate sprouting, the mini-tubers were treated with gibberellic acid (10 mg L^{-1}), by immersing them for 10 min. After treatment, they were air-dried and stored in the dark until sprouting occurred. Subsequently, they were planted in pots filled with Carolina Soil substrate (peat, perlite, vermiculite, limestone, roasted rice hulls, organic residue and NPK). The plants were grown in a greenhouse inside insect-proof cages until they were used in the experiments.

Due to the biological diversity among ToCV isolates from different hosts (Vicentin et al. 2022), a ToCV isolate found naturally infecting potato plants was selected for this study (GenBank PQ815848). The isolate was maintained in potato plants of the Agata and Asterix cultivars and periodically renewed through transmission by *B. tabaci* MEAM1 or MED.

The *B. tabaci* MEAM1 colony was reared on collard plants (*Brassica oleracea*), whereas the *B. tabaci* MED colony was reared on cotton plants (*Gossypium hirsutum*). The identity of these cryptic species was confirmed every 6 months using molecular analyses. Total DNA was extracted from adult insects using the Chelex protocol (Walsh et al. 1991). PCR analysis was performed with the Bem23F and Bem23R primers, which amplify a 200-bp fragment for *B. tabaci* MEAM1 and a 400-bp fragment for *B. tabaci* MED (Kontsedalov et al. 2012).

2.2 | ToCV Detection by Reverse Transcription-PCR

Total RNA from each plant to be analysed was extracted from leaf tissues or tubers using the CTAB protocol (Doyle and Doyle 1987). The extracted total RNA was used to detect ToCV by reverse transcription (RT)-PCR, employing specific primers

to amplify an 834-bp fragment corresponding to the coding regions of part of the RNA-dependent RNA polymerase protein (RdRp), the entire p22 protein and part of the p6 protein of this crinivirus. The primers used were p22-7537-F and p22-8371-R (Bello, Watanabe, et al. 2020). RT-PCRs were performed using 2 μL of total RNA, 6.25 μL of GoTaq Green Master Mix (Promega), 3.75 μL of nuclease-free water, 0.2 μL of each primer at a concentration of 10 μM and 0.1 U of AMV reverse transcriptase (Promega). The RT-PCR amplification conditions were as follows: reverse transcription at 42°C for 50 min, followed by an initial denaturation step at 95°C for 2 min. This was followed by 35 cycles of denaturation at 95°C for 1 min, annealing at 54°C for 1 min, extension at 72°C for 1 min; and a final extension at 72°C for 10 min. The resulting RT-PCR product was analysed by 1% agarose gel electrophoresis; the amplified fragments were stained with ethidium bromide and visualised under UV light using a transilluminator.

2.3 | Assessment of ToCV Incidence in Potato Fields in São Paulo State

Leaf samples from potato plants were collected during 2022, 2023 and 2024, from some of the main potato-producing regions in the state of São Paulo. In 2022, ToCV incidence was evaluated in 11 potato fields located in the cities of Avaré, Espírito Santo do Pinhal, Itaberá, Itaí, Itaporanga, Paranapanema, Piraju and Vargem Grande do Sul. In 2023, assessments were conducted in six potato fields situated in Casa Branca, Itapetininga, Angatuba, Vargem Grande do Sul and Buri. In 2024, five fields were evaluated in Casa Branca, Paranapanema and Vargem Grande do Sul. For each field, symptomatic or asymptomatic leaves were randomly collected from 50 to 100 plants. They were placed in labelled plastic bags, transported to the laboratory under refrigerated conditions, and stored in a freezer at −80°C for subsequent total RNA extraction and RT-PCR analysis for ToCV detection.

2.4 | Identification of *B. tabaci* Cryptic Species in Potato Fields in São Paulo State

Adult whiteflies were collected from potato plant leaves in the same fields and during the same periods as the ToCV incidence assessments. Adults were collected using an entomological aspirator and immediately transferred to 1.5 mL microtubes containing ethanol. The samples, each consisting of a single whitefly adult, were transported to the laboratory and stored at −20°C until molecular identification of cryptic species was performed. Identification was conducted via PCR with the primers Bem23F and Bem23R, which enable distinction between *B. tabaci* MEAM1 and *B. tabaci* MED based on the size of the amplified DNA fragment (Kontsedalov et al. 2012).

