Tropical Plant Pathology (2021) 46:1–12
https://doi.org/10.1007/s40858-020-00377-2

REVIEW

An overview of citrus canker in Brazil

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Received: 5 April 2020 / Accepted: 26 May 2020 / Published online: 24 June 2020

Abstract
Citrus growers in several states of Brazil, but mainly in São Paulo (SP), have battled during 60 years against citrus canker (*Xanthomonas citri* subsp. *citri*) using exclusion and eradication methods. Since its first detection in 1957, the eradication program has undergone many modifications and efforts were made to suppress rather than eradicate the disease. When the eradication protocols became less strict during the late 2000s and early 2010s, the number of canker-affected citrus orchards in SP, the largest orange-producing area in the world, started to set consecutive records annually. In addition, research data and experiences in the citrus-producing regions, where the disease has been managed successfully, encouraged the adoption of a similar strategy in Brazil. Given the expansion of the disease in the country and its non-homogeneous distribution across the states, a new federal legislation came into effect in 2017. Since then, each state can define a status regarding the presence and control of citrus canker: (i) area with no occurrence, (ii) pest-free area, (iii) area under eradication, and (iv) area under risk mitigation. The establishment of an official status is not mandatory for the state, but those with an undefined status are not allowed to market fruit to other states and countries. For the first time, the disease can be managed without the need to eradicate the citrus trees in canker-affected areas even at high incidence, given that no serious losses due to citrus canker are expected if the recommended control measures are properly followed. An historical overview of the eradication program, the current legislation, and the status of citrus canker for all states in Brazil are reviewed.

Keywords Control · Eradication · Mitigation · Status · *Xanthomonas citri* subsp. *citri*

History of the eradication program in São Paulo state

Citrus canker (*Xanthomonas citri* subsp. *citri*), also known as Asiatic citrus canker, was detected for the first time in Brazil in Presidente Prudente, a municipality of São Paulo state (SP), in March 1957. It was hypothesized that the pathogen was introduced into the country *via* contaminated citrus propagating material originated from Japan (Bitancourt 1957). The disease was initially observed in leaves of key lime (*Citrus aurantifolia*), further confirmed by researchers of the Biological Institute of the state (Santos 1991). Citrus canker, which originated in Southeast Asia, is one of the most important diseases affecting citrus. It reduces both the productivity of citrus trees due to premature drop of affected fruit and the marketability of fresh fruit. In addition to causing depreciation in the appearance of the fruit, citrus canker restricts the commercialization of the production to other regions, due to the risk of spreading the pathogen, especially to canker-free citrus-growing regions (Gottwald et al. 2002; Behlau and Belasque 2014).

Immediately after citrus canker was confirmed in SP, eradication efforts were undertaken to prevent the spread of the disease (Amaral 1957). Initially, the citrus canker eradication program (CCEP) was based on the success of a similar program previously adopted in the USA (Dopson 1964). During six decades, the protocol of the CCEP in SP suffered many modifications (Santos 1991; Behlau et al. 2016). Since the beginning, the program was either coordinated or oversighted by the State Secretary of Agriculture (SSA) of SP (Behlau and Belasque 2014; Behlau et al. 2016).

In the first years, a period known as "emergency" phase (Table 1), the eradication protocol was based on the removal of diseased trees and non-symptomatic trees within a radius of 12 m from each focus followed by inspections every 90 days in orchards where the disease was found as well as in neighboring properties (Santos 1991). These measures alone were not sufficient to stop the spread of the disease; thus, in the

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Table 1 Main events and phases during the 60 years of the citrus canker eradication program (CCEP) in São Paulo (SP) state

Event/phase	Year	Main measures/changes
Emergency	1957	Removal of affected tress and those within a 12-m radius in 29 municipalities in northwest SP
Total eradication	1957	Removal of all citrus trees and interdiction for new citrus plantings in 29 municipalities in northwest SP
Expansion of the eradication campaign	1962	Removal of all citrus trees only in the affected properties. Removal of the citrus trees in neighboring farms located within a radius of 1000 m from the affected farm. Interdiction for new citrus plantings in the affected municipalities
Launch of the National Eradication Campaign (CANECC)	1975	Fund, coordinate, and standardize the citrus canker eradication efforts in all affected states of the country
Foundation of the Fund for the Protection of Citrus (Fundecitrus)	1977	Responsible for citrus defense in SP. The main objective was to finance and manage the CCEP in SP, as regulated by the CANECC
Stability	1983	Interdiction on the establishment of new citrus plantings started to be applied only to the affected properties and no longer to the entire municipality
	1987	The radius of eradication was reduced to 50 m
	1995	The radius of eradication was reduced to 30 m. Three methods of eradication were allowed to be used in the country: removal of the affected trees associated with (i) removal, (ii) drastic pruning, or (iii) defoliation of the other citrus trees contained within a radius of 30 m from the focus tree. SP adopted option (i)
	1997	Drastic pruning of the affected trees associated with copper sprays on the surrounding trees within a 30-m radius was added as a fourth option for eradication. SP continued adopting option (i)
The 0.5% law	1999	Removal of the entire block when the incidence of trees with citrus canker exceeded 0.5%. Removal of affected trees within a 30-m radius when the incidence of diseased trees was 0.5% or lower
The beginning of the end	2009	Removal of only the symptomatic trees and those within a radius of 30 m, regardless of the incidence of symptomatic trees in the block
End of the agreement between SSA and Fundecitrus	2010	Inspections of orchards and removal of affected trees became a responsibility of the growers with the supervision of the State Secretary of Agriculture (SSA)
The last act	2013	Removal of the symptomatic trees only. Spray of copper bactericides within a 30-m radius. Inspection of orchards by the growers every 3 months and submission of semiannual reports to the SSA

same year, citrus canker was found in several municipalities in the northwestern region of SP, known as Alta Sorocabana, where it was first found. Hence, other measures were incorporated to the newly created CCEP in 29 municipalities located in the affected area or nearby, known as "contaminated region." The most impacting actions were the destruction of all citrus orchards and citrus nursery trees, the prohibition of new citrus plantings, the closure of all citrus nurseries, the imposition of barriers to the trade of citrus fruit and nurseries trees originating from this area, and the launch of a statewide warning campaign to growers about the risks of contamination by citrus canker (Amaral 1957; Santos 1991).

