

Citricultor

Fundecitrus
SCIENCE AND SUSTAINABILITY
IN CITRICULTURE

TECHNICAL VISIT TO CHINA

To combat greening, Fundecitrus evaluates Chinese studies with peptides and AI and the establishment of a partnership

Strategies to combat
greening

CPA CITROS WILL FOCUS ON 3 RESEARCH LINES: DISEASE AND VECTOR MANAGEMENT, PLANT-BACTERIA-PSYLLID INTERACTION, AND PRODUCTION AND DAMAGE MITIGATION

GREENING IS SERIOUS STUFF



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Citricultor

CITRICULTOR magazine is a free publication edited by the Fundo de Defesa da Citricultura - Fundecitrus. Fundecitrus, a world reference in science for citriculture, is a non-profit private institution established in 1977 and maintained by citrus growers and processors in the state of São Paulo, Brazil, to foster the sustainable development of the Brazilian citrus belt.

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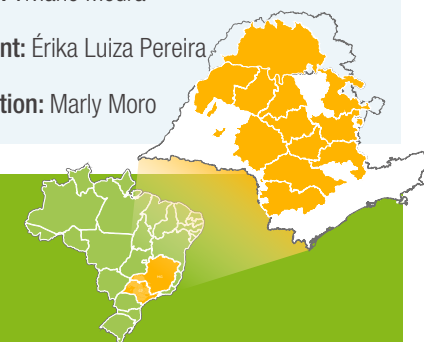
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BRAZILIAN CITRUS BELT

The São Paulo and West-Southwest Minas Gerais citrus belt, located in the Southeast region of Brazil and comprised of approximately 350 cities, is the main orange juice producing region in the planet: three out of five glasses of orange juice consumed in the world are produced here. In this region, citriculture creates 200 thousand direct and indirect jobs and collects 189 million dollars in taxes.



INTERVIEW

Lilian Amorim, director of CPA Citros, emphasizes that the center will be a milestone in the progress of collaborative research on behalf of the global citrus industry



RESEARCH

Discover the CPA Citros three main research lines aimed at transforming greening management



CHINA

Fundecitrus evaluates Chinese studies on peptides and AI to combat greening



BIOTECHNOLOGY

Repellent plant releases up to 40 times more caryophyllene to ward off the psyllid. See how this strategy will work



SUSTAINABILITY

Beyond juice, orange yields co-products of growing value

Advances in knowledge and agile communication with citrus growers are expected

ACCORDING TO CPA DIRECTOR, LILIAN AMORIM, THE MAIN INNOVATION OF THE CENTER LIES IN COLLABORATIVE RESEARCH, WITH STANDARDIZED METHODS AND INSTANT INFORMATION SHARING

It was meant to be an interview, but it turned into a lesson — one filled with robust knowledge and elegant argumentation. No wonder. From her master's degree in phytopathology at Université Paris-Sud (Paris XI) — now Université Paris-Saclay, one of the most prestigious in the world — in 1984, to her appointment as director of the Applied Research Center (CPA) for Innovation and Sustainability in Citriculture, a partnership between the São Paulo Research Foundation (FAPESP), through the Luiz de Queiroz School of Agriculture (Esalq/USP), and Fundecitrus, spans more than 40 years of career.

In that period, she conducted research in the field of epidemiology, a branch of science that studies the incidence and distribution of diseases in annual crops (beans,

sunflower, soybeans), fruit trees (plum, guava, passion fruit, strawberry, nectarine, peach), as well as various citrus diseases (citrus canker, black spot, citrus flower rot, citrus sudden death, greening).

With the teaching approach that has made the full professor at the Luiz de Queiroz School of Agriculture one of the institution's most recognized faculty members, Lilian Amorim explains in a clear and accessible way why greening is such a complex and destructive disease. As if we could see the disease process from within, from transmission by the psyllid *Diaphorina citri* to the multiplication of the bacteria in the orange tree. Just like an encyclopedia illustration.

In the interview, or rather, in the following lesson, the Professor also discusses citrus farming in the tropics, the disease behavior in the face

of climate change, the importance of knowledge, the relationship between academia and the market, and her vision for the CPA.

Lilian has a past — and she has a future; a challenging one. Alongside Fundecitrus researcher Renato Bassanezi, deputy director, Lilian will lead the CPA, an intelligence network that virtually brings together 75 researchers from 19 research institutions and 36 departments in seven countries (Brazil, USA, Portugal, Spain, France, England, and Australia), whose primary goal is strengthening the fight against greening by improving current management, mitigating damage, and seeking long-lasting solutions. More than a past and a future, Lilian has con-

fidence. "I believe that the CPA will be a milestone in the progress of collaborative research and that it will accomplish all its propositions," she says. So be it.

IS IT MORE DIFFICULT TO GROW CITRUS CULTURES IN A COUNTRY OR REGION WITH TROPICAL CHARACTERISTICS? DOES THE CLIMATE MAKE THE CROP MORE SUSCEPTIBLE TO PESTS AND DISEASES?

A few decades ago, Professor Armando Bergamin Filho — a pioneer in Brazilian research on plant disease epidemiology in the 1970s, who passed away in January — and I worked on tropical plant diseases. In most cases, their epidemiological variables differ significantly from those of temperate-climate diseases. The entire conceptual basis of plant disease epidemiology is grounded in examples of important diseases prevalent in temperate regions, such as wheat and potato foliar diseases. Great emphasis is placed on disease progression rates, that is, the speed at which the disease incidence increases: the higher the rate, the more severe the epidemic. In the tropics, disease progression rates are not necessarily high, but epidemics are nonetheless severe.

WHAT IS THE BIOLOGICAL EXPLANATION FOR THIS DIFFERENCE?

In temperate-climate countries, the harsh winter causes perennial crops to lose their leaves and reduces the inoculum of pathogens, leading to temporal epidemiological discontinuity. Consequently,

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CONVENTIONAL MANAGEMENT MEASURES THAT RELY ON CHEMICAL CONTROL OF THE PATHOGEN ARE NOT APPLICABLE [IN COMBATING GREENING]. IN ORDER TO ELIMINATE THE PATHOGEN, OUR ONLY OPTION IS ERADICATING THE TREE

the evolutionary strategy of pathogens has been to produce the highest possible number of generations. This is completely different in the tropics, where most perennial crops retain their foliage throughout the year. The main discontinuity in tropical epidemics is spatial. Although plant tissue is present, the plant species do not grow in aggregated stands, but rather intermixed with various other species. Pathogens have always been prevented from finding other host plants, as they grew far apart from each other. As such, the evolutionary pathogenic strategy in the tropics is to produce inoculum all the time, to increase the likelihood of a spore being deposited on another host plant, located far from the original one.

YOU WERE GOING TO TALK ABOUT SEVERITY, WHOSE FUNDAMENTAL ASPECTS ARE DIFFERENT HERE AND THERE, I SUPPOSE.