2.5 | Analysis of ToCV Transmission Efficiency to Potato Plants by *B. tabaci* MEAM1 and MED

Adults of both *B. tabaci* cryptic species were separated and confined in cages (11 cm height × 9 cm diameter) containing potato leaves from the Agata or Asterix cultivars infected with ToCV. The insects were allowed a 24-h virus acquisition access period (AAP). Subsequently, the insects were transferred ($n = 10$) to other cages of the same size containing a healthy potato plant from the respective cultivars. The insects were provided a 24-h inoculation access period (IAP) to transmit the virus. After the IAP, all insects were removed using an entomological aspirator, and the plants were sprayed with the insecticide cyantraniliprole to eliminate any remaining insects. For each cryptic species, 10 potato plants from each cultivar were inoculated. ToCV transmission was confirmed 30 days after inoculation by RT-PCR. The experiment was conducted three times.

2.6 | Evaluation of the Rate of ToCV Detection in Tubers and Vertical Transmission of the Virus to the Next Generation

To assess the detection rate of ToCV and its vertical transmission, tubers produced by plants of the Agata and Asterix cultivars infected with the virus were analysed. Half of the tubers produced by each plant were used to evaluate the ToCV detection rate. This involved extracting total RNA from the tubers, followed by RT-PCR analysis. The remaining half of the tubers were used for vertical transmission analysis. These tubers were planted in pots containing substrate, and 20 days after plant emergence, total RNA was extracted from the leaf tissue of the plants. RT-PCR was then performed to assess the presence of ToCV.

2.7 | Evaluation of the Latent and Incubation Periods of ToCV in Potato Plants

The latent and incubation periods of ToCV were evaluated following its transmission by *B. tabaci* MED to potato plants cv. Agata. Potato plants were inoculated with ToCV 14 days after emergence, using 30 viruliferous insects per plant during a 24-h IAP. The inoculated plants were subsequently used as virus sources for assays conducted at different time intervals. ToCV acquisition by *B. tabaci* MED adults was assessed at 4, 8, 12 and 16 days post-inoculation (dpi). At each interval, 50 virus-free adult *B. tabaci* MED were confined separately on infected potato plants for a 24 h AAP. Groups of 30 insects were then transferred separately to healthy potato plants for a 24-h IAP. The same infected plants were used as virus sources for all acquisition intervals. In each experiment, five potato plants were evaluated as virus sources. After inoculation, all potato plants were kept in cages in a greenhouse and sprayed with the insecticide cyantraniliprole to eliminate the insects. Virus transmission from source plants to healthy plants was confirmed 30 dpi by RT-PCR. The incubation period of ToCV in potato plants was evaluated based on symptom expression, with daily observations of the virus source plants. The experiment was conducted twice.

2.8 | Statistical Analysis

The chi-square (χ^2) test was used to analyse the efficiency of *B. tabaci* MEAM1 and MED in transmitting ToCV to potato plants, the rate of ToCV detection in tubers, and the vertical transmission of the virus to plants of the next generation. The analyses were performed using JASP software, v. 0.18.3. To compare the latent and incubation periods of ToCV, the potato plant status

was expressed using binary responses: $Y=1$ (acted as virus source) or $Y=0$ (did not act as virus source) for the latent period; and $Y=1$ (symptomatic) or $Y=0$ (asymptomatic) for the incubation period. Survival analysis was used to model the time until the event of interest. Kaplan–Meier plots were constructed, and the latent and incubation periods were compared using the log-rank test (Mantel–Cox). This analysis was performed with GraphPad Prism software, v. 8.0.2.

3 | Results

3.1 | ToCV Incidence and Identification of the Cryptic Species of *B. tabaci* in Potato Fields in São Paulo State

Leaf samples were collected from potato plants during 2022, 2023 and 2024 in the main potato-producing regions of São Paulo state. These samples were analysed to detect ToCV through molecular methods. The results showed a low incidence of ToCV in the evaluated potato fields (Table 1). In 2022, ToCV was identified only in a field in Avaré, with an incidence of 4%. In 2023, the virus was detected with an incidence of 18% in a field in Vargem Grande do Sul. In 2024, ToCV was again identified only in Vargem Grande do Sul, with an incidence of 4%. In all other fields during these years, no plants tested positive for this crinivirus (Table 1).