Five months after the beginning of the eradication campaign, in November 1957, citrus canker had not stopped spreading throughout the restricted region. In response, the CCEP protocol was tightened up and the "total eradication" plan was implemented in the affected region (Santos 1991) (Table 1). This phase was characterized by the adoption of even more drastic measures associated with the deployment of a larger number of inspectors and additional financial

support aimed at removing all citrus trees in the restricted region regardless of the presence of the disease. The program also created a geographic isolation zone, with systematic inspections of the transit of plant materials on highways and railways. These efforts resulted in a substantial reduction of the disease. By 1961, citrus canker was declared eradicated in 21 municipalities after the inspection of approximately 11 thousand citrus farms and the destruction of 1.2 million citrus trees (Santos 1991).

Nevertheless, new foci of the disease were found in backyard trees toward east of the area where the original detections were found. By that time, there was a great concern with the citrus export zone in the central region of SP, distinguished by its modern, large, and contiguous citrus groves. These two factors led, by late 1962, to the intensification of the CCEP by the creation of the "expansion" plan (Table 1). This plan established a new methodology for eradication and extended the surveillance to other canker-free municipalities of the state, especially those bordering the affected area located south of the Tiete River, which roughly splits evenly SP from NW to SE (from Sorocaba to the banks of the Paraná River). The revised protocol determined the eradication of all citrus trees and the interdiction for new citrus plantings only in the affected properties. Additionally, to preserve canker-free properties in the affected municipalities, only the citrus trees located within a radius of 1000 m from the affected farm, not the entire municipality as previously stipulated, had to be removed. These areas were regularly inspected at no more than 2-year interval. In addition, a strict control of the transit of citrus fruit and nursery trees was implemented throughout the state. At the same time, the accreditation of nurseries with the SSA, as well as the registration of the origin and destination of the plant material and the sanitary certification of the nursery trees, became mandatory (Santos 1991).

Despite these efforts, the advance of citrus canker continued to open new paths in SP and, in 1974, the disease was first discovered in the northern region of the state. That was also the first confirmation of citrus canker at the upper side of the state across the Tiete River (Santos 1991). Thus, encouraged by the unstoppable spread of citrus canker from the original epicenter not only in SP but also in other states, in 1975, a national eradication campaign, officially known as CANECC, was launched by the Ministry of Agriculture to coordinate and standardize eradication efforts in all affected states of the country (Table 1). In addition, threatened by the spread of the disease in SP, the producers and the citrus industry founded Fundecitrus (Fund for Citrus Protection) in 1977, shortly after the CANECC started operating (Table 1). The newly created institution was empowered by an agreement with the SSA, responsible for plant health defense in SP, and its main objectives were to finance and manage the CCEP in SP, as regulated by the CANECC.

Although the CCEP significantly reduced the incidence of citrus canker in SP during the 1970s, it did not prevent the dissemination of the disease to other regions. Thus, in 1979, citrus canker was discovered in several municipalities of the citrus export zone, the core of the SP citrus industry. The first detections occurred in Monte Alto and Cândido Rodrigues, followed by Limeira, Taquaritinga, Fernando Prestes, Itajobi, and Araraquara (Santos 1991). At that time, due to the continuous detections in SP and the weakening of the eradication efforts in other states where the disease was becoming endemic, the viability of the CCEP began to be questioned, even in SP. Because of these uncertainties and political pressure, in subsequent years, the Ministry of Agriculture started alleviating the eradication protocol. In 1982, the farms with no occurrence of the disease were allowed to establish new citrus plantings. Until then, besides the eradication of all citrus trees in affected farms, planting new orchards in all properties in the municipality was prohibited (Santos 1991).

In SP, the CCEP continued but suffered several changes. The radius of eradication was reduced to 50 m in 1987 (Brasil 1987), and to 30 m in 1995 (Brasil 1995). The protocol established in 1995 was more flexible and determined three methods to be used by the SSA in each state where citrus canker was present: removal of the affected trees associated with (i) removal, (ii) drastic pruning, or (iii) defoliation of the other citrus trees contained within a radius of 30 m from the focus tree (Brasil 1995). The radius size for this protocol was based on studies conducted in Argentina that showed that the canker-causing bacteria could be detected up to 32 m from the inoculum source after a rain-blown event (Stall et al. 1980). Two years later, in 1997, a new protocol added a fourth option: drastic pruning of the affected trees associated with copper sprays on the surrounding trees within a 30-m radius (Brasil 1997). Regardless of the method adopted, the property was prohibited from planting new citrus trees for at least 2 years after the last detection and all fruit production in that farm during that period had to be destined to the juice industry. In SP, the removal of affected and surrounding trees was the only option adopted during all these years.

Despite the modifications in the protocol, from late 1970s to late 1990s, the CCEP went through a period of stability of citrus canker in SP (Table 1). Although the disease had not been eradicated, the number of outbreaks remained stable at minimal levels (Fig. 1), protecting growers from significant losses. However, during the late 1990s, the number of symptomatic trees in the state increased and the spatial pattern of diseased trees became less aggregated. It was soon determined that the protocol became less effective because of the citrus leafminer (*Phyllocnistis citrella*), introduced into the country in 1996 (Gimenes-Fernandes et al. 2000; Gottwald et al. 2007).