In the tropics, as described, a truly important factor for successful epidemics is the continuous production of inoculum, which often results from the expansion



Lilian Amorim

Image: Galeano Films

of lesions, rather than from an increased number of lesions. Therefore, the infection rate, usually measured by the increase in the number of lesions, may be low in the tropics, but the area covered by lesions — the severity of the disease — is high. And the continuous dissemination of inoculum perpetuates the disease in the host plants. In summary, diseases have evolved differently in temperate-climate regions and in the tropics. Tropical diseases tend to be severe, not necessarily because of the favorable climate, but rather due to the strategies pathogens use to cause the disease.

HAVE YOU EVER COME ACROSS A DISEASE AS SERIOUS AS GREENING?

I am not aware of a disease as devastating as greening. It is an extremely complex, hard-to-control disease, whose cure has not been found yet. Plants gradually lose their ability to produce, fruit drop rises, and the diseased plants collapse after approximately five to eight years. During this period, depending on the quality of control measures, they may have served as inoculum for the infection of many other plants. In the case of greening, all varieties that produce commercial fruits are susceptible. Another key point is that the bacterium colonizes the phloem vessels, and to reach them, it relies on a strategic ally: the psyllid. The bacterium is not concerned about reaching its habitat because the vector carries it over there. Once it reaches the phloem, the bacterium has

the entire plant at its disposal, as it is carried to the roots and from there to the aerial organs [*stem, branches, leaves, flowers, fruits*] in a systemic colonization process. And phloem is a tissue that is difficult for chemicals to reach. Therefore, conventional management measures that rely on chemical control of the pathogen are not applicable. In order to eliminate the pathogen, we choose to eliminate the tree. Vector control remains an option, but there are also many barriers to this strategy, given the insect preference for feeding on very young tissues. This insect habit makes spraying really challenging, since all shoots should be protected. How can this be achieved in an adult plant?

WHAT ARE YOUR EXPECTATIONS REGARDING THE CPA?

The CPA does not have a brick-and-mortar headquarters; it integrates different laboratories in Brazil and abroad in a joint, cooperative research approach that avoids redundancies. The greening problem is notoriously serious, and there are several research laboratories dedicated to the subject. However, the new approach at CPA is to conduct research collaboratively, with standardized methods, real-time information sharing, and systematic meetings to discuss results. Another group of researchers who were not involved in citrus farming agreed to participate in the CPA, given the importance of the topic. These researchers bring a fresh perspective to the

problem, possibly contributing with new ideas. Breakthroughs in knowledge development and rapid information transfer to the primary users — the producers — are anticipated. I believe that the CPA will be a milestone in the progress of collaborative research and that it will be successful in all its propositions: understanding the disease, improving management, mitigating damage, and, perhaps, promoting a more effective control.

WE TALKED ABOUT RESEARCH, NOW LET'S TALK ABOUT EDUCATION AND TECHNOLOGY TRANSFER.

The educational module of the CPA is not limited to training human resources through scholarship holders [*there are 129 scholarship grantees in the project*]. This module will focus on publicizing the importance of citrus fruits and greening to a large student audience at the elementary, middle, and higher education levels. Knowledge transfer to citrus growers will be ensured through field programs, participation in events, such as Expocitros and Citriculture Week, dissemination of news in specialized magazines, like Citricultor, and in traditional journalistic media.

THE CPA IS A PARTNERSHIP BETWEEN FAPESP AND FUNDECITRUS THROUGH ESALQ/USP. HOW DO YOU ASSESS THIS JOINT WORK BETWEEN PUBLIC AND PRIVATE SECTORS?

Both Fapesp and USP prioritize high-quality research that

pushes the boundaries of knowledge. Problem-oriented research is an approach in which expanding the frontier of knowledge is associated with solving a specific problem. This approach facilitates the raising of funds in the private sector. Most often, the solution of real problems that interest society drives economic, social, and/or environmental benefits. However, there are some research projects whose importance is less tangible. For example, the exploration of the origin of supernova stars. From a layperson's perspective, stellar archaeology may seem less important than the search for a cure for cancer. However, it has significant implications for understanding the evolution of chemical substances in the universe — implications that could, in the future, even relate to curing cancer. Fapesp and USP support all kinds of high-quality research, whether basic or applied. However, since cutting-edge research is expensive, the private sector support is essential to cover costs, and the benefits of the results will certainly be shared by all.

IN ADDITION TO BEING A DIRECTOR, YOU ARE ALSO A RESEARCHER AT THE CPA, IN THE FIELD OF CLIMATE CHANGE. THIS IS ALWAYS A CONTROVERSIAL SUBJECT, AS IT BRINGS IDEOLOGICAL DEBATES TO THE SURFACE; IT OFTEN SEEMS THAT THERE IS LITTLE ALIGNMENT BETWEEN WHAT SCIENCE INDICATES AND WHAT THE PRODUCTIVE SECTORS PERCEIVE. WHAT CAN BE STATED AS FACTUAL INFORMATION?

The increase in carbon emissions and its connection to rising temperatures and to the higher prevalence of extreme events are facts. The problem is that the long-term effect of these changes in production chains is uncertain. One way to infer about the effect of climate change on production chains is through forecasting models, which are based on well-established patterns in the present to predict the future. However, all models have some degree of uncertainty, in part because the primary data that feed these models are never complete. And most of the data entered into the models are obtained through segmented climate variables that are undergoing changes. It is very difficult to experimentally simulate the increase of CO₂ and other greenhouse gases associated with the rise in temperature and water deficit.

WHAT HAVE YOU OBSERVED SO FAR?

Our group conducts experiments by subjecting plants to a combination of moderate limitation of water availability with high temperatures — 5°C above average — and evaluates the development of diseases in this situation, always with appropriate controls. We have observed that there is no standard response of diseases to these adverse environmental conditions. In grapevines, for example, the results we obtained showed that adverse environmental conditions reduce the pathogen infection frequency, but the damage to



TARGETED RESEARCH COMBINES KNOWLEDGE EXPANSION AND THE SOLUTION OF A SPECIFIC SOCIETY PROBLEM, WITH ECONOMIC, SOCIAL, AND/OR ENVIRONMENTAL GAINS

the plant is much greater than in any other situation. There is significant leaf necrosis, even at low disease intensity. Our hypothesis is that plant defense mechanisms against abiotic stress [*non-living components of an ecosystem, such as water, soil, sunlight*] and against pathogenesis [*the onset of the disease*] become unbalanced when the plant is exposed to all these factors simultaneously. However, this behavior is not shared by all the fruit trees we work with.

AND HOW DO CLIMATE CHANGES IMPACT GREENING?

We will carry out experimentation and modeling considering these very climatic variables, water limitation, and high temperatures, in an attempt to simulate dry spells. With the results achieved, we hope to be able to predict the development of the disease in areas that may be subject to these environmental variations. Although the forecast may carry some uncertainty, the outcomes may support decisions about investments in new plantations, for example, helping to avoid regions where the severity of greening may be exacerbated. 🍊

Citriculture

CPA: 3 lines of research



CREATED BY LEADING INSTITUTIONS, THE NEW SCIENTIFIC CENTER INVESTS IN THE GENERATION AND DISSEMINATION OF KNOWLEDGE TO TRANSFORM THE MANAGEMENT OF GREENING IN CITRUS GROVES

Approved early this year, the Applied Research Center for Innovation and Sustainability in Citriculture (CPA Citros) has the mission of promoting the establishment of new research groups and the consolidation of existing groups, aimed at developing greening control measures, particularly in areas of knowledge not currently explored by industry research. Overall, there will be three fundamental research lines. Basic lines encompass the understanding of pathogen-plant-vector interactions, with emphasis on histopathology, physiology, genetics and metabolism, as well as on the consequences of climate change. The research projects will provide the foundational knowledge to applied research involving greening management, with emphasis on host genetic resistance and on chemical, biological, physical, and crop control measures of the bacterium and its vector.