In addition to evaluating ToCV incidence, monitoring of the predominant cryptic species of *B. tabaci* was conducted in all visited fields. The presence of the cryptic species MED was confirmed in 2022, but only in a field in Itaporanga. Of the 10 adult insects evaluated in this field, molecular analyses identified two as *B. tabaci* MED and eight as *B. tabaci* MEAM1. In all other fields where whiteflies were collected in 2022, insects analysed were identified as *B. tabaci* MEAM1. In 2023, whiteflies were found only in two fields in Casa Branca, and all were identified as *B. tabaci* MEAM1. In 2024, no whiteflies were found in any of the evaluated fields (Table 1).

TABLE 1 | Occurrence of tomato chlorosis virus (ToCV) and the cryptic species *Bemisia tabaci* Middle East–Asia Minor 1 (MEAM1) and Mediterranean (MED) in potato fields in São Paulo State during 2022, 2023 and 2024.

Year	County	Coordinates	ToCV[a]	MEAM1[b]	MED[b]
2022	Avaré	22°57′29″ S 48°48′46″ W	4/100	100	0
	Espírito Santo do Pinhal	22°04′25″ S 46°48′58″ W	0/100	100	0
	Itaberá	23°43′49″ S 49°07′01″ W	0/100	100	0
	Itaí	23°28′20″ S 49°03′31″ W	0/100	100	0
	Itaporanga	23°36′03″ S 49°25′32″ W	0/100	80	20
	Paranapanema	23°28′17″ S 48°48′34″ W	0/100	100	0
	Paranapanema	23°34′17″ S 48°40′41″ W	0/100	100	0
	Paranapanema	23°26′08″ S 48°46′03″ W	0/100	100	0
	Piraju	23°08′14″ S 49°23′45″ W	0/100	100	0
	Vargem Grande do Sul	21°57′44″ S 46°58′17″ W	0/100	100	0
	Vargem Grande do Sul	21°49′54″ S 46°56′38″ W	0/100	100	0
2023	Buri	23°36′20″ S 48°39′56″ W	0/50	—	—
	Campina do Monte Alegre	23°31′00″ S 48°31′18″ W	0/50	—	—
	Casa Branca	21°44′14″ S 47°04′51″ W	0/50	100	0
	Casa Branca	21°43′40″ S 47°05′03″ W	0/50	100	0
	Casa Branca	21°44′56″ S 47°08′22″ W	0/50	—	—
	Itapetininga	23°31′58″ S 48°02′12″ W	0/50	—	—
	Vargem Grande do Sul	21°49′54″ S 46°56′38″ W	9/50	—	—
2024	Casa Branca	21°47′32″ S 46°58′12″ W	0/50	—	—
	Casa Branca	21°48′20″ S 46°59′41″ W	0/50	—	—
	Paranapanema	23°19′11″ S 48°46′50″ W	0/50	—	—
	Vargem Grande do Sul	21°49′49″ S 46°56′35″ W	0/50	—	—
	Vargem Grande do Sul	21°48′40″ S 46°59′54″ W	2/50	—	—

Note: —, No whiteflies were detected in the surveyed fields.
[a]Number of infected plants/number of plants tested.
[b]Percentage of whiteflies identified as MEAM1 and MED.

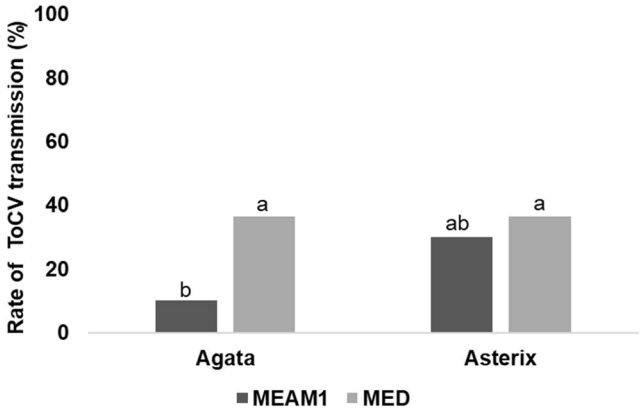

FIGURE 1 | Transmission efficiency of tomato chlorosis virus (ToCV) by *Bemisia tabaci* MEAM1 and MED to potato plants of the cultivars Agata and Asterix. Different lowercase letters indicate a significant difference according to the chi-square test.

