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RESEARCH ARTICLE

TERRITORIAL CHARACTERIZATION AND PHYTOSANITARY RISK CLASSIFICATION OF CITRUS FRUIT CONSOLIDATION UNITS IN THE RECÔNCAVO REGION OF BAHIA, BRAZIL

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Abstract

Fruits entering Consolidation Units originate from multiple properties and regions, further emphasizing their logistical importance and role in phytosanitary connectivity. The phytosanitary risk of 15 units located in five municipalities in the Recôncavo region of Bahia was characterized and classified. The study incorporated secondary data, a structured questionnaire comprising 37 questions, field observations, georeferencing, and aerial orthomosaics obtained using a drone and processed with opensource software. The orthomosaics enabled the delimitation of 0–200 m, 200–400 m, and 400–600 m distance zones between the units and nearby orchards. These zones were interpreted as a gradient of spatial exposure rather than merely as distancebased categories. Most units (93.3%) processed Tahiti acid lime, 86.7% received fruits from thirdparty orchards, and 66.7% supplied the international market. The highest operational intensity was recorded in June and July. Only 33.3% of the units cleaned vehicles and equipment, whereas 73.3% reported disposing of waste in open dumps. In the integrated assessment, 66.7% of the units were classified as high risk, 6.7% as medium risk, and 26.7% as low risk. The study concluded that the location of Consolidation Units may pose a risk of introducing diseases such as huanglongbing (HLB) and citrus canker into orchards in the Recôncavo region of Bahia. This risk arises from the interaction among geographical exposure, phytosanitary vulnerabilities, and the management and disposal of unmarketable fruits. The findings may also guide professionals and inspection authorities in adopting methodologies and technologies that can be implemented without significantly increasing operational costs.

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Introduction: -

Tahiti acid lime cultivation in the Recôncavo region of Bahia constitutes a citrus supply chain of high economic and commercial significance, within a scenario where citrus fruits rank among the most cultivated and traded globally, with a distinction between fresh fruit and processing markets (Spreen et al., 2020). In this context, both lemons and limes have gained increasing relevance in international trade, with global exports growing by approximately 50.9% between 2014 and 2023. Furthermore, limes stand out for their market appeal, which is driven by their seedlessness, deep green color, and high juice yield (Khezev et al., 2025; Romero-Barrera et al., 2022).This economic importance requires Consolidation Units (Packinghouses) to operate with a high standard of organization, as postharvest losses, lack of infrastructure, and inadequate management compromise the competitiveness of the supply chain and its ability to add value (Spreen et al., 2020).The quality of the tahiti acid lime is the result of the interaction among various pre and postharvest factors, such as the production location, the rootstock used, storage temperature, the sanitization process, and the harvesting method (Romero-Barrera et al., 2022).

From a phytosanitary standpoint, the compliance of Consolidation Units is critical because Huanglongbing (HLB)transmitted by the Asian citrus psyllid (Diaphorina citri) and ranked among the most impactful citrus diseasesspreads primarily through the transport of infected or contaminated plant material and fruits (Wang, 2020; Bragard et al., 2021; Younas et al., 2025). Although Bahia is recognized as a diseasefree area, it requires continuous monitoring due to the imminent risk of introduction, particularly in a producing region where awareness of the issue remains low and technical assistance is limited (De Oliveira et al., 2021). Thus, the assessment of these units must integrate traceability, operational barriers, and waste management under a systems approachcombining interventions across multiple stages of the supply chain to minimize pest exposure, infestation, and establishment, while also demanding the proper disposal of agroindustrial waste to prevent environmental contamination and preserve sanitary control (Van Klinken et al., 2020).

The objective of this study was to characterize and classify the phytosanitary risk of 15 citrus fruit Consolidation Units (Packinghouses) located in Cruz das Almas, Governador Mangabeira, Muritiba, Sapeaçu, and Santo Antônio de Jesus, in the Recôncavo region of Bahia. To achieve this, official data, field observations, waste management information, and images captured by remotely piloted aircraft (RPA) were integrated, with an emphasis on factors associated with pest introduction and dissemination.

Materials and Methods: -

The study was conducted across 15 citrus fruit Consolidation Units (Packinghouses) located in the municipalities of Cruz das Almas, Governador Mangabeira, Muritiba, Santo Antônio de Jesus, and Sapeaçu, in the Recôncavo region of Bahia. Aerial images and orthomosaics were acquired using a DJI Air 2S remotely piloted aircraft (model DA2SUE1), equipped with an FC3411 camera (serial number 42UQJ3E23A00B3). The equipment is approved by the National Telecommunications Agency (ANATEL, under code No. 00586-23-06500) and registered with the National Civil Aviation Agency (ANAC, under tail number PP-758378250). All flights were previously requested and authorized by the competent regulatory bodies through the System for Requesting Airspace Access by Unmanned Aircraft (SARPAS). Flight operations were conducted at altitudes ranging from 50 to 120 meters above ground level (AGL), complying with the maximum altitude limits established for this type of operation. Flight altitude was individually determined based on the location, spatial extent, surrounding environmental features, and the presence of potential obstacles within the areas surrounding the Consolidation Units.

Flight planning and automated execution were carried out using the Copterus, DroneLink, or Map Pilot Pro applications, selected according to compatibility and the specific requirements of each area. Aerial photographs were processed using WebODMa free and opensource platform developed by OpenDroneMapas well as the free software Google Earth. The use of these software programs enabled the generation of georeferenced images without requiring specific software licenses for image processing and treatment. Furthermore, the adoption of opensource and free tools aimed to demonstrate the applicability of lowcost or costfree technological resources in inspection activities, territorial mapping, scientific research, and plant health defense, thereby broadening the potential use of these tools by field practitioners, public institutions, and the scientific community. Each Consolidation Unit was characterized regarding its geographic location, fruit reception and processing capacity, physical infrastructure, operational workflow, and waste management procedures for discarded fruit, debris, and plant residues generated after processing. Distances between the units and local, municipal, state, and federal roads were also evaluated, considering that proximity to transit routes could facilitate the ingress and movement of fruits lacking phytosanitary documentation or from unidentified sources.