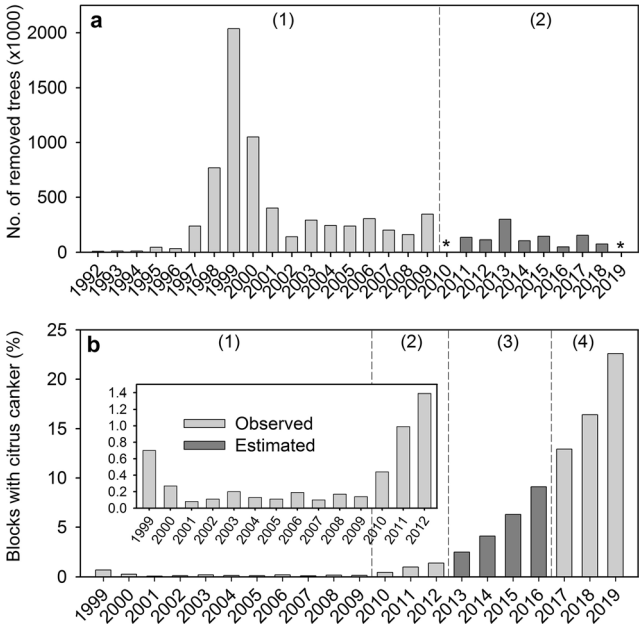

Fig. 1 Number of citrus trees removed during the citrus canker eradication program (CCEP) in São Paulo state from 1992 to 2019 (**a**) and incidence of blocks with citrus canker in the state from 1999 to 2019 (**b**). In **a**, (1) and (2) represent data provided by Fundecitrus and the State Secretary of Agriculture, respectively. A single asterisk indicates years with no available data. In **b**, the estimated incidence was obtained from Behlau et al. (2016), (1) to (4) indicates the different protocols adopted by the CCEP in the corresponding period: (1) removal of the entire citrus block when the incidence of symptomatic trees exceeded 0.5% or removal of symptomatic trees and those within a 30-m radius when incidence was ≤ 0.5%, (2) removal of symptomatic trees and those within a 30-m radius regardless of the incidence of the disease in the block, (3) removal of symptomatic trees and spray of copper on the remaining trees located within a 30-m radius, and (4) compulsory removal of trees was abolished and replaced by management of the disease in the field

Wounds caused by the feeding of the larvae of the miner on young leaf and stem tissues increase the likelihood of infection of trees at more distant locations from the inoculum source (Gimenes-Fernandes et al. 2000; Jesus et al. 2006). This is due to the fact that these wounds remain predisposed to penetration of *X. citri* subsp. *citri* carried by water splash during rainstorms for longer periods than mechanical wounds caused by thorns, abrasion of soil particles, and trimming, and that lower inoculum doses can cause disease (Chagas et al. 2001; Christiano et al. 2007). Thus, although the insect does not act as a vector (Belasque et al. 2005), it exacerbates both the incidence and severity of citrus canker (Graham et al. 1996; Jesus et al. 2006; Christiano et al. 2007; Hall et al. 2010).

Because the citrus leafminer affected the efficiency of the 30-m eradication radius (Gottwald et al. 2007; Belasque et al. 2010), a new protocol for eradication, known as "0.5% law" (Table 1), was established in June 1999 (São Paulo 1999). According to this protocol, an entire block had to be removed when the incidence of symptomatic trees exceeded 0.5%. In blocks with 0.5% incidence or less, only the symptomatic trees and those within a 30-m radius had to be removed. A citrus block refers to a group of trees within a farm of the same variety and age under the same management, usually separated by a road or other barrier. This methodology was based on the analysis of the distribution of canker-affected trees within many citrus blocks with the endemic occurrence of the CLM in SP, which revealed that the frequency of satellite foci of citrus canker increased significantly when the incidence of symptomatic trees in the block was higher than 0.5% (Gottwald et al. 2007).

In order to quantify the incidence of citrus canker in 1999, a statewide survey was undertaken in 10% of the blocks in the citrus-growing areas of SP and Triângulo Mineiro. Although the Triângulo Mineiro is located in Minas Gerais state, this region is part of the SP citrus belt (Neves and Trombin 2017). The inspections, as well as the removal of trees, were conducted by Fundecitrus as follows: (i) one out of every five trees (20%) in a row was inspected in detail; and (ii) the remaining four trees (80%) were inspected continuously. For detailed inspections, surveyors walked slowly around the tree and stopped every two steps in order to scan the canopy thoroughly for symptoms of the disease. For the continuous surveys, the inspectors walked alongside four trees in the row looking at the canopy without stopping until reaching the fifth tree, which was inspected in detail. In 1999, four thousand inspectors worked in the SP eradication campaign and approximately 2 million trees were removed, which were either symptomatic or located in the proximity of symptomatic trees (Massari and Belasque 2006; Behlau et al. 2014; Fig. 1). From 2000 to 2009, the inspections were based on annual surveys conducted in 5% of the citrus blocks, randomly selected within each citrus production region. During these years, a series of inspections, performed as described in detail by Behlau et al. (2016), were carried out to monitor the affected blocks during the 2-year quarantine period.

Several methods for eradication were used by the CCEP, but the protocol adopted from 1999 to 2009 was the most successful and well documented of all (Behlau et al. 2016). During that time, the eradication campaign in SP quickly reduced the peak of affected blocks from 0.70% in 1999 to ≤ 0.20 in subsequent years until 2009 (Fig. 1), when the protocol was modified once again (Belasque et al. 2010; Behlau et al. 2014, 2016). Of over 5000 detected foci, 65% were eliminated by removing the entire block when incidence of affected trees exceeded 0.5%, either when disease was first detected (48%) or at a subsequent detection (17%) during the quarantine period. The removal of citrus trees within a 30-m radius was responsible for 28% of the foci elimination. The latter method was not an effective stand-alone measure for eradication. Instead, the removal of all trees within the block when incidence was higher than 0.5% was the key factor for the successful suppression of the disease statewide during that time (Behlau et al. 2016).

In 2009, there was a new change in the legislation pushed by the citrus growers from the northwest of SP, where the

incidence of citrus canker was the highest (São Paulo 2009). The protocol returned to the guidelines used from the mid to late 1990s and determined the eradication of only the symptomatic trees and those existing within a radius of 30 m, regardless of the incidence of symptomatic trees in the block (Belasque et al. 2010; Behlau et al. 2016). This modification marked the "beginning of the end" and led in January 2010 to the termination of the agreement between the SSA and Fundecitrus (Table 1). The main reason was that Fundecitrus would have to significantly increase the number of inspectors to keep the incidence of citrus canker under control given the less stringent rules. From this moment on, inspections and removal of trees became a responsibility of the growers under the supervision of the SSA. This change had an immediate impact on the incidence of citrus blocks with canker outbreaks, which went from 0.14%, in 2009, to an unprecedented 1.39%, in 2012 (Behlau et al. 2016; Fig. 1).