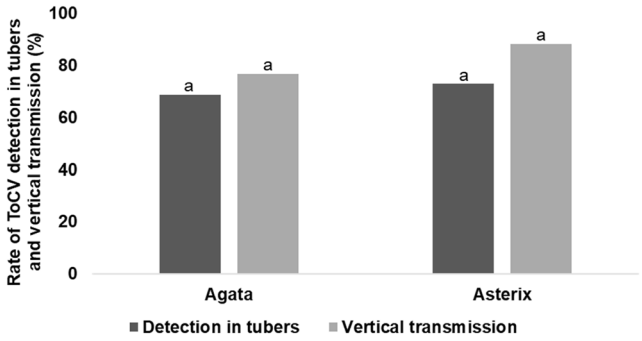

FIGURE 2 | Detection rate of tomato chlorosis virus (ToCV) in potato tubers and its vertical transmission to plants of the next generation in the cultivars Agata and Asterix. Lowercase letters indicate no significant differences between detection rates in different cultivars according to the chi-square test.

3.2 | Efficiency of ToCV Transmission to Potato Plants by *B. tabaci* MEAM1 and MED

The results of three independent experiments indicated significant differences in ToCV transmission rates to potato plants cv. Agata between MEAM1 and MED ($\chi^2 = 5.96$; $p = 0.015$; $\varphi = 0.315$). The transmission efficiency for MEAM1 was 10% (3/30), whereas that of MED was 36.6% (11/30) (Figure 1). In contrast, no significant difference was observed in the transmission efficiency of this crinivirus between MEAM1 and MED to potato plants cv. Asterix ($\chi^2 = 0.300$; $p = 0.584$; $\varphi = 0.071$). For this cultivar, the transmission efficiency for MEAM1 was 30% (9/30), while for MED it was 36.6% (11/30) (Figure 1).

Bemisia tabaci MEAM1 transmitted ToCV with similar efficiency (not significantly different) to potato plants of cvs. Agata (3/30) and Asterix (9/30) ($\chi^2 = 3.75$; $p = 0.053$; $\varphi = 0.250$). Similarly, *B. tabaci* MED transmitted the virus with equal efficiency to both Agata (11/30) and Asterix (11/30) plants ($\chi^2 = 0$; $p = 1$; $\varphi = 0$) (Figure 1).

3.3 | Rate of ToCV Detection in Tubers and Vertical Transmission of the Virus to the Next Generation

In this experiment, tubers produced by 15 ToCV-infected potato plants of cv. Agata and 14 ToCV-infected potato plants of cv. Asterix were tested. No significant differences were found in ToCV detection rates between tubers of the Agata and Asterix cultivars ($\chi^2 = 0.229$; $p = 0.632$; $\varphi = 0.045$). Similarly, there was no significant difference in the vertical virus transmission to plants of the next generation between the two cultivars ($\chi^2 = 2.129$; $p = 0.145$; $\varphi = 0.144$) (Figure 2).

The 15 Agata plants produced 124 tubers. Total RNA was extracted from 64 tubers, and ToCV was detected in 44 of them (68.8%) via RT-PCR. The remaining 60 tubers were planted to evaluate the vertical transmission rate of the crinivirus to the next generation. ToCV was detected in 76.7% of the evaluated plants (46/60) (Figure 2). For the Asterix cv., the 14 plants produced 90 tubers. ToCV was detected in 35 out of the 48 tubers analysed (72.9%) by RT-PCR. The vertical transmission rate of the virus to the next generation was 88.1% (37/42) (Figure 2).

3.4 | Latent and Incubation Periods of ToCV in Potato Plants

A significant difference was observed between the latent and incubation periods of ToCV in potato plants ($p = 0.0001$). All potato plants tested as sources became infected with ToCV. The latent period varied, with some plants becoming sources of inoculum as early as 4 dpi, while others required up to 12 days (Figure 3). Symptom onset was observed between 33 and 38 dpi. Initially, symptoms appeared as mild chlorosis on the older leaves, which progressively intensified. In some cases, purplish spots also developed on the leaves (Figure 4).