Distances between the Consolidation Units, access roads, and orchards belonging to Production Units were determined based on fieldcollected geographic coordinates, the generated orthomosaics, and geoprocessing tools within a Geographic Information System (GIS) environment. Based on this information, proximity zones were established, and the spatial distribution of key features relevant to phytosanitary risk assessment was analyzed. For the characterization of the units, a data collection instrument comprising 37 questions was applied, covering aspects related to the types of processed products, the origin and destination of the fruits, processing capacity, physical infrastructure, hygiene conditions, flow of people and vehicles, sanitation of machinery, equipment, and tools, as well as the final disposal of unsellable products and plant residues. In the risk assessment, information regarding the behavior of the Asian citrus psyllid (Diaphorina citri) was considered, including its dispersal capacity, flight radius, and the influence of the height and distribution of vegetation surrounding the units. Primary pathways for the dissemination of the citrus canker pathogen, Xanthomonas citri subsp. citri (formerly named Xanthomonas axonopodis pv. citri), were also evaluated.

The analysis examined the potential for pathogen spread via contaminated seedlings, fruits, and plant debris, as well as clothing, harvesting tools, machinery, equipment, vehicles, animals, insects, wind, and winddriven rain. Accordingly, the inherent risk factors for each Consolidation Unit were evaluated, including the number of employees, movement of people, vehicle traffic, fruit provenance, cleaning and disinfection protocols for machinery and utensils, and procedures adopted for waste handling and disposal. Documentary data were extracted from the databases of the State Agency for Agricultural Defense of Bahia (ADAB), specifically from the SIDAB system, which records information on Plant Transit Permits (PTVs), Internal Plant Transit Permits (PTIVs), Phytosanitary Certificates of Origin (CFOs), and Consolidated Phytosanitary Certificates of Origin (CFOCs). Based on the information provided in the CFOs, the origin, volume, and characteristics of the fruits originating from Production Units and entering the Consolidation Units were identified.Documentary information was complemented by data collected through the survey instrument applied across the 15 Consolidation Units. Integrating these datasets enabled the calculation of total volumes as well as monthly and annual averages of fruits received, processed, and dispatched by each unit. The results of this analysis enabled the identification of peak months for fruit arrival, processing, and dispatch, which were considered critical periods due to the heightened movement of products, people, vehicles, equipment, and plant residues. These periods represented key focus windows for phytosanitary surveillance and inspection activities, given the potential increase in the risk of introduction and dissemination of citrus pests and diseases.

Results and Discussion: -

Citrus fruit Consolidation Units in the Recôncavo region of Bahia are essential to spatial organization and trade within the supply chain, as they structure fruit flows from various production areas to markets with diverse operational and sanitary requirements. That being said, these facilities are not limited to serving merely as entry and exit points for products; they also function as logistical hubs for consolidation, sorting, processing, storage, and distributionwhich elevates their economic importance while simultaneously heightening their vulnerability to phytosanitary risks. This territorial centrality becomes even more significant when considering that expanding the spatial reach of these units generally leads to increased operational complexity. Diversity in product origin, commercial destinations, processed goods, active workforce, and peak movement periods exerts immense pressure on physical infrastructure, hygiene protocols, traceability, and sanitary control. Consequently, the operational efficiency of these units is directly tied to managing workflows, minimizing losses, and ensuring compliance with plant health protection standards.

For this reason, the disposal of unsellable fruit and processing waste cannot be treated as a secondary stage, but rather as an element that directly impacts the quality of management across the entire operation. This is because handling rejected material tangibly reflects a unit's internal organizational standard, its capacity to segregate risks, and its commitment to sustainability and biosecurity. Therefore, improper waste management not only compromises system efficiency but also increases the likelihood of maintaining and spreading phytopathogenic agents. Within this perspective, the discussion must be guided by the intersection among spatial coverage, heightened operational flows, and sanitary vulnerability. As processing volume increases within Consolidation Units, there is a corresponding need for proportional sanitary barriers, robust traceability systems, and safe procedures for disposing of unsellable fruit and plant residues. Lacking these measures, facilities become increasingly susceptible to the introduction and dissemination of agents associated with the entry of absent quarantine pestsparticularly during periods of high fruit movement, in close proximity to production areas, and in the absence of preventive controls.

Territorial scope of the units:-
Figure 1 indicates that 92.9% of the survey instruments were completed by technical managers, whereas 7.1% were completed by the owners. This result highlights the source of the data, showing a predominance of respondents directly involved in technical management. Nevertheless, it should be noted that these data remain selfreported and require validation through field observations, official documents, and aerial imagery.

Figure 2 illustrates the distribution of the 15 units across the five municipalities, with Cruz das Almas concentrating 53.3% of the total facilities. Figure 2 also depicts a wellbalanced spatial distribution between rural areas (53.3%) and urban areas (46.7%).