In a scenario of uncertainty regarding the future of CCEP in SP, in October 2013, the protocol was modified again and became even less rigorous (São Paulo 2013). This Resolution abolished, for the first time in the history of the eradication program, the obligation to remove asymptomatic trees located around the foci. Instead, according to that protocol, only the symptomatic trees had to be eliminated. In addition, trees within a 30-m radius had be sprayed with copper, the orchards had to be inspected every 3 months, and growers were required to submit semiannual reports to SSA listing the inspections and the information on disease detection (Behlau et al. 2016). This was the "last act" before the CCEP was definitely terminated in SP (Table 1).

Other states

Soon after citrus canker was identified in SP in the late 1950s, the disease was also tracked down in the neighboring states Paraná (PR), Mato Grosso (MT), and Mato Grosso do Sul (MS). The foci were detected in citrus groves established with nursery trees produced in SP where citrus canker had been originally found (Amaral 1957; Bitancourt 1957). In addition, migration of people in Brazil was intensified during the 1950s and 1960s. Thus, infected nursery trees brought by colonizers played a major role in the dissemination of the pathogen and establishment of the disease in these areas (Leite 1989). In the first broad survey carried out in 1961, citrus canker was found in 12 municipalities in the north and northwest regions of PR (Leite and Mohan 1990). Meanwhile, in MS, intensive surveys performed with the support of experienced inspectors from PR and SP identified the disease in several municipalities in the central and southern regions of the state. The eradication protocol was identical to that used in SP with detailed registration of affected properties and inspection of transit of fruit and nursery trees (Santos 1991). However, the eradication efforts in these states were not as immediate and organized as in SP, which contributed to further spread of the disease and impaired the CCEP (Santos 1991).

Although measures were taken to restrict the spread of the disease in PR, the contaminated area reached approximately half of the state in 1982 (Leite 1989). As in SP, until the early 1980s, in PR quarantine regulatory measures were applied at the municipality level, *i.e.*, the finding of citrus canker in orchards of a single property implied the prohibition of all other properties in the municipality for the cultivation of citrus (Leite and Mohan 1990). However, the criteria adopted by the eradication program were revised and the regulatory measures for quarantine and eradication started to be applied at the property level. Initially, these measures were considered for all citrus trees, whether affected or not. Subsequently, with the establishment of modifications to the eradication criteria, only diseased trees and those adjacent to them within a radius of up to 1000 m were eliminated. At that time, after eradication, the property was quarantined and prohibited from growing or propagating citrus for 1 year. After the quarantine period, only citrus cultivars recommended for the state were allowed to be planted (Hatschbach 1986; Leite and Mohan 1990).

The eradication efforts did not achieve the expected success in PR due mainly to technical, economic, and political difficulties. Thus, claiming that there were no sufficient funds for the maintenance of CANECC, in 1990 PR started following a specific legislation (Resolution 79/90 from August 02, 1990), which authorized new plantations in canker-free properties and adoption of integrated management measures to control the disease (Paraná 1990). Thereafter, removal of affected trees was performed throughout the farm only before a new citrus planting was established using less susceptible cultivars. After that, if citrus canker was detected, no trees were eliminated. Instead, the orchard was protected with copper sprays and arboreal windbreaks to prevent or minimize impact of the disease (Leite and Mohan 1990).

A new era of control

Since 2009, the incidence of orchards affected by citrus canker in SP has increased. This situation did not necessarily represent a threat to the continuity of the citrus industry, but it did show a need for important changes and paradigm shift. During the early years of the epidemics, the possibilities to stop the disease from progressing were exhaustively discussed. The conclusions were unanimous in pointing out the return of the rigor of CCEP as the only technically effective alternative. The major obstacles, however, for the resurgence of the program were (i) the relatively high incidence of the disease, which was setting new records each year, would require the removal of a substantial part of the orchards; (ii) the fight against greening disease (huanglongbing, HLB), which

required increasing attention and resources; and (iii) the need to spend a significant amount of money and resources at a time of low fruit prices due to high production.

The evolution of the discussions about the future of the legislation that regulates the control of citrus canker in Brazil led to the consensus that the return of an efficient CCEP would not be possible. In addition, the results of research produced in the last decades and the successful experiences in citrus-producing regions that carry out the management of the disease, such as Argentina, Uruguay, and Florida, USA, encouraged the adoption of a similar strategy in states with high incidence of the disease. Nevertheless, the distribution of citrus canker was not uniform throughout Brazil. In most of the states, the disease was absent or present at low incidence.

Thus, taking into account the continuous and irreversible growth of citrus canker in SP, the largest orange-producing area in the world (Neves and Trombin 2017), and the heterogeneous distribution in the country, a new and revolutionary federal legislation, known as Normative Instruction No. 37 (IN 37), was published in September 2016 and came into effect in March 2017 (Brasil 2016). Although this regulation was compatible with the situation of the disease in the country and maintained citrus canker as a quarantine disease, some of the determinations were harmful to the producers of fresh fruit. Thus, to meet the demand, in May 2018, a new version, known as Normative Instruction No. 21 (IN 21), was implemented following the main premises established in the previous document (Brasil 2018). IN 21 is the current legislation that regulates the control of citrus canker in Brazil. It allows each state of the federation to adopt a different status regarding the presence and incidence of the disease in citrus orchards. For the first time in the history of the country, citrus canker may be managed using control measures in replacement of eradication of trees in areas with high incidence of the disease.