Another applied research line, focused on damage mitigation and increased production, will emphasize production systems, plant nutrition, damage reduction, loss assessment, disease occurrence risk, and the economic analysis of management measures and

their impacts. However, research on other aspects of the culture may be developed in the future. According to the vice president of CPA Citros and researcher at Fundecitrus, Renato Bassanezi, in addition to research, the center will gear considerable efforts in education, knowledge dissemination, and technology transfer. "The CPA Citros will take action not only in the ongoing human resources training programs at the institutions involved, but also in offering distance learning courses, seminars, workshops, and scientific dissemination on social media, aiming to reach a wider and more diverse audience," he highlights. "All technological advancements produced will be transferred to producers through meetings, training sessions, and field visits," he adds.

The CPA Citros is the result of an unprecedented partnership between Fundecitrus, the São Paulo Research Foundation (Fapesp), and Luiz de Queiroz School of Agriculture of the University of São Paulo (Esalq/USP). The center will be granted investments amounting to approximately R\$ 90 million in the next five years, renewable for another five. 

GET TO KNOW THE 3 RESEARCH LINES OF CPA CITROS:

01

MANAGEMENT OF THE DISEASE AND VECTOR

RESISTANCE AND BREEDING

- ▶ Deadly curry leaf tree (*Bergera koenigii*) against psyllids
- ▶ Psyllid-repellent citrus
- ▶ Psyllid-resistant citrus and related species
- ▶ Resistance genes to the bacterium
- ▶ Gene editing
- ▶ Citrus resistant to bacteria or psyllids
- ▶ Resistant citrus as rootstocks

CHEMICAL CONTROL

- ▶ Insecticide efficacy
- ▶ Insecticides in dwarfing rootstocks
- ▶ Application frequency according to shoot emergence
- ▶ Psyllid resistance to insecticides
- ▶ Biology of resistant psyllids
- ▶ Selectivity to natural enemies
- ▶ Spray volume adjustment
- ▶ Protocol and evaluation of antibiotics, enzyme inhibitors, and bacteriophages

BIOLOGICAL, PHYSICAL, AND CROP CONTROL

- ▶ Biological insecticides and their combination with chemical insecticides
- ▶ Nano and microparticles with essential oil and/or microorganisms
- ▶ Association of kaolin with vigorous and dwarfing rootstocks
- ▶ Strategies for applying kaolin on border rows
- ▶ Individual plant coverage
- ▶ Insecticide peptides
- ▶ Attractiveness of other Rutaceae species to the psyllid
- ▶ Microbial metabolites, botanical extracts, and antimicrobial peptides

02

PLANT-BACTERIA-PSYLLID INTERACTION

BIOCHEMISTRY, PHYSIOLOGY, GENETICS, AND METABOLISM

- ▶ Citrus, Myrtle, and Curry Leaf Tree (*Bergera koenigii*) Sequencing
- ▶ Defense responses: RNAs and metabolic pathways in Citrus, Myrtle, and *Bergera koenigii*
- ▶ Proteomics of bacteria in citrus/myrtle phloem
- ▶ Specific inhibitors against the bacteria
- ▶ Design of new peptides and antibiotics
- ▶ Psyllid and bacteria transmission inhibitors
- ▶ Metabolic profile of genotypes resistant and susceptible to the bacterium and repellent to the psyllid
- ▶ Physiological responses of resistant and susceptible genotypes
- ▶ Culture of the bacterium with genome and metabolome information

PATHOSYSTEM AND MICROBIOME

- ▶ Microbiome of healthy and diseased citrus
- ▶ Microbiome of the psyllid development and behavior
- ▶ Microbiome of bacterial control
- ▶ Microbiome of the plant defense system activation
- ▶ Peptides and other secondary metabolites in plants treated with microorganisms

HISTOPATHOLOGY OF THE INTERACTION

- ▶ Anatomy and ultrastructure of phloem cells in resistant and susceptible plants
- ▶ Distribution and movement of the bacteria in the phloem and interaction with plant cells and psyllid cells

CLIMATE CHANGE ACTION ON THE INTERACTION

- ▶ Temperature in the transmission and colonization of bacteria
- ▶ Periods of water deficit in the transmission and colonization of the bacteria
- ▶ Morphoanatomical and physiological changes in diseased citrus with water deficit
- ▶ Periods of high temperature and drought in disease progression

03

INCREASED PRODUCTION AND DAMAGE MITIGATION

PRODUCTION SYSTEMS

- ▶ Low-vigor varieties in *Flying Dragon*
- ▶ Variegated varieties
- ▶ Interstocking for high-density dwarfing rootstocks
- ▶ Pruning systems
- ▶ Agroforestry systems (shade and organic matter)

NUTRITION AND LOSS REDUCTION

- ▶ Micronutrients and biostimulants
- ▶ Organic compounds
- ▶ Calcium-based fertigation
- ▶ Plant growth regulators

ASSESSMENT OF RISKS AND LOSSES

- ▶ Modeling citrus growth and production
- ▶ Multiple infections in the progression of severity and damage
- ▶ Loss of production and fruit drop due to severity
- ▶ Future loss simulation
- ▶ Agricultural and climatic risk for psyllids in expansion areas
- ▶ Modeling for disease sampling in expansion areas
- ▶ Micro and macroeconomic analyses on the impact of the disease

Fundecitrus in CHINA

Cutting-edge research in greening control

TECHNICAL MISSION OF THE INSTITUTION CLOSELY MONITORED RESEARCH WITH INNOVATIVE PEPTIDE-BASED THERAPY AND ARTIFICIAL INTELLIGENCE TO VERIFY ITS EFFECTIVENESS FOR DISEASE TREATMENT

In tackling greening, building partnerships is essential to improve disease management and move towards a definitive and sustainable solution. This guideline has always been part of Fundecitrus' actions, permeating all its areas of operation with the purpose of keeping the Brazilian citrus industry competitive and resilient. Institutional alliances are becoming increasingly vital in addressing the sector's most pressing phytosanitary challenge.

With this purpose in mind,

the executive director of Fundecitrus, Juliano Ayres, and the researcher, Nelson Wulff, visited China at the end of July, on a technical mission aimed at learning about innovative strategies for controlling greening and strengthening partnerships with distinguished scientific institutions.

The agenda included visits to research centers, groves, and participation in an international symposium on biotechnological innovations used to control the disease. One of the highlights was the visit to the

greenhouse of the Chinese Academy of Sciences in Beijing, accompanied by Professor Jian Ye, director of the Department of Agromicrobiomics and Biotechnology at the Academy's Institute of Microbiology. Local laboratories are currently conducting experiments with therapeutic peptides aimed at controlling and possibly curing greening. The formulations tested include compounds described in an article published this year by Jian Ye and colleagues in the April edition of the prestigious **Journal Science**, as well as a new ge-

neration of molecules which are still in the development phase.