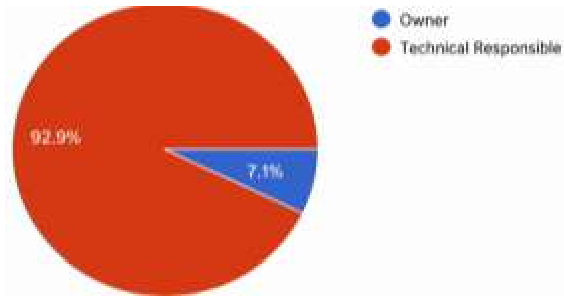


Figure 1. Distribution of respondents completing the data collection instrument across 14 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

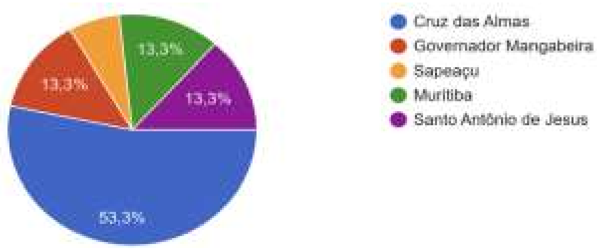


Figure 2. Distribution of fruit consolidation units by municipality of location across 15 facilities in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

The spatial distribution of the Consolidation Units demonstrates their essential role in the territorial organization of citrus farming in the Recôncavo region of Bahia. Regional centrality for receiving, processing, and distributing fruit is evidenced by the concentration of 53.3% of the units in Cruz das Almas. Concurrently, the distribution of 53.3% of the facilities in rural areas and 46.7% in urban areas highlights a chain that directly links production sites with processing operations. Rural positioning provides physical proximity to orchards and Production Units, whereas urban location tends to offer better connectivity to services, transport networks, and consumer markets. While this spatial arrangement streamlines logistics, it also establishes interconnecting routes through which fruit, packaging, transport, labor, and plant waste continuously circulate.

The majority of questionnaires were completed by technical managers, suggesting that the data were predominantly provided by personnel directly involved in the operational management of the Consolidation Units. This direct involvement tends to enhance the descriptive consistency of the data, despite the selfreported nature of the survey instrument (Baležentis et al., 2023; MacDonald, 2020). Consequently, crossreferencing these findings with complementary validation strategies is crucial, as the agrifood chain literature emphasizes that analytical robustness depends on the observed scale, the supply chain links covered, and the integration of diverse datasets and spatial methods (Baležentis et al., 2023; Meyer et al., 2023; Ribeiro et al., 2023). This becomes even more critical in territorialized food systems, where the connections among production, circulation, and land use are frequently not fully captured by direct surveys alone and require validation through observational and geospatial data (Meyer et al., 2023).

The presence of 53.3% of the units in Cruz das Almas can be viewed as an indicator of territorial centrality, as agrifood networks typically structure themselves around a limited number of hubs capable of concentrating flows, coordination, and logistical infrastructure (Cheng et al., 2023; Yang et al., 2023; Pan et al., 2024). This perspective aligns with studies indicating that the spatial distribution of production dictates the location of logistical hubs, and that hubandspoke models can integrate resources, maximize infrastructure utilization, and reduce transport costs (Pan et al., 2024). In citrus supply chains, centralizing collection and distribution within structured hubs optimizes efficiency, reduces reliance on intermediaries, and increases financial returns for growers, consolidating the strategic role of these facilities in regional coordination (Vargas-Muñoz et al., 2025). The wellbalanced distribution between facilities located in rural and urban areas points to a network that directly connects production zones, processing sites, and consumer markets, consistent with the literature on ruralurban linkages in food systems (Schreiber et al., 2020; Meyer et al., 2023).

While this spatial arrangement can enhance logistics, it also increases the movement of fruit, packaging, vehicles, personnel, and waste, meaning that the efficiency of Consolidation Units (Packinghouses) relies on the synergy between infrastructure, coordination, and waste management (Li et al., 2023). According to the literature on agricultural and citrus supply chains, postharvest losses, weak market integration, and inadequate infrastructure represent major sources of inefficiency, whereas the management of decaying fruit and residues is critical to achieving favorable economic and environmental performance (Gardas et al., 2019). Therefore, the disposal of unsellable fruit should be recognized as the ultimate indicator of a facility's operational quality: circular and reverse logistics models demonstrate that waste streams can be reintegrated into the supply chainreducing food loss, water consumption, emissions, and operational costswhile centralized, wellplanned arrangements often leverage economies of scale to foster system sustainability (Shahsavani et al., 2024; Cavenaghi et al., 2026).

The spatial reach of these Consolidation Units extended beyond their host municipalities. Although all facilities processed and transformed fruit from the Recôncavo region of Bahia, several also received produce from the Litoral Norte, Chapada Diamantina, and Far South regions of Bahia. This highlights these units as hubs of convergence and redistribution, as 86.7% handled fruit from external sources. While this diversity of origins ensures a more consistent supply and market expansion, it increases traceability complexity, given that each additional supplier or region of origin represents an extra link that must be identified, documented, and monitored. According to Figure 3, 66.7% of the establishments engage in export activities, underscoring the production, market, and territorial reach of these Consolidation Units. This indicates that a substantial proportion of these facilities are integrated into commercial networks that extend beyond regional and national borders, thereby driving higher requirements for quality, standardization, phytosanitary certification, and product traceability.

In Figure 4, which details processed products intended for export, the Tahiti acid lime emerged as the most prominent fruit, with 80% of the facilities highlighting its relevance, while 13.3% mentioned sweet oranges. Three units, representing 20% of the total, reported that they do not process products for export. The Tahiti acid lime stands out as the predominant variety, rendering it crucial for both trade and the operations of the evaluated facilities**.**

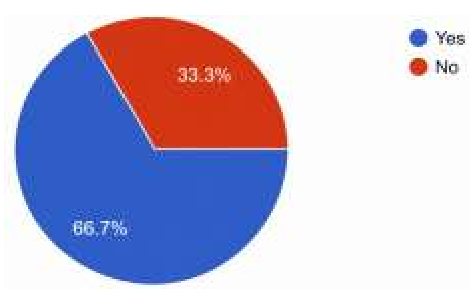


Figure 3. Proportion of fruit consolidation units serving export markets across 15 facilities in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