According to IN 21, a different status may be adopted within one state. Each status defines a set of measures to be used to prevent or to manage the disease. The status of an area is determined based on annual surveys coordinated by the SSA of each state. The results are submitted to MAPA for approval and made official through Resolutions. Having a defined status is not mandatory. However, areas with an unknown status are not allowed to commercialize and transport fruit to other states. The IN 21 describes four status regarding the occurrence of citrus canker, as follows (Fig. 2):

1. Area with no occurrence: area where citrus canker is absent as determined by surveys. In this area, the control measures are focused on preventing the introduction of the disease by monitoring the transit of plant material and planting healthy nursery citrus trees.
2. Pest-free area (ALP, *Área livre da praga*): delimited area in which citrus canker does not occur, within a larger area where the disease is present or its occurrence is unknown. In this area, the control measures are also focused on preventing the introduction of the disease by monitoring the transit of plant material and planting healthy nursery citrus trees.
3. Area under eradication: area where citrus canker occurs with restricted distribution or low incidence. In addition to monitoring the transit of plant material and planting of healthy citrus trees, the disease is controlled by removal of affected and suspect trees associated with frequent inspections. Once the occurrence of citrus canker is officially confirmed, one of the following two measures should be adopted: (i) elimination of the focus tree and spray of copper on the reaming citrus trees within a radius of 30 m from the focus tree; or (ii) elimination of the focus tree and of all citrus trees located in the perifocal area with a minimum radius of 30 m.
4. Area under risk mitigation system (SMR, *Sistema de mitigação de risco*): area where orchards have an intermediate or high incidence of citrus canker and the eradication of diseased trees is no longer a viable alternative. In orchards under this status, citrus canker control follows a set of management measures aimed at reducing the impact of the disease on crop production and disease dissemination. In addition, fresh fruit marketed to other states or countries must be processed and sanitized after harvest in certified packaging houses before shipping to prevent the spread of the disease.

The major change of the current legislation is the possibility to maintain trees with citrus canker in the field in areas under the SMR. In this status, the efforts that once were concentrated on the inspection of orchards and the removal of affected and suspect trees are now focused on the implementation of integrated management measures aimed at protecting the fruit from infections and minimizing or even avoiding the losses caused by the disease in the field due to premature fruit drop. Thus, in areas under SMR, it is expected that the incidence of affected trees increases due to the end of the eradication program, and not the mitigation system itself. Management of citrus canker may be performed by planting healthy nursery trees, choosing less susceptible cultivars whenever possible, spraying copper-based bactericides, installing arboreal windbreaks, controlling the citrus leafminer, and applying resistance inducers. The efficiency of these measures has been comprehensively described in several studies (Leite and Mohan 1990; Stein et al. 2007; Behlau et al. 2010; Graham et al. 2011; Graham and Myers 2013; Moschini et al. 2014; Graham et al. 2016; Behlau et al. 2017; Canteros et al. 2017; Ference et al. 2018; Behlau 2019).

The SMR also regulates the processing of fresh fruit in the packing houses. The implementation of this status enables the

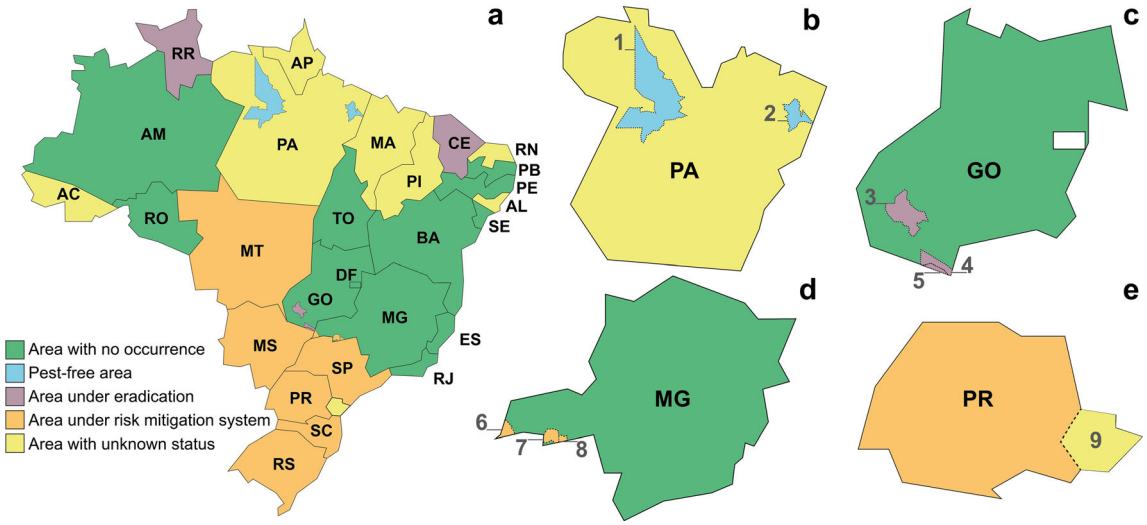

Fig. 2 Status regarding the presence and control of citrus canker adopted in the different states of Brazil according to the current legislation. In **b**, 1 indicates the municipalities of Alenquer, Belterra, Mojuí dos Campos, Monte Alegre, Prainha, and Santarém, and 2 indicates the municipalities of Ourém, Irituia, Garrafão do Norte, Capitão Poço, and Nova Esperança do Pará. In **c**, areas 3, 4, and 5 indicate the municipalities of Jataí, Itajá, and Lagoa Santa, respectively. In **d**, areas 6, 7, and 8, represent the municipalities of Carneirinho, Frutal, and Planura, respectively. In **e**, area 9 indicates the mesoregions of Curitiba and Paranaguá

production and commercialization of canker-free fruit harvested from orchards with citrus canker. Therefore, the SMR has a more prominent impact on citrus growers dedicated to the fresh market. According to the current protocol, orchards intended for the production of fruit for fresh trade to disease-free states or countries must follow several determinations. The area needs to be pre-registered with the state plant protection agencies. Before harvest, the orchards need to be inspected, under the responsibility of the grower, for the incidence of canker-affected fruit. A harvest authorization is granted only if the incidence does not exceed 1%. In the packing house, all fruit should be rinsed and decontaminated before packing and shipping. Sodium hypochlorite is the only product allowed by IN 21 to be used for that purpose (Brasil 2018). However, the legislation also allows the recognition of alternative products, provided that their efficacy and safety are scientifically demonstrated. In the packing house, symptomatic fruits eventually harvested should be withdrawn at any time during processing. Fruit produced for the in-state market are exempt from washing and decontamination. However, no cankered fruit is allowed to be marketed in or out of the state of origin.