4 | Discussion

The first report of ToCV in Brazil occurred in 2006, in tomato plants in São Paulo state (Barbosa et al. 2008). Since then, ToCV has spread across the country and has become the predominant virus in tomato crops (Esquivel-Fariña et al. 2021; Nogueira et al. 2024). It has also been identified naturally infecting other economically and socially important plants in Brazil, including sweet pepper (Barbosa et al. 2011), potato (Freitas et al. 2012), eggplant and scarlet eggplant (Fonseca et al. 2016), teak (Borges et al. 2019) and cucumber (Bello, Gorayeb, et al. 2020; Bello, Watanabe, et al. 2020).

The first identification of ToCV in potatoes in Brazil occurred in 2011, when plants of the cv. Agata exhibiting leaf curling and interveinal chlorosis, especially in older leaves, were found in a field in Goiás state (Freitas et al. 2012). Surveys between 2013 and 2017 recorded ToCV incidence of 39% (16/41) in Minas Gerais, 0% (0/1) in Paraná, and 33% (1/3) in São Paulo (Mituti et al. 2018). Another survey from 2015 to 2018 in Paraná state found no ToCV in the 243 plants analysed (Keller et al. 2023). These results align with the present study, where ToCV was identified in only three potato fields in the major production regions of São Paulo state between 2022 and 2024, with incidence ranging from 4% to 18%.

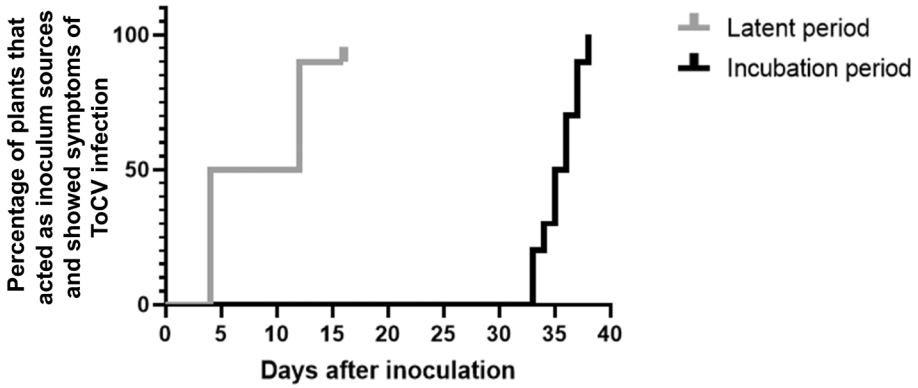

FIGURE 3 | Cumulative risk curves (derived from the inverse transformation of the Kaplan–Meier estimate) showing the time after transmission when infected potato plants became a source of inoculum of tomato chlorosis virus (ToCV) (latent period) or when inoculated plants began to exhibit symptoms (incubation period). The whitefly *Bemisia tabaci* MED was used as the transmission vector.

FIGURE 4 | Symptoms induced by tomato chlorosis virus (ToCV) in potato plants. (a) The first symptoms are characterised by chlorosis on older leaves. (b) As the disease progresses, chlorosis intensifies and spreads towards younger leaves. (c) In advanced stages, chlorosis affects nearly the entire plant, and purplish spots appear on some leaves. [Colour figure can be viewed at wileyonlinelibrary.com]

Insects play a crucial role in plant virus transmission. The presence of efficient vector species in a region often determines the outbreak of viral epidemics (Nogueira et al. 2024). Since its introduction in Brazil in the early 1990s, *B. tabaci* MEAM1 has been the predominant whitefly species (Fernandes et al. 2022). Following the arrival of *B. tabaci* MED in 2013, this species has expanded throughout Brazil, infesting ornamental plants in floriculture (Da Silva Rodrigues et al. 2021; Moraes et al. 2017) and sweet pepper and cucumber greenhouse crops (Bello, Gorayeb, et al. 2020; Bello, Watanabe, et al. 2020). Recently, an increase in *B. tabaci* MED populations was observed in soybean fields in São Paulo state (Barreto da Silva et al. 2024). Additionally, in some tomato cultivation, both in open fields and greenhouses, *B. tabaci* MED has emerged as the predominant whitefly species (Lima Alvarez et al. 2024; Nogueira et al. 2024).