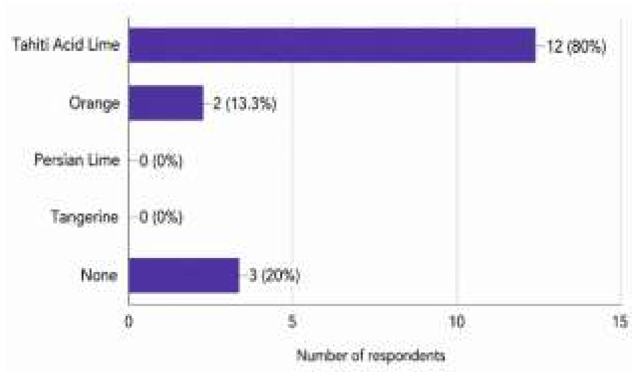


Figure 4. Frequency of processed products intended for export markets across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

The production specialization of the Consolidation Units (Packinghouses) is depicted in Figures 5 to 9. In Figure 5, 93.3% of the units reported processing Tahiti acid lime (Citrus latifolia). In Figure 6, 66.7% stated they process sweet orange (Citrus sinensis). Sweet lime (Citrus limettioides), shown in Figure 7, was reported by 20% of the units, and mandarin (Citrus reticulata), shown in Figure 8, by 13.3%. In Figure 9, all units reported no processing of noncitrus species. These findings corroborate the specialization of the facilities within the citrus supply chain, as well as their direct alignment with the central theme of this thesis. The high frequency of Tahiti acid lime processing indicates that this fruit accounts for the majority of operations, even as sweet orange, sweet lime, and mandarin suggest a degree of diversification within the citrus group.

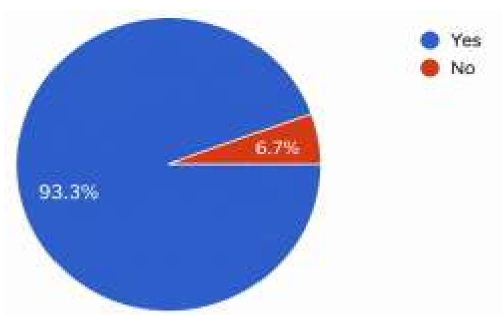


Figure 5. Proportion of consolidation units processing Tahiti acid lime (Citrus latifolia) across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

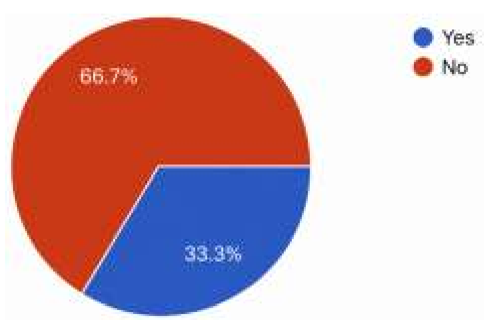


Figure 6. Proportion of consolidation units processing sweet orange (Citrus sinensis) across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

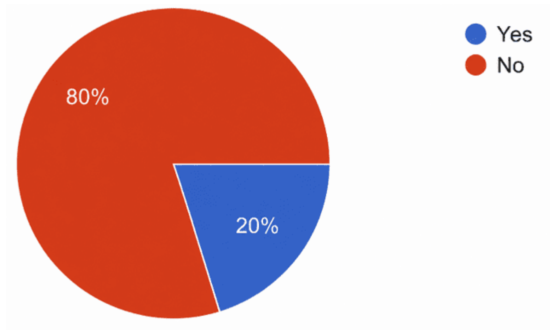


Figure 7. Proportion of consolidation units processing sweet lime (Citrus limettioides) across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

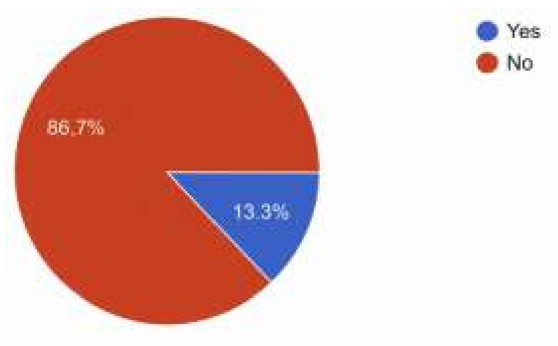


Figure 8. Proportion of consolidation units processing mandarin (Citrus reticulata) across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

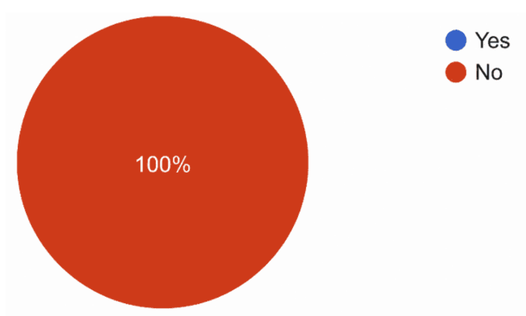


Figure 9. Proportion of consolidation units processing noncitrus fruit species across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

Product diversification should not be viewed merely as a market advantage. Processing multiple citrus species can involve batches from different farms, regions, and cultivation methods, all moving through shared reception, sorting, processing, storage, and dispatch areas. Vehicles, containers, machinery, tools, and personnel may also be shared. Consequently, the diversification of processed fruits makes source identification, batch segregation, facility sanitation, and the maintenance of inflow and outflow records even more critical. Without these guidelines, products from different sources can mix within the operational workflow, compromising traceability and complicating the identification of the origin farm in the event of disease outbreaks or documentary noncompliance.

According to Figure 10, 46.7% of the Consolidation Units (Packinghouses) processed fruit from their own production, whereas 53.3% did not utilize this source of supply. This result demonstrates that nearly half of the establishments exhibited some level of direct integration between production and postharvest handling. This relationship was further detailed in Figure 11, which showed that in 20% of the cases, the Production Unit was located on the same property as the Consolidation Unit. In 33.3% of the cases, ownproduction occurred on a separate property, while 46.7% reported having no dedicated Production Unit. The proximity of the Consolidation Unit to the Production Unit can reduce transport time, logistical costs, and postharvest damage. However, it also directly links the orchard to the packing facility, vehicle traffic, and waste storage or disposal sites. Therefore, improper management of unsellable fruit, leaves, branches, crates, and equipment can become a more significant phytosanitary factor under these conditions.