The SMR not only requires investments and modernization of the production chain but also brings benefits by increasing the quality of the fresh fruit. Although it represents an additional challenge to the supply chain of fresh fruit, the adoption of the SMR status should not impair the market or exports, as long as producers undertake to adopt the risk mitigation measures available. In fact, the protocol represents an adaptation to the reality of citrus canker in the field. The regulation of the control of the disease during pre- and post-harvest of fresh fruit enables the existence of affected orchards and, at the same time, minimizes the risks of dissemination of the disease. The SMR also creates opportunities for field research on the control of the disease and facilitates the communication of results to citrus growers and professionals of the industry. This situation is similar to what has been practiced for years in Argentina, where citrus canker is widespread. This country is the world's largest exporter of fresh lemons, which are highly susceptible to the disease. This was made possible by the adoption of rigorous measures that reduce the disease in orchards and culling fruit with symptoms eventually harvested before reaching the final destination (Canteros et al. 2017).

Orchards for the production of fruit for the juice industry do not need to be registered under the SMR with the SSA in the states or areas under this status and, consequently, dispense with the need for inspections and certifications. As citrus canker does not affect the quality of the juice (Behlau and Belasque 2014), in these orchards, the main concern related to citrus canker is to prevent losses due to premature fruit drop by adopting the appropriate measures for disease control. In addition, growers need to take care to transport the fruit to the industry by using adequate coverage of the cargo to avoid the involuntary dispersion of fruit possibly contaminated by the citrus canker bacteria.

Current citrus canker status throughout the country

Southeast region

- São Paulo

The SSA of SP adopted the SMR for citrus canker in March 2017 (Resolution No. 04, March 27, 2017),

immediately after the IN 37 was published (Fig. 2a). The adoption of this status was encouraged by the increase of the disease in previous years as described earlier in this document (Fig. 1). Since then, as expected, the incidence of symptomatic trees continued to increase (Figs. 1b, 3a). The survey conducted by Fundecitrus in 2019 revealed that citrus canker was present in 22.6% of the orange blocks. This incidence is 42% higher than that recorded in the previous year, when 15.9% of the block were affected. The survey also revealed that 15.1% of trees had citrus canker. This incidence corresponded to 29.3 million orange trees and is 34% higher than in 2018, when the incidence of symptomatic trees reached 11.7% (Fig. 3a). It is important to mention that, in addition to the orchards located in SP, these data also include a few orchards located in the Triângulo Mineiro region, state of Minas Gerais (MG), which are also part of the citrus belt of SP (Neves and Trombin 2017).

The incidence of citrus canker increased in almost all property sizes, orchard ages, and regions (Fig. 3c and 4). The disease occurred in all tree age strata. The age group of 6 to 10 years was the most affected with 21.2% of trees with symptoms of the disease. In the other age groups, the incidences ranged from 11.4 to 14.0% affected trees (Fig. 3b). The incidence also varied according to the number of trees in the properties, being higher in the smaller properties. In farms with up to 10,000 trees, the incidence of trees with citrus canker was 22.4%. Conversely, in properties with over 200,000 trees, the incidence dropped to 11.0% (Fig. 3c). The survey also revealed that citrus canker is present in all citrus-growing areas of SP (Fig. 4). The northwest and central regions of the state are the most affected. The highest incidences of canker-symptomatic trees were registered in the Votuporanga area with 71.4%, followed by São José do Rio Preto, Matão, Bebedouro, and Duartina. The lowest incidences were recorded in the south, southeast, and northeast of SP. The mesoregions of Itapetininga, Altinópolis, and Porto Ferreira had less than 1% diseased trees (Fig. 4).

With the end of the eradication program and adoption of the SMR, the disease will continue to spread. Based on the incidence of blocks with citrus canker registered in surveys from 2009, when the epidemics started, until the last assessment in 2019, it is possible to estimate that the disease will be present in 50% and 100% of the citrus blocks by 2024 and 2029, respectively (Fig. 5). As stated earlier, this does not mean a threat to the citrus industry, but a need for a rapid change in the way the disease is controlled. Only a few years have passed since the disease started to be managed in SP. However, based on the experience of other countries and many farms in the state, where citrus canker has been present for a longer time, it is possible to predict that the growers will have no serious impact due to the disease if the recommended control measures are properly applied (Behlau 2019).

- Minas Gerais

Initially, when the federal legislation changed in 2017, MG was recognized as a state under eradication of citrus canker. Because the incidence of trees with citrus canker was concentrated in a few municipalities in the Triângulo Mineiro region, which makes border with SP, and the reaming citrus areas were free of the disease, the status of MG was updated in 2019 (Resolution No. 03, September 12, 2019). Currently, only the municipalities of Planura, Frutal, and Carneirinho are under the SMR (Fig. 2a, d). The estimated incidence of trees with citrus canker in these areas according to the last survey conducted by Fundecitrus in 2019 was 4.2%. The reaming territory of MG is under the status of no occurrence of the disease (Fig. 2a, d).

- Rio de Janeiro and Espírito Santo

In Rio de Janeiro (RJ) and Espírito Santo (ES), the disease was never reported. Both states are under status of area with no occurrence of the disease (Fig. 2a). This status was made official in RJ and ES through the Resolutions No. 03, from March 15, 2018, and No. 01, from January 2, 2018, respectively.