The present study found that *B. tabaci* MEAM1 was the predominant species in most potato fields, with *B. tabaci* MED identified in only one field. Whitefly populations were generally low across all evaluated areas, probably contributing to the low ToCV incidence. Additional factors, such as the absence of nearby virus inoculum sources, may also have influenced this outcome.

According to Rocha et al. (2012), high infestations of whiteflies in potato crops in Brazil were uncommon, although population outbreaks began to occur from 2001 onwards. Freitas et al. (2012) reported that the first identification of ToCV in

potato plants in Brazil occurred in a field severely infested with *B. tabaci* MEAM1. Studies evaluating the resistance of potato genotypes and clones to *B. tabaci* MEAM1 have shown that most of them are suitable hosts for this pest (Rocha et al. 2012). Although potatoes are effective hosts for *B. tabaci* MEAM1, other viruses transmitted by this vector that have already been identified naturally infecting this host, such as the begomoviruses tomato severe rugose virus (ToSRV) and tomato yellow vein streak virus (ToYVSV), are not widely disseminated in the main potato-producing regions of the country and generally occur at low incidences (Inoue-Nagata et al. 2016). A similar scenario has been observed for ToCV in Brazil to date. Further studies with *B. tabaci* MED are needed to understand its behaviour concerning the main potato cultivars grown in Brazil.

In the present study, after a 24-h AAP and IAP, adults of *B. tabaci* MED transmitted ToCV to potato plants cv. Agata more efficiently (36.6%) than *B. tabaci* MEAM1 (10%). For plants of the Asterix cv., the efficiency of ToCV transmission by *B. tabaci* MEAM1 and MED was similar, with values of 30% and 36.6%, respectively. In Spain, a study reported that the ToCV transmission efficiency from tomato plants to potato using 40 adults of *B. tabaci* MED ranged from 25% to 95%, while transmission from potato to tomato was 40% (Fortes and Navas-Castillo 2012). In Brazil, a study using approximately 20 adults of *B. tabaci* MEAM1 per plant found a ToCV transmission efficiency of 50% from tomato to potato and 46.6% from infected potato plants to healthy ones (Mituti et al. 2018). Pinto et al. (2021) demonstrated that under high inoculum pressure, *B. tabaci* MEAM1 transmitted ToCV to 21 potato genotypes, including the main cultivars planted in Brazil, with efficiency ranging from 50% to 100%. Together, these data indicate that both cryptic species can contribute to the spread of ToCV in potato crops.

The transmission of viruses through vegetative propagation material is a critical concern in potato cultivation, where plant multiplication relies on seed tubers. This practice facilitates the perpetuation of viruses, reducing plant vigour and increasing production losses throughout successive growing cycles (Mondal et al. 2023). This study revealed a high detection rate of ToCV in tubers and its significant vertical transmission to plants in the subsequent generation for two of the main potato cultivars grown in Brazil. The vertical transmission rate was 88.1% for plants of the cv. Asterix and 76.7% for plants of the cv. Agata.

The latent and incubation periods of viruses in plants are fundamental to understanding the epidemiology of viral diseases. The latent period refers to the interval between inoculation and the point when the virus becomes transmissible to other plants by the vectors, while the incubation period refers to the time between virus inoculation in the plant and the appearance of the first symptoms (Favara et al. 2019). The present study found that, on average, ToCV-infected potato plants become inoculum sources 8 dpi, with symptoms appearing approximately 35 dpi. These findings are consistent with those reported for ToCV in tomato plants, where the average latent period was 13 days and the incubation period was 30 days (Favara et al. 2019). The results suggest that infected potato plants can serve as ToCV inoculum sources before symptoms appear, which may hinder early detection and effective disease management.

In conclusion, the results of this study suggest that ToCV is not widely distributed in potato crops in the state of São Paulo. Although low whitefly populations were observed in the evaluated fields, *B. tabaci* MEAM1 was the predominant species associated with the crop. Transmission assays demonstrated that both *B. tabaci* MEAM1 and MED can transmit ToCV to potato plants, indicating that both species can contribute to the spread of the virus in the field. Furthermore, the high rate of vertical transmission of ToCV to the next generation of plants is a significant finding and warrants attention. This transmission mode could potentially increase ToCV incidence in potato crops. Continued monitoring of potato production areas for whitefly populations and ToCV incidence is therefore essential to assess and mitigate the potential future impact of this virus.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon request.

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