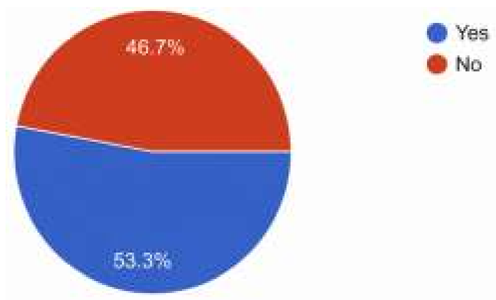


Figure 10. Distribution of fruit consolidation units by location in rural or urban areas across 15 facilities in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

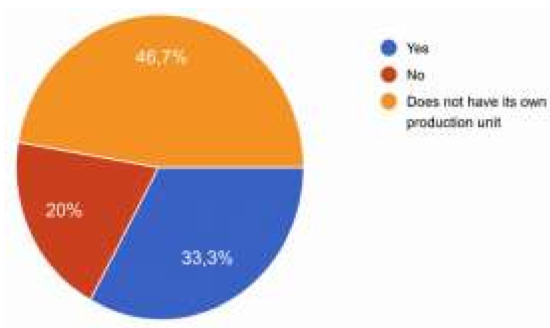


Figure 11. Distribution of consolidation units according to the location of their own production unit, whether on the same property or in a distinct area, across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

Figure 12 indicated that 86.7% of the facilities received and processed thirdparty fruit, whereas only 13.3% did not engage in this practice. This finding is fundamental to understanding the territorial function fulfilled by the Consolidation Units (Packinghouses). The predominant processing of thirdparty fruit demonstrates that these facilities do not operate merely as extensions of a single orchard or business enterprise, but rather as hubs of convergence where produce from multiple properties and suppliers gathers. From an economic perspective, this operational structure can lead to more efficient capacity utilization, a more consistent product supply, and the ability to serve markets that demand high volumes and uninterrupted availability. From a phytosanitary standpoint, however, each additional supplier represents a new point of origin that must be identified, documented, and monitored.

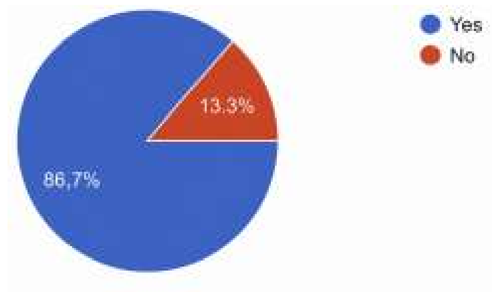


Figure 12. Proportion of consolidation units receiving and processing thirdparty fruit across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

When fruit from multiple properties is not properly segregated, it can lose its identity during the receiving, processing, packaging, or dispatch stages. This compromises traceability and complicates identifying the origin of a batch when a phytosanitary issue is detected. Therefore, receiving thirdparty fruit requires registering suppliers, identifying origin properties, verifying phytosanitary documentation, segregating batches, and controlling transport vehicles and packaginga requirement primarily enforced through the use of the CFO (Phytosanitary Certificate of Origin), which is issued by a qualified technical professional responsible for the Production Unit.

Figures 13 to 16 demonstrate the territorial extent of this fruit supply. In Figure 13, all units reported receiving and processing fruit from the Recôncavo region of Bahia, indicating a strong integration of these facilities with the regional production base. Regarding Figure 14, 20% of the units reported receiving fruit from the Chapada Diamantina region, whereas 80% did not. Thus, only three of the 15 units received produce from this region. In Figure 15, 13.3% of the units reported receiving and processing fruit from the Far South region of Bahia, while 86.7% lacked this supply flow—representing the lowest percentage of fruit reception among all regions external to the Recôncavo covered by the survey instrument. In Figure 16, 40% of the units stated they receive fruit from the Litoral Norte region, whereas 60% did not, making this area the primary external source of fruit outside the Recôncavo.

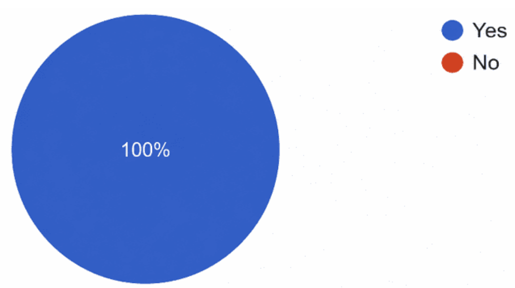


Figure 13. Proportion of consolidation units receiving and processing fruit from the Recôncavo region of Bahia across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

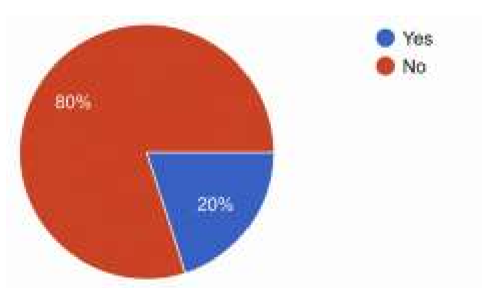


Figure 14. Proportion of consolidation units receiving and processing fruit from the Chapada Diamantina region across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

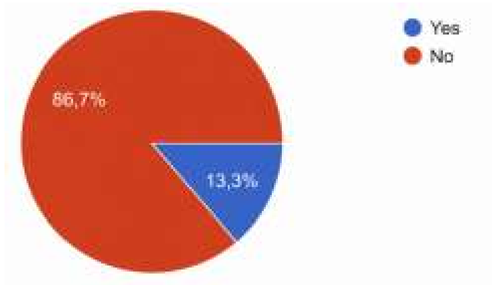


Figure 15. Proportion of consolidation units receiving and processing fruit from the Far South region of the state of Bahia across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