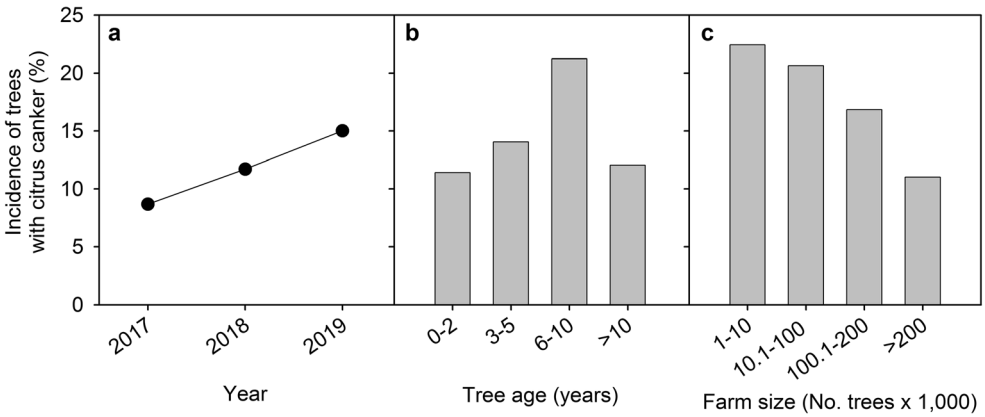

Fig. 3 Incidence of trees with citrus canker in São Paulo citrus belt per year from 2017 to 2019 (**a**), age of the citrus orchards (**b**), and size of the farms (**c**)

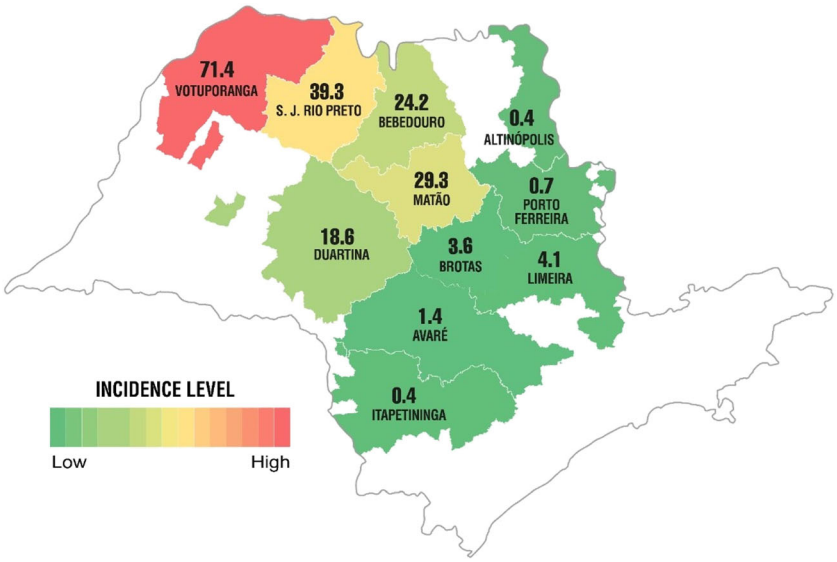

Fig. 4 Incidence of trees with citrus canker throughout the citrus-growing mesoregions of São Paulo state based on Fundecitrus survey in 2019. Each mesoregion is comprised of several municipalities

South region

- Paraná

Citrus canker has been present in PR since 1957 (Bitancourt 1957). The history of the disease in this state is described earlier in this document. Differently from other states, PR started to manage the disease in 1990, after the eradication efforts failed and a state Resolution was published allowing growers to stablish citrus orchards in canker-free properties. After planting, these farms ended up being recontaminated. However, the symptomatic trees were not removed because of the disease. Instead, citrus canker was controlled using integrated measures based on previous experiences from Argentina and Uruguay and on research results produced locally. Thus, PR became a pioneer state for canker management in Brazil and a reference for other states under similar disease occurrence (Leite and Mohan 1990).

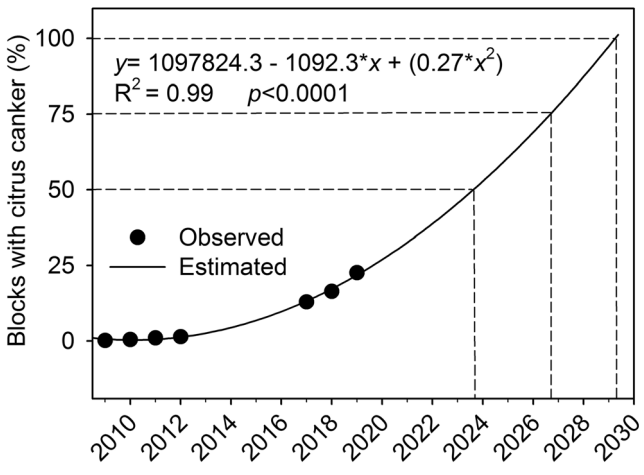

Fig. 5 Estimated incidence of citrus blocks with citrus canker in São Paulo state from 2009 to 2030 based on the incidence reported by Fundecitrus surveys in 2009 to 2012 and 2017 to 2019

Currently, based on the Resolution No. 18, from December 06, 2017, most of PR is under the SMR status (Fig. 2a, e). Although citrus canker is present in much of the state, in the mesoregion of Curitiba, an important tangerine-producing belt, and in the neighboring mesoregion of Paranaguá, the disease has not yet occurred. However, currently, these areas have no official recognized status (Fig. 2a, e). For this reason, PR submitted a process to the Ministry of Agriculture, which is relying on an official decision, requesting the recognition of 31 municipalities in the mesoregions of Curitiba and Paranaguá as pest-free areas or ALP (Fig. 2a, e). The municipalities included in the request to be recognized under the APL status are Adrianópolis, Agudos do Sul, Almirante Tamandaré, Araucária, Antonina, Balsa Nova, Bocaiuva do Sul, Campina Grande do Sul, Campo Largo, Campo Magro, Cerro Azul, Colombo, Contenda, Curitiba, Doutor Ulysses, Fazenda Rio Grande, Guaraqueçaba, Guaratuba, Itaperuçu, Mandirituba, Matinhos, Morretes, Paranaguá, Pinhais, Piraquara, Pontal do Paraná, Quatro Barras, Rio Branco do Sul, São José dos Pinhais, Tijucas do Sul, and Tunas do Paraná. The ALP status will allow producers in these areas to send their fruit out of the state without adopting the measures required by the SMR, such as the decontamination of fruit in the packing house. In addition to reducing costs, it will allow the tangerines to be harvest at the optimal stage of ripeness. According to the producers, when decontamination is required, the fruit must be harvested greener to prevent or reduce damage during the cleaning process. Thus, ALP will also contribute to produce fresh tangerines with higher quality and less cost (J. Croce Filho 2020, personal communication).