HOPE

Chinese research has identified, for the first time, a natural resistance mechanism against greening in citrus family plants, such as *Berberis koenigii* (curry leaf) and *Murraya paniculata* (orange jasmine). These species express a protein variant capable of activating the plants natural immunity. Based on this discovery, researchers used artificial intelligence to develop antiproteolytic antimicrobial peptides (APPs) — small molecules designed to replicate this effect in orange trees. The most promising molecule so far, the APP3-14, has shown healing effects in a controlled environment and reduced disease severity in field tests.

According to Wulff, the results obtained in the greenhouse are encouraging, although the field trials still require time for consolidation. "This work involved significant efforts from three Chinese institutions. In greenhouses, the diseased orange trees performed better with the treatment. In the field, after three months, the treated plants showed lower symptom severity than those that did not receive the peptide. Therefore, at least two years are needed for results to become robust," he explains.

He emphasizes that a defi-

nitive cure has not yet been achieved in the plants treated in the field, but a significant reduction in symptoms was observed. "The main goal of Chinese researchers is to find a cure for the disease — which would be an extraordinary breakthrough. Nevertheless, even if the new technology can only make symptoms milder, it will greatly benefit the management and productivity of groves as well as the quality of fruits," he adds.

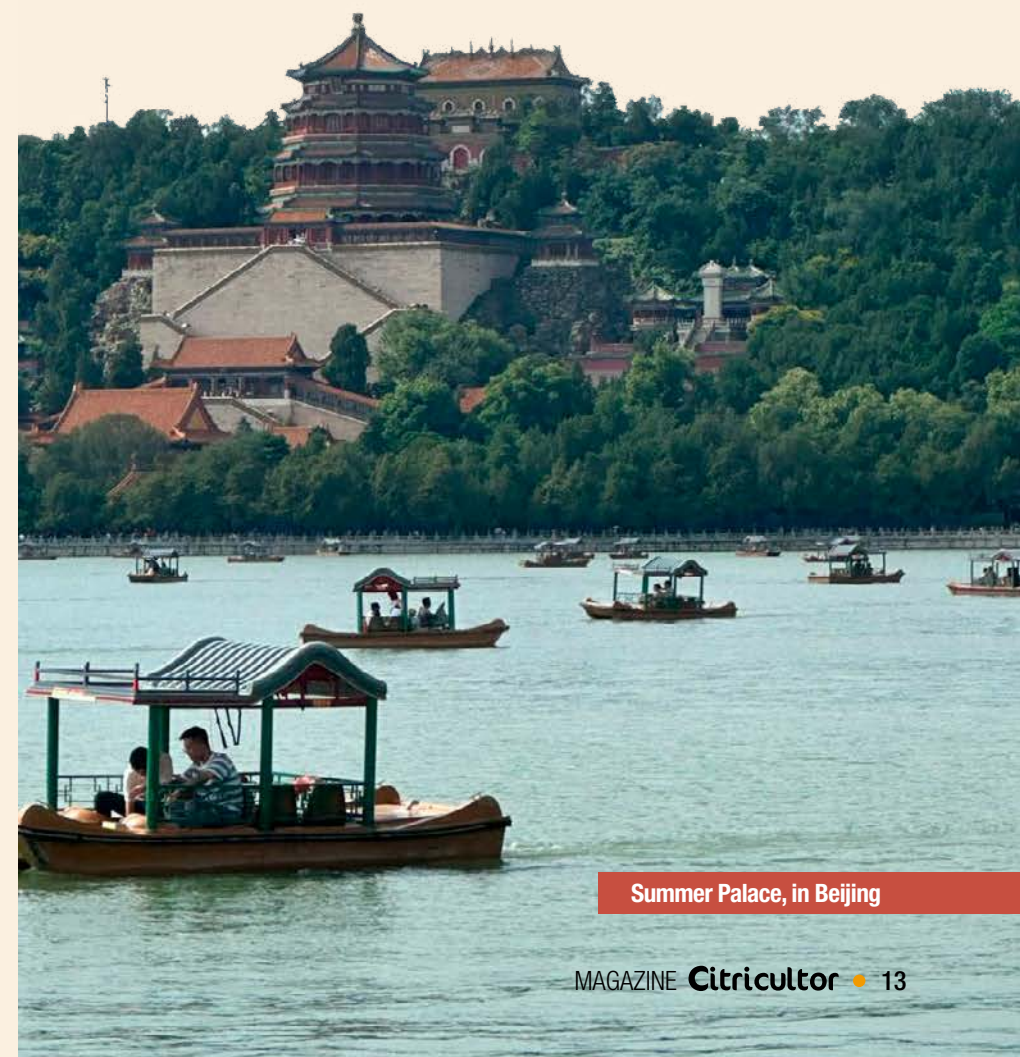
FUTURE AND SYNERGY

The next step is the rapid formalization and expansion of the

CHINESE EXPERIMENTS IN CONTROLLED ENVIRONMENTS ARE PROMISING, ALTHOUGH MORE TIME IS STILL REQUIRED TO CONFIRM FIELD TESTS

partnership with Chinese institutions, enabling the testing of peptides in Brazil — both in greenhouses and in experimental groves with plants of different ages and disease severity levels. This step is essential to evaluate the effectiveness of the treatment under the specific conditions of the Brazilian citrus belt.

"Should this strategy prove to be effective, it will represent a paradigm shift and a concrete



Summer Palace, in Beijing

hope, not only for the Brazilian citrus industry, but for the entire global production. Undoubtedly, this meeting with Chinese researchers marked a significant advancement, opening new perspectives for robust international scientific cooperation. It also paves the way for the short-term application of the technology in Brazil to assess its true potential in controlling greening — a global challenge that citrus farming has endured for years," says Ayres.

Recognized as one of the cradles of citriculture, China is currently the world's largest producer of citrus and has stood out for the rapid adoption of technologies in different sectors. Their technical and scientific modernization is also witnessed in the field, with important advances in the management of citrus farming — many of which

are aligned with Fundecitrus guidelines.