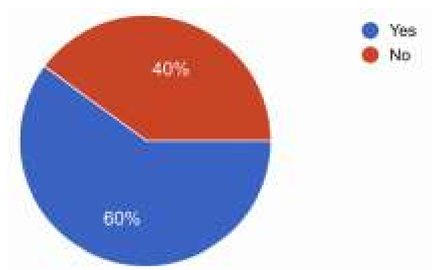


Figure 16. Proportion of consolidation units receiving and processing fruit from the Litoral Norte region of Bahia across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

Analysis of Figures 5 to 9 reinforces that the Consolidation Units are specialized within the citrus supply chain, characterized by operational focus on a limited range of fruits and the total absence of noncitrus speciesa pattern aligned with the economic and commercial importance of citrus in global agrifood supply chains (Beshara et al., 2024; Peña-Orozco et al., 2023; Muñoz Torres et al., 2022). This specialization is also consistent with production systems oriented toward highly demanding markets, where production, postharvest handling, and marketing tend to organize around specific quality and sustainability standards (Muñoz Torres et al., 2022; Peña-Orozco et al., 2023).

The predominance of Tahiti acid lime, accompanied by the secondary presence of sweet orange, sweet lime, and mandarin, indicates a diversification restricted to the citrus group itself rather than a broad diversification of the production system. This pattern is typical of supply chains where a few commodities concentrate volume, value, and managerial focus (Beshara et al., 2024; Qian et al., 2020). Nevertheless, this specialization should not be viewed solely as a market advantage, because processing different citrus species within shared facilities increases operational complexity and heightens the need for internal controls over product origin, batch segregation, and lot movement (Qian et al., 2020). Joint processing of fruits originating from multiple properties, regions, and production systems elevates the risk of batch mixing during receiving, sorting, packaging, and dispatch stages, thereby reducing traceability precision if packinghouse design and operations are not adequately controlled. Food processing literature demonstrates that achieving traceability in this environment is more challenging than in primary production precisely due to raw material diversity, batch mixing, and resource transformations throughout processing. Consequently, maintaining fruit identity requires physical segregation of batches, linkage between batches and traceable units, and a combination of control methods tailored to the operational setting (Qian et al., 2020).

Experimental evidence shows that simple modifications to packing line design can reduce fruit mixing and improve traceability. Sanitation requirements also escalate in this context, as packinghouses face resource constraints, knowledge gaps, outdated equipment, language barriers, and high staff turnover, while cleaning verification frequently relies solely on visual inspection. Therefore, strengthening training materials, standardizing messaging on cleaning and sanitation, and investing in appropriate equipment and surface materials are recommended to mitigate contamination risks and prevent loss of batch identity (Hamilton et al., 2025). Figures 10 to 16 demonstrate that these facilities go beyond simply processing ownfarm production, functioning primarily as hubs of convergence for thirdparty fruit and distinct territoriesa characteristic typical of citrus supply chains with low actor coordination and fragmented supply (Peña-Orozco et al., 2023; Peña-Orozco et al., 2021; Vargas-Muñoz et al., 2025). In such contexts, coordination among growers, intermediaries, and retailers tends to enhance the logistical and social performance of the supply chain, reducing costs and emissions while expanding employment, particularly when integrated into threeechelon chains (Peña-Orozco et al., 2023).

Studies on smallholder citrus supply chains reveal that joint harvest consolidation and distribution through food hubs reduce logistical costs, improve load utilization, and can increase farmers' income by 55.9% compared to individual sales (Vargas-Muñoz et al., 2025). This territorial role also depends on infrastructure and market access, as smallscale citrus growers face recurring constraints involving credit, substandard marketing facilities, high transport costs, and poor road infrastructure connecting rural areas to urban markets (Naseer et al., 2023). The strong grounding in the Recôncavo, combined with fruit reception from Litoral Norte, Chapada Diamantina, and Far South regions, points to a regional citrus redistribution network; however, literature indicates that longer supply chains are not inherently less sustainable, as social and environmental impacts vary according to production, management, and transport strategies (Muñoz Torres et al., 2022).

This territorial expansion heightens phytosanitary requirements, as plant and fruit diseases can compromise domestic and international citrus trade across the entire supply chain (Rovetto et al., 2024; Strano et al., 2022). Research recommends an integrated approach encompassing preharvest monitoring, postharvest inspection, packinghouse procedures, shipping conditions, equipment sanitation, and temperature management during storage and transport (Hattingh et al., 2020; Rovetto et al., 2024). This is particularly crucial for export markets, where the cold chain is central to extending shelf life and complying with phytosanitary protocols, and where the majority of intransit noncompliances stem from temperature deviations (Khumalo et al., 2021). Regulatory pressure has also intensified, driven by stricter sanitary and phytosanitary requirements and frequent barriers linked to pests, chemical residues, and resource limitations for implementing risk management systems (Phologane et al., 2024). Although risk varies according to the pathogen and pathway involved, probabilistic models demonstrate that risk assessment must encompass every stage of the fruit pathway, from orchard production to final destination (Gottwald et al., 2021). Furthermore, imported consignments showing symptoms have yielded viable isolates of Xanthomonas citri pv. citri, reinforcing the necessity for continuous surveillance by both exporting and importing countries (Volkers et al., 2024).