- Santa Catarina

Citrus production in Santa Catarina (SC) is concentrated in small family farms located in three regions: in the west (Chapecó mesoregion), in the south (Criciúma mesoregion), and in the northeast (Itajaí Valley). Citrus canker was first reported in SC in the 1980s. Since then, the disease has spread to all the major citrus-producing areas of the state. Because of that, SC also adopted the SMR status after the publication of the Resolution No. 12, on May 16, 2017 (Fig. 2a).

- Rio Grande do Sul

In Rio Grande do Sul (RS), the first detection of citrus canker occurred in 1980 in Santiago, a municipality located in western region of the state. In the same year, the disease was also found in other municipalities in the northwestern region such as Uruguaiana, Itaqui, São Borja, São Luiz Gonzaga, Santo Antônio das Missões, and São Francisco de Assis (Santos 1991). The initial outbreaks of citrus canker in RS did not develop from the inoculum from contaminated areas of PR, which has Santa Catarina (by that time with no reports of disease), as an intermediate state. The entry of citrus canker in RS occurred through the western region bordering the Argentine province of Entre Rios, highly contaminated by the disease and where no eradication attempts were in course (Santos 1991).

Despite the urgency required by CANECC, which promptly responded to the first detections by allocating resources, it took almost 2 years for the state officials to join the campaign and start to remove the affected citrus trees. As a consequence, the eradication program failed and the disease spread to the most important citrus regions of the state. On April 04, 2017, RS was recognized officially as an area under the SMR status, after the publication of the Resolution No. 11 (Fig. 2a).

Central-west region

- Goiás

Initially, Goiás (GO) was recognized though the Resolution No. 2, from March 14, 2017, as a state under no occurrence of citrus canker. However, after detections of the disease in backyard trees in 2018, the status of the municipalities of Jataí, Itajá, and Lagoa Santa was changed to areas under eradication, while the rest of the state remained as area under no occurrence of the disease. This status update was made official trough the Resolution No. 2, from July 16, 2019 (Fig. 2a, c).

- Mato Grosso and Mato Grosso do Sul

As described earlier, citrus canker has been present in Mato Grosso (MT) and Mato Grosso do Sul (MS) since the 1950s, before the original territory of MT was divided into the two states in 1977 (Santos 1991). Because the disease is currently widespread, MT and MS adopted the SMR status through the Resolutions No. 3 and No. 5, respectively, both published on March 22, 2017 (Fig. 2a).

- Federal District

The Federal District (DF) is recognized by the Resolution No.14, from September 11, 2017 as an area with no occurrence of citrus canker (Fig. 2a).

Northwest region

- Bahia, Sergipe, Pernambuco, and Paraíba

The second largest citrus belt of Brazil is located in northern Bahia (BA) and southern Sergipe (SE) (Neves and Trombin 2017). In northwest Brazil, besides these two states, Pernambuco (PE) and Paraíba (PB) were recognized as areas with no occurrence of citrus canker. This status became official in BA, SE, PE, and PB through the Resolutions No. 10 (March 30, 2017), No. 16 (September 20, 2017), No. 17 (September 28, 2017), and No. 19 (December 8, 2017), respectively (Fig. 2a).

- Maranhão, Piauí, Alagoas, and Rio Grande do Norte

Although Maranhão (MA) and Piauí (PI) are states under an unknown status, citrus canker was recently detected in these states. Because MA and PI have no significant production of citrus, their unknown status may remain indefinitely. This condition implies that growers from these states are not allowed to ship fresh fruit to other states. Instead, fruit may be marketed locally, within the state of origin, as long as they do not present symptoms of the disease. Alagoas (AL) and Rio Grande do Norte (RN) are two other states in northwestern Brazil that are under an unknown status regarding the occurrence of citrus canker. AL and RN, unlike MA and PI, have never had an official report of the disease (Fig. 2a).

- Ceará

Ceará (CE) is the only state in the northeast that was recognized as an area under eradication of citrus canker. The disease was first reported in this state in December 2011. Since then, eradication efforts have been carried out following protocols established by the federal legislation. The entire state of CE was recognized as an area under eradication on August 25, 2017, through the Resolution No. 13 (Fig. 2a).

North region

- Amazonas and Rondônia

In northern Brazil, only Amazonas (AM) and Rondônia (RO) are under the status of no occurrence of citrus canker. The Resolutions No. 15 (September 11, 2017) and No. 2 (January 4, 2018), respectively, made official the status of these states (Fig. 2a).

- Acre and Amapá

Acre (AC) and Amapá (AP) are states with unknown status (Fig. 2a). As other states in the northeast, AC and AP have no significant citrus production and are only allowed to market fresh canker-free fruit locally.

- Pará

The state of Pará (PA) has a unique situation in the country. Two important citrus-growing areas were recognized as canker-free areas or ALP. One area, recognized through the Resolution No. 1, from March 7, 2017, is located in the northwest of the state and comprises the municipalities of Alenquer, Belterra, Mojuí dos Campos, Monte Alegre, Prainha, and Santarém. A second canker-free area in northeast PA was acknowledged on March 27, 2017. This area comprises the municipalities of Ourém, Irituia, Garrafão do Norte, Capitão Poço, and Nova Esperança do Pará (Fig. 2a, b). As ALP areas, these municipalities are allowed to market the production to other states and countries with no obligation to decontaminate the fruit in the packing house before shipping.

- Roraima

Roraima (RR) is the only state under eradication of citrus canker in the north. The disease was first detected in RR in October 2002 and eradication attempts have been undertaken since then. The state was declared officially as an area under eradication on March 27, 2017, through the Resolution No. 8 (Fig. 2a).

Acknowledgments The author is thankful to José Croce Filho, Juliano F Galhardo, Paulo JP Marques, Paulo R P Brandão, Caroline T Marçal, and Marcílio M Araújo from ADAPAR, Paraná; Fabiane dos Santos from CIDASC, Santa Catarina; Luiz CC de Guamá, from ADEPARA, Pará; and Eriko T Sedoguchi from the Ministry of Agriculture for kindly providing valuable information about the official status and occurrence of citrus canker in the country.

Funding information The National Council for Scientific and Technological Development - CNPq is also acknowledged for granting a research productivity fellowship to the author (grant no. 309261/2016-3).

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