Over the past 15 years, the country has boosted its citrus industry with actions that are not foreign to São Paulo and Minas Gerais citrus growers, such as the implementation of protected nurseries, elimination of diseased plants, use of traps for monitoring and controlling the psyllid, strategic selection of planting areas, and integrated management of neighboring properties. The constant pursuit of innovation and scientific cooperation is part of Fundecitrus' DNA, both nationally and internationally. Overcoming the challenges in citrus farming requires unity, sense of urgency, and the engagement of the world's leading researchers. With this spirit of collaboration, we believe that we can uncover the 'Achilles' heel' of greening," concludes Ayres. 🍊



In Ganzhou, "cages" with anti-aphid mesh shelter the orange trees treated with peptides



Nelson Wulff; Xuefeng Wang; Wei Jun (deputy mayor); Juliano Ayres; Jian Ye; Lu Zhanjun, at Yangming Museum, in Chongyi



In Beijing, Xuefeng Wang and Jian Ye in the greenhouses of the Institute of Microbiology of the Chinese Academy of Sciences



Cover of the Science journal, April 2025



Treatment with peptides in field experiment; molecule is injected into the orange tree

Juliano Ayres and Jian Ye: future partnership between Fundecitrus and the Chinese Academy of Sciences



MAIN
PRODUCING REGIONS

Source: FAO STAT and USDA

PRODUCTION
YEAR/2023-2024 CROP
Approximately
48 million tons
of citrus

**MAIN
PRODUCTS**
Tangerine
Grapefruit
Sweet orange



**PRODUCTION
DESTINATION**

97.2%
for the
domestic
market

2.8%
for exports

TANGERINES, MANDARINS,
CLEMENTINES, AND SATSUMAS
27.0 million tons

ORANGES
7.6 million tons

OTHER CITRUS
13.15 million tons

Typical symptoms
of greening in Ganzhou, China:
smaller fruits, reverse coloration,
and mottling on the leaves

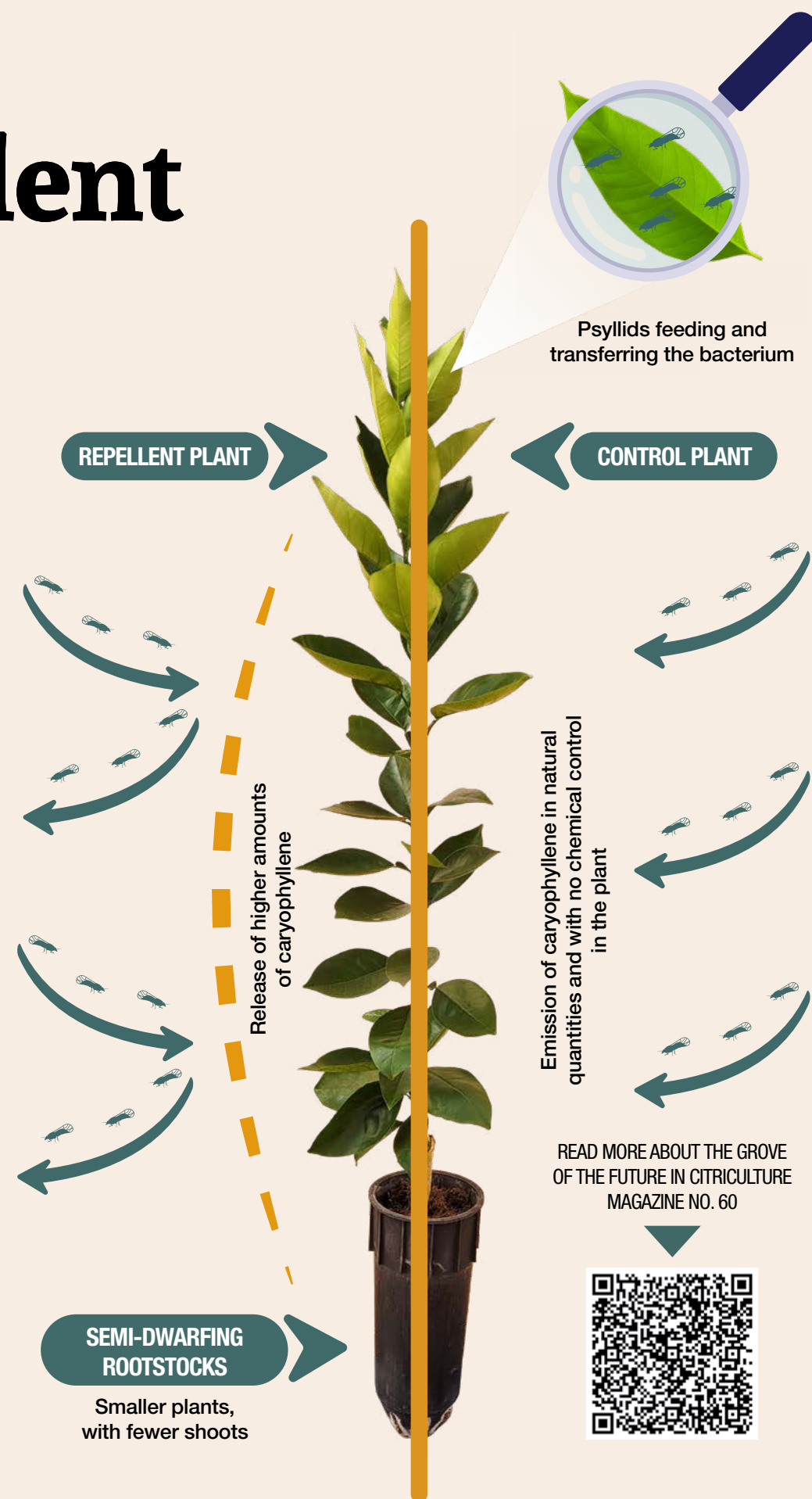
How the repellent orange tree will work

COUPLED WITH OTHER GROVE DEFENSE MECHANISMS, A VARIETY UNDER DEVELOPMENT WILL BE ABLE TO REPEL THE PSYLLID FROM THE GROVE; STUDIES SHOW THAT THE NEW ORANGE TREE EMITS UP TO 40 TIMES MORE CARYOPHYLLENE THAN THE CONVENTIONAL PLANT

B iotechnology studies developed by Fundecitrus play a strategic and transformative role in strengthening citriculture in the citrus belt, especially in the face of growing challenges posed by climate change, sustainability requirements, demand for productivity — and the greatest of all hurdles — greening. Fundecitrus, in partnership with research institutions around the world, has been steadfastly working since 2009 on the development of orange trees capable of repelling psyllids in

commercial groves. This initiative aims to provide a sustainable and long-term solution for greening mitigation.

The research project found that caryophyllene, a volatile compound released by citrus leaves — and even more intensively by guava trees — acts as a natural repellent to the psyllid. Observations made in Vietnam groves, where guava trees were interspersed with citrus trees, showed a lower incidence of greening, suggesting that the volatile compound interfered with the insect behavior.



"Based on these findings and using genetic engineering, we managed to boost the natural production of this volatile compound in orange trees," explains Fundecitrus researcher, Nelson Wulff. The analyses demonstrated that the new plants released much higher levels of the compound, when compared to control plants, making them repellent to psyllids in controlled environments. Studies reveal that the new orange trees may emit 40 times more caryophyllene than conventional plants.

GROVE OF THE FUTURE

The repellent plant will be part of a specific grove layout that will adopt a psyllid management strategy called *push, pull, and kill* (repel, attract, and exterminate). The orchestrated system works by integrating a planting system with barriers, using border lines with refuge and attraction areas to the psyllid, and curry tree plants — highly attractive to the psyllid — treated with systemic insecticides and whose genetics will incorporate lethal characteristics in the future. "Generally speaking, the border can be considered an area of attraction, without repellent features, which serves to attract and eliminate the psyllid," complements the executive director of Fundecitrus, Juliano Ayres.