Finally, waste management and the handling of unsellable fruit must be treated as integral components of facility management rather than peripheral activities, as circular citrus supply chain models demonstrate that integrated decisions regarding production, distribution, recycling, and facility location can simultaneously enhance environmental and economic performance (Goodarzian et al., 2022). In supply chains designed under circular economy principles, it was possible to eliminate plastic crate waste and fruit residue, achieve a 42% reduction in water consumption, decrease carbon emissions by 3%, and slightly reduce total operational costs compared to linear networks (Shahsavani et al., 2024). Evidence from fully traceable fresh produce chains also indicates that sharing time and temperature data yields more noticeable benefits in downstream links and contributes to reducing food waste (Glew et al., 2021). Collectively, these sources support the interpretation that production specialization, thirdparty fruit reception, and interterritorial circulation elevate the economic significance of Consolidation Units, while necessitating proportional controls in traceability, segregation, sanitation, cold chain management, phytosanitary documentation, and waste management (Beshara et al., 2024; Bollen et al., 2007; Khumalo et al., 2021).

Operational pressure and seasonality:-

Figure 17 illustrates the number of employees allocated across the 15 Consolidation Units. A predominance of facilities operating with small teams was observed, with 40% employing only one to five workers. In comparison, 26.7% had between 30 and 50 employees, while 20% employed more than 50. The staff ranges of 10 to 20 and 20 to 30 workers accounted for 6.7% of the units each. These findings highlight that the evaluated facilities vary in size and labor structure, ranging from smallscale operations to those with large workforces and higher operational complexity. The peak fruit processing months are highlighted in Figure 18. June and July were cited by 93.3% of the units, representing the main period of operational intensification. January was indicated by 73.3%, May by 46.7%, and August by 40%. The months of February, March, and April were highlighted by 33.3% of the facilities each, while September, October, November, and December were mentioned by 20%. These percentages are not mutually exclusive, as the survey allowed respondents to select multiple months. The data indicate that the highest operational concentration occurred between June and July, with another significant peak period at the beginning of the year.

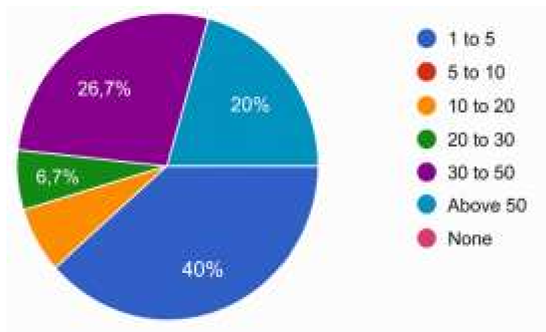


Figure 17. Distribution of fruit consolidation units by number of employees across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026

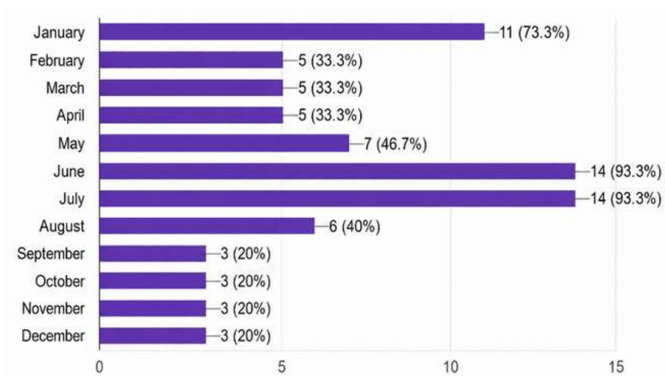


Figure 18. Frequency of months indicated as peak fruit processing periods across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

The Consolidation Units (Packinghouses) processed the species depicted in Figures 5 to 9. The main fruit was Tahiti acid lime, found in 93.3% of the facilities. For sweet orange, processing reached 66.7%, whereas sweet lime was processed in 20% and mandarin in 13.3% of the units. No facility reported processing noncitrus species. Thus, the establishments specialized in citrus postharvest handling, predominantly Tahiti acid lime, although a portion also worked with other species within the same group. Because a single facility could process more than one species, the percentages should be interpreted as independent responses. As shown in Figure 10, 46.7% of the units utilized fruit from their own Production Unit, while 53.3% did not make use of ownproduction fruit. In Question 24, 20% of respondents indicated that the Production Unit was located on the same property as the Consolidation Unit, 33.3% reported that own production occurred on another property, and 46.7% marked that they did not have a dedicated Production Unit. The minor discrepancy between the percentages in Figures 10 and 11 may stem from the response format of the questions regarding own production and Production Unit location.

As illustrated in Figure 12, 86.7% of the Consolidation Units processed thirdparty fruit, whereas 13.3% did not receive products from external suppliers. Collectively, Figures 5 to 10, Figure 12, Figure 17, and Figure 18 suggest that the analyzed units vary in workforce scale, exhibit seasonality in processing concentration, display citrus specialization, and rely predominantly on raw material sourced from multiple suppliers. The data reveal that the Consolidation Units are operationally heterogeneous, with small and largescale structures coexisting, pointing to variations in their capacity to receive, process, and distribute fruit. Literature indicates that larger facilities can benefit, in terms of operation and cost, from economies of scale; however, this does not eliminate the need to align physical capacity, operational organization, and product flow (Ge et al., 2018). Facility management regarding fresh fruit is intimately tied to the coordination between material flow, information flow, and the organization of supply activities. The concentration of processing in June and July, alongside another peak in January, serves as an indicator of operational seasonalitya wellrecognized characteristic in citrus supply chains where coordinating stages, inputs, and outputs across the supply chain is essential (Beshara et al., 2024; Zacarías et al., 2020). Citrus destined for the fresh market requires careful harvesting, handling, processing, storage, and transport, meaning that peak processing periods heighten the operational pressure on sanitation, batch segregation, dispatch, and loss minimization (Zacarías et al., 2020).