Within the border rows, grafted onto semi-dwarfing rootstocks, the repellent orange trees will not be attractive to insects that manage to overcome the double barrier. Along with their repellent trait, the plants will receive an application of kaolin in the first years after planting, adding another layer of protection to them. "The psyllid repellency opens up a new perspective for tackling the world's most severe citrus disease, but it is important to note that this technology is part of an even larger project, called the grove of the future. This is the most promising path until we manage to develop a resistant plant," concludes Ayres.

CURRENT SCENARIO AND OUTLOOK

Fundecitrus is carrying out the selection and testing phase of genetically modified orange trees. As citrus fruits are perennial crops, field studies and long-term evaluations are essential to verify the effectiveness and safety of the technology before its commercial approval.

2025-2026 Orange Crop Grows 36%

WITH FAVORABLE CLIMATE, IMPROVED MANAGEMENT, AND INCREASE IN THE NUMBER OF PRODUCTIVE TREES, FUNDECITRUS FORECASTS 314.6 MILLION BOXES, REACHING THE AVERAGE LEVEL OF THE LAST TEN YEARS

The 2025-2026 orange crop forecast in the São Paulo and West-Southwest Minas Gerais citrus belt, the main orange producing region in Brazil, is estimated at 314.60 million boxes of 40.8 kg. The announcement was made by Fundecitrus at the 11th edition of the Crop Estimate Survey (PES), held in May. The projected volume represents a growth of 36.2% compared to the previous cycle, which closed at 230.87 million boxes.

This number keeps the production level within the average range of the last ten years. The significant increase is attributed to the higher number of

fruits per tree, favored by good weather conditions during the second bloom, technical advances in management by citrus growers, and an increase in the number of trees in the productive phase. The estimated average productivity for this crop is 869 boxes per hectare and 1.72 boxes per tree, representing an expressive recovery compared to the 2024-2025 crop season, which recorded 687 boxes per hectare and 1.37 boxes per tree.

BLOOM PROFILE

The year of 2024 was marked by a dry spell, with rainfall 55%

below the historical average from June to September and temperatures 3.2°C above average. This climatic condition impaired the initial flowering of orange trees, leaving only 20.7% of the projected yield attributable to this bloom. Water scarcity in the soil has particularly impacted non-irrigated areas. As a result, the fruits of this bloom were concentrated in regions with higher irrigation coverage and in places benefited by localized rains.

Recovery began in October, with more intense and regular rains that extended into December, reversing the dry scenario and favoring a second abundant bloom. This bloom was also be-

nefited by the rains in January and February 2025, which ensured good fruit setting and development. Consequently, the second bloom accounted for the largest yield share of the 2025-2026 crop, amounting to approximately 70% of the estimated production.

According to the executive director of Fundecitrus, Juliano Ayres, in addition to the more favorable weather, citrus farmers have invested in better management practices, such as nutrition, irrigation, and pest and disease control, resulting in a superior crop. "The good news is that this year's crop has returned to strong levels, offering relief and renewed optimism to the sector after a cycle of sharp decline. We need to keep the groves in good condition to remain competitive and continue advancing with confidence in Brazilian citrus farming," says Ayres.

GREENING

Greening remains the main phytosanitary problem in the São Paulo and Minas Gerais citrus industry. The high incidence and severity of the disease in the citrus belt continue to be a concern for the sector, directly impacting the fruit drop rate. In the previous crop season, the disease was the main cause of the premature fruit drop, accounting for 51% of the total 17.8% drop rate. The overall drop rate is projected at 20% for the 2025-2026 crop season, 2.2 percentage points higher than the previous cycle. ●



PRODUCTION LEVELS
ESTIMATED WITHIN
TEN-YEAR AVERAGE,
INDICATING RECOVERY
IN GROVE YIELDS

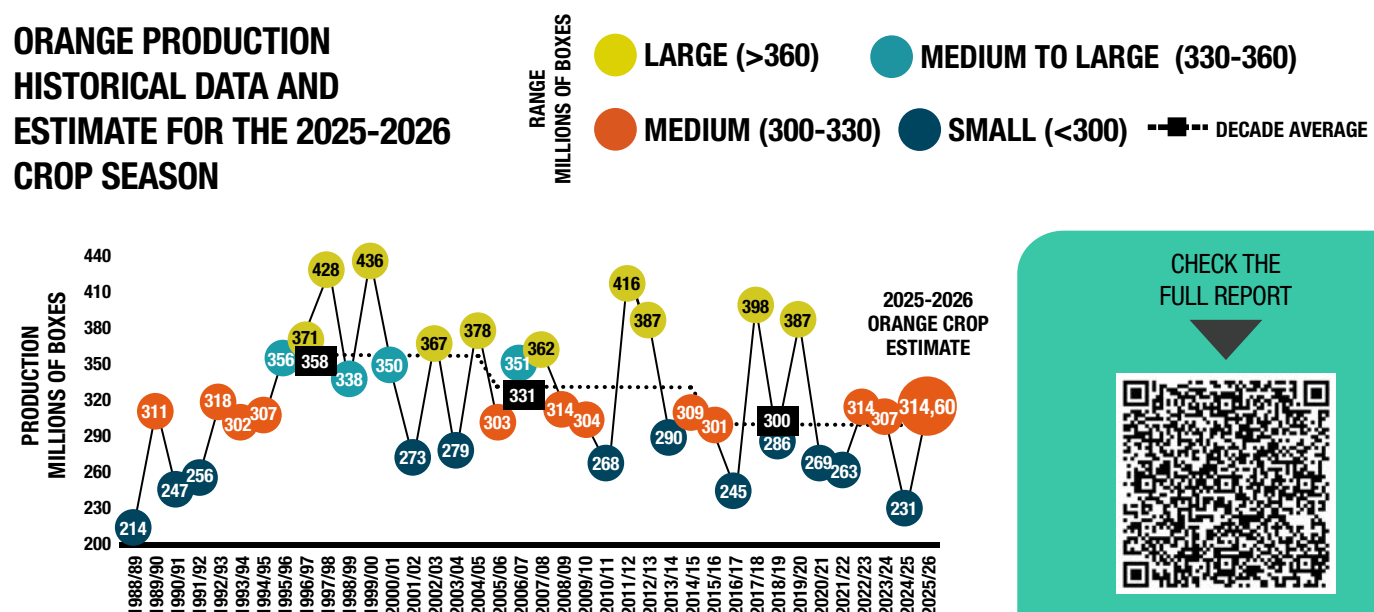
NEW MAPPING SURVEY

SHOWS EXPANSION OF CITRUS FARMING IN SP AND MG STATES

In 2025, Fundecitrus released the new edition of the Tree Inventory, which updates the data on São Paulo and Minas Gerais citrus belt. According to the survey, the region has currently 182.7 million productive trees, spread over an area of 362,000 hectares. The numbers represent a notable climb compared to the previous census, conducted in 2022. Productive age groves were expanded by 18,000 hectares, with the addition of 12.7 million fruit-bearing trees. This increase results from the low eradication rate observed in the period and the addition of trees that had not yet reached their productive phase. Another positive data revealed by the new census was the increased coverage of irrigated groves. Currently, 45% of the total area relies on

irrigation systems, a rise of nine percentage points compared to the previous census. According to the Crop Estimate Survey (PES) coordinator at Fundecitrus, Guilherme Rodriguez, the survey not only shows the growth in planted area and number of trees but also emphasizes the importance of continuous monitoring. “The inventory is an essential planning tool for the citrus sector, playing a strategic role in guiding growers’ decisions and providing an in-depth overview of citriculture in the world’s leading orange-producing region,” he concludes. The Tree Inventory and Crop Estimate Survey are supervised statistically by the full professor (volunteer) of FCAV/Unesp, José Carlos Barbosa.

ORANGE PRODUCTION HISTORICAL DATA AND ESTIMATE FOR THE 2025-2026 CROP SEASON



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Rootstocks as production and management strategy for greening

STUDIES WITH VIGOROUS AND DWARFING VARIETIES OFFER STRATEGIC SOLUTIONS FOR PRODUCTION IN SCENARIOS OF CLIMATE CHANGE AND DISEASE PROGRESSION

Since 2014, Fundecitrus, Embrapa Mandioca e Fruticultura (Cassava and Fruticulture), and Fundação Coopercitrus Credicitrus — with the support of the São Paulo Research Foundation (Fapesp) — have been gearing joint efforts to conduct studies for the development of new rootstocks for citrus farming in order to meet the diverse demands of the field, notably more intensive orange production systems aiming at the sustainability of the sector and its long-term competitive edge. Results from studies in more than 30 experimental fields across the citrus belt show that

no rootstock has demonstrated resistance to greening, the leading challenge in global citrus farming. However, some of them stand out for their tolerance to drought, high yield, and easy management.

The studies indicate that the global temperature rise in recent years, because of climate change, has directly impacted rainfall patterns, requiring producers to implement strategic measures to mitigate the effects of these changes on grove production. According to the Embrapa researcher at Fundecitrus, Eduardo Girardi, who is spearheading this work, dry seasons have always existed

in the citrus belt, and citrus growers have adapted their farming practice to the climatic situation. However, it is important to bear in mind that the scenario is no longer the same. "Significant droughts have always marked the history of citrus farming, and despite the expansion of irrigation, most groves remain rainfed. It turns out that climate change, with periods of more intense and damaging droughts, along with the expansion of citrus farming to new and hotter regions, pose challenges that require strategic adjustments to mitigate the effects on production," he emphasizes.

VARIETIES

The results of these studies provide citrus growers with important rootstock varieties to meet various production strategies. Vigorous rootstocks, such

as IAC 1710, Sunki Tropical tangerine, and some new citrandarins, as well as the traditional Rangpur lime, are more resistant to dry periods and exhibit greater sprouting under limited water supply. This intense and out-of-season sprouting requires additional measures against psyllids to prevent further spread of greening. "On the other hand, these rootstocks are much more productive in rain-fed agriculture. We are talking about double the yield per tree when compared to dwarf or semi-dwarf varieties. However, vigorous rootstocks cannot be planted too densely, as they require more intensive pruning and strict management, with particular attention to spray coverage to prevent psyllid infestations," he explains.

On the other hand, semi-dwarfing and dwarfing rootstocks, such as the Flying Dragon trifoliate, are mainly

**DWARFING
ROOTSTOCKS REDUCE
PLANT VIGOR AND
HINDER PSYLLID
FEEDING**

used to reduce plant size by 30 to 70%, facilitating farming practices, and increasing planting density, which can result in higher yield per area in irrigated and well-managed groves. These rootstocks are also chosen according to their adaptability to different soil types, disease resistance, and influence on fruit quality. According to Girardi, these rootstocks are more sensitive to drought and consequently they should be grown in irrigated systems. These plants have a lower yield per tree; therefore, higher planting density is required to achieve greater productivity per area. Since they are smaller, their advantage is facilitating psyllid monitoring and spraying, as well as enabling less intense pruning and future mechanized harvesting," he affirms.



▶ Drought-tolerant rootstock with off-season sprouting (left) compared to the traditional drought-sensitive Swingle citrumelo (right)



IMPACTS ON GREENING INCIDENCE

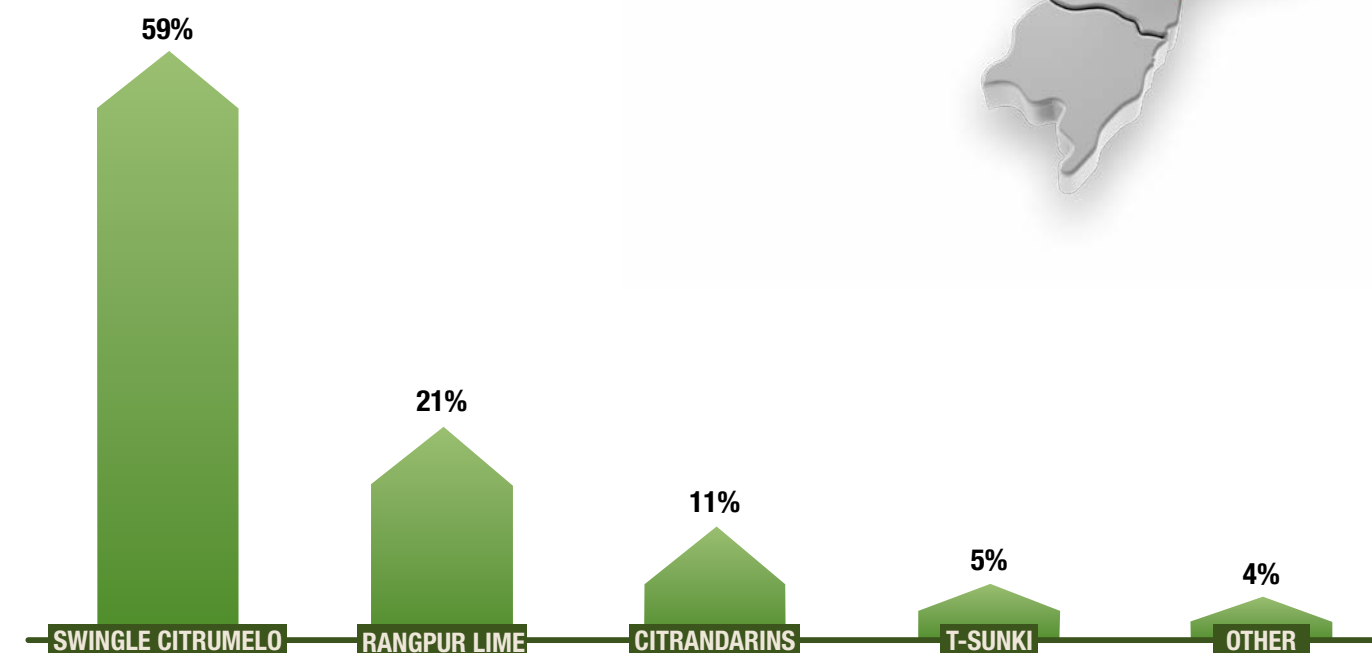
Several studies have been conducted in citriculture to unearth a plant resistant to greening. It has been quite a long journey involving several countries and researchers from different areas of science. Meanwhile, other strategies have stood out as measures to mitigate the effects of the disease. Experiments conducted by Fundecitrus and Embrapa at the Bebedouro Experimental Station (SP) have been showing that it is possible to develop rootstocks that hardly multiply the greening bacterium — but the study still requires more time. “The work took place in a

field-controlled environment using Australian citrus hybrids. However, the rather basic experiment requires further studies. This demonstrates that the path is viable and promising, but there are other limiting factors, such as susceptibility to citrus blight virus. Unfortunately, we are aware that no rootstock currently makes the canopy tolerant or resistant to greening. Nevertheless, in the future, the combination of both canopy and rootstock resistant varieties will be highly important,” explains Girardi. On the other hand, according to the executive direc-

tor of Fundecitrus, Juliano Ayres, studies are pointing to the conclusion that dwarfing and semi-dwarfing rootstocks will facilitate disease management in groves and, hopefully, mitigate disease incidence. “These plants are smaller and have the unique ability to reduce the canopy vigor. Hence, they produce less sprouting, which is the main food supply for psyllids. With fewer sprouts and a more effective management coverage, protection will be of higher quality, hindering the spread of psyllids and even generating savings in the volume of products used,” he concludes.

SALE OF ROOTSTOCKS IN THE CITRUS BELT

According to data from the Department of Agriculture and Livestock Advocacy of the State of São Paulo, almost 18 million rootstocks were sold in the state of São Paulo in 2024



FUTURE

According to the experiments, some hybrids mainly with tangerines and trifoliate are expected to be commercialized soon, offering traits of high drought tolerance, just like the traditional vigorous rootstocks. For instance, in the severe drought recorded in 2024 in Bebedouro, this group did not show wilting of new plants and maintained a satisfactory production level in the following crop. “This is a very promising result,” he celebrates. Other rootstocks,

from the dwarfing or semi-dwarfing group, were more sensitive to drought, but some presented better results than the Swingle citrumelo, a variety present in at least 56% of the citrus belt groves. By 2026, 10 new rootstock varieties are expected to reach the market.

CHOOSING WISELY

According to Fundecitrus agronomist, Olavo Bianchi, it is important for citrus growers to consider important issues upon choosing which rootstock to use. Bearing in mind the purpose of

commercialization, the key factor is the alignment between planting strategy, canopy variety, management, and regional climatic conditions. “When producers are about to establish their groves, it is very important to think about the future, the harvesting operation, water supply, labor, and the combination of rootstock and canopy. It is worth pointing out that we live in a very diverse citrus industry, with very different climatic and geographical characteristics. All of this should be factored in the equation,” he explains. 🍊

Orange Beyond Its Juice

FROM PEEL TO PULP: THE ADDED VALUE OF ORANGE BY-PRODUCTS AND THEIR NEW APPLICATIONS

Brazil is undoubtedly the leading player in orange juice production worldwide. Approximately 80% of the beverage consumed comes from our domestic industry, consolidating a production chain that supplies markets in Europe, the United States, and Asia. With its highly technological industrial complex and a specialized agricultural sector, Brazil has become a global benchmark both in production and innovation in this industry.

Over the past few decades, orange juice has always been the flagship of the citrus chain, whether in concentrated form or as NFC (*Not From Concentrate*) — ready to drink juice. However, the sector has undergone a deep transformation: the so-called orange by-products — previously holding a secondary role — have now become valuable elements within this process.

Their image has changed so dramatically that even the terminology has been adjusted within the sector. “We are using the term by-products, which has always been used. It is a term that appears in textbooks. However, in recent

years, we have been shifting to ingredients or coproducts, because they have become incredibly relevant for the entire chain,” says the research and development manager of the multinational JBT, which provides technological solutions for the food and beverage industry, Daniela Kharfan.

Essential oils, for example, have become considerably valuable. “In recent years, the peel essential oil has led to exponential price increases and a wealth of applications in various segments,” she explains. Essential oil, d-limonene, terpenes, pectin, and fibers are among the orange-derived substances that have established their own markets, with demand steadily increasing. “Inside the orange, the juice itself is available, which can be concentrated or NFC. But apart from juice, there are citrus oils — such as essential oil, d-limonene, and terpenes — and solids, including frozen orange pulp, pulp for extraction, and pectin. These coproducts have

become indispensable for the sustainability of the business,” she claims.

SUSTAINABILITY AND NEW OPPORTUNITIES

The rising demand for these coproducts is directly linked to the industry's growing concern with sustainability and economic efficiency. The full use of oranges reduces waste, increases sector profitability, and creates new market opportunities.

JBT, in partnership with the nanotechnology company BioSmart, for exam-



WHAT CAN BE USED FROM ORANGES?

The whole use of oranges goes far beyond what we drink from the glass. The industry extracts several components with a long list of applications, ranging from food to cleaning products and cosmetics.



Peel essential oil

Used in the fragrance, cosmetics, cleaning products, and even in food flavoring industries.



Frozen orange pulp

Small segments of oranges frozen and exported to be reconstituted into juice in other countries.



D-limonene

Natural solvent extracted from the peel, used in eco-friendly cleaning products and in the chemical industry.



Pectin extraction

Substance found in the orange peel, used in the production of jams, sweets, and pharmaceutical products.



Terpenes

Compounds with aromatic and therapeutic properties, used in the formulation of perfumes and medicines.



Citrus meal and pellets

Solid orange waste processed and transformed into animal feed.

ple, has been studying new ways to harness orange waste, especially in the development of sustainable bioproducts. One of their latest projects investigates the use of citrus waste to produce bioplastics and other biodegradable materials, demonstrating the potential of oranges beyond the food sector. The study highlights that this approach directly contributes to reducing the environmental impact and to paying due value to the production chain.

Another initiative of the company is the development of the BioECO Solutions project, focused on using orange coproducts to create new sustainable ingredients. The investigations are placing a bet on the use of these ingredients in formulations for cosmetics, functional foods, and even in the pharmaceutical industry, exploring antioxidant and bioactive properties of the fruit. This approach further expands

the possibilities for the application of ingredients extracted from oranges. “A sharp change witnessed in recent years was the relentless pursuit of advanced use for the compounds found in oranges. They are abundant in nutritional and aromatic qualities, rendering them suitable for multiple applications,” confirms Daniela Kharfan.

This movement strengthens the circular economy in the citrus industry, ensuring a useful and profitable destination to every part of the orange. Once prized almost solely for their juice, oranges have become a complete asset, with ingredients supporting a wide range of industries worldwide.

Moreover, the Polytechnic School of the University of São Paulo (USP) has been seeking alternatives for the more efficient utilization of orange waste, aiming to add value to these by-pro-

ducts and curb the environmental impact. Another example is the research conducted by the São Paulo State University (Unesp), which studied the water activity in co-products of the juice industry, including orange peel, with the purpose of optimizing the drying and storage processes of these materials. These academic and industrial initiatives reinforce the trend of valuing orange by-products, thereby contributing to sustainability and innovation in the Brazilian citrus sector. 🍊

THE RISING DEMAND FOR THESE COPRODUCTS IS DIRECTLY LINKED TO THE INDUSTRY'S GROWING CONCERN WITH SUSTAINABILITY AND ECONOMIC EFFICIENCY



Fundecitrus initiative that supports producers in adopting good labor practices, promoting safer, responsible, and legislation-compliant management.