Tahiti acid lime and sweet orange predominated, followed by sweet lime and mandarin, reinforcing the citrus specialization of these facilities and aligning with the economic and commercial importance of citrus in agrifood supply chains (Beshara et al., 2024; Zacarías et al., 2020). Simultaneously, the finding that 86.7% of the units process thirdparty fruit while only a fraction utilizes ownfarm production suggests that these facilities act as hubs of raw material concentration from multiple suppliers. Previous research on agroindustrial supply indicates that fruit processing industries commonly engage multiple suppliers to secure supply alternatives, higher volumes, and continuity of supply (Suryaningrat, 2016). In this configuration, aspects such as raw material handling, storage, scheduling, inventory, capacity, and facility organization directly impact processing performance (Suryaningrat, 2016). The data therefore indicate that operational risk in Consolidation Units is linked not only to team size or processed volume, but also to the ability to maintain control, continuity, and quality within a system that is seasonal, citrusspecialized, and dependent on multiple supply sources (Beshara et al., 2024; Suryaningrat, 2016; Zacarías et al., 2020).

Sanitary barriers:-

Figure 19 presents the data regarding employee training to recognize fruit with symptoms of Huanglongbing, also known as Greening or HLB. Of the 15 Consolidation Units (Packinghouses) evaluated, ninerepresenting 60%indicated that their staff had participated in this type of training. The remaining six facilities, accounting for 40%, reported that their employees had not been trained to identify symptomatic fruit for the disease. Figure 20 illustrates the data on staff training for recognizing fruit with symptoms of citrus canker. Eighty percent of the sample (twelve units) indicated that their employees had received training, whereas three units (20%) reported having no trained workers for this function. Thus, the proportion of training dedicated to citrus canker recognition was higher than that for HLB.

Figure 21 depicts the reported existence of a communication protocol with agricultural defense agencies in the event of detecting absent quarantine pests. Fourteen responses were recorded for this question, one fewer than the total number of surveyed units. All 14 respondents (100%) affirmed that the company possessed a communication protocol, with no negative responses. This result indicates that the vast majority declared adopting procedures to notify relevant authorities when encountering suspicious phytosanitary situations. In Figure 22, the implementation of sanitation practices for vehicles and equipment arriving at the packing facility can be observed. This procedure was carried out by only 33.3% of the units (five out of 15 responded yes). The remaining ten facilities (66.7%) stated that they do not perform this procedure. Among the four indicators analyzed, facility/vehicle sanitation recorded the lowest frequency of positive responses when compared to the training percentages and the reported presence of communication protocols.

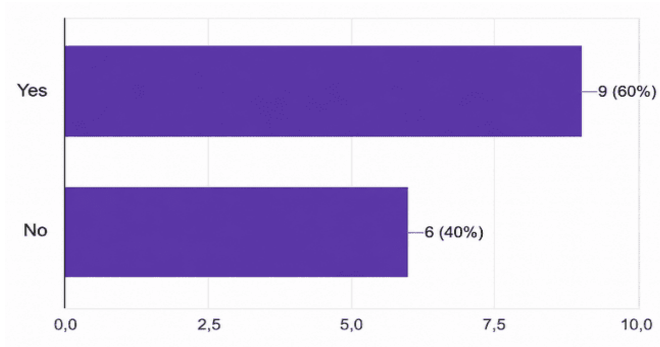


Figure 19. Proportion of consolidation units whose employees received training to identify symptomatic fruit for greening (HLB) across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

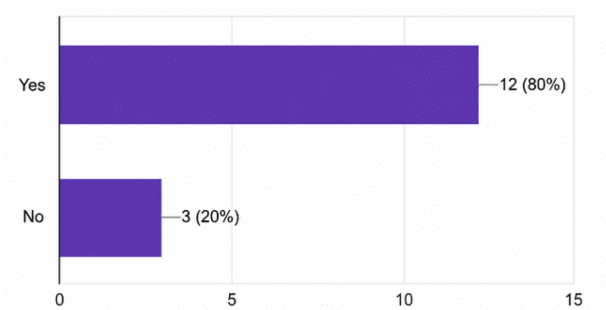


Figure 20. Proportion of consolidation units whose employees received training to identify symptomatic fruit for citrus canker across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

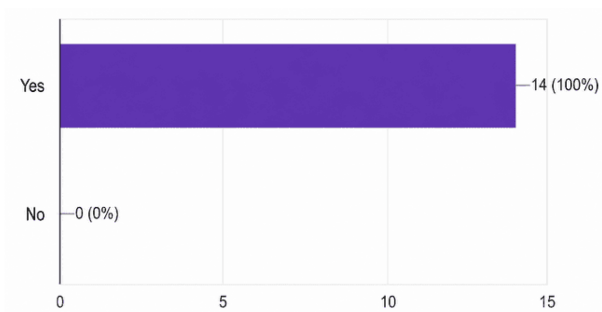


Figure 21. Proportion of consolidation units possessing a communication protocol with agricultural defense agencies in the event of detecting absent quarantine pests across 14 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

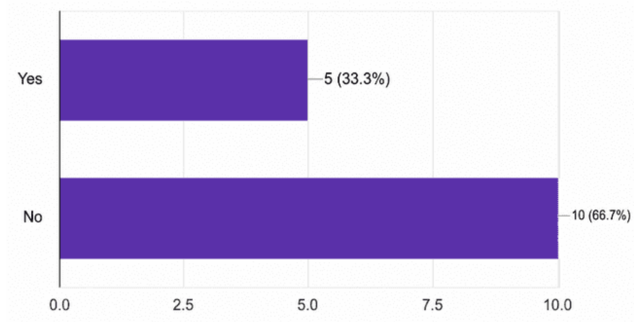


Figure 22. Proportion of consolidation units implementing sanitation practices for vehicles and equipment entering the packing facility across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

Taken together, Figures 19 to 22 show that symptom recognition practices and communication protocols with agricultural defense agencies were more prevalent among the facilities than preventive measures against the entry of vehicles and equipment. Although 60% and 80% of units indicated having received training on HLB and citrus canker, respectively, and all respondents in Figure 21 affirmed having a communication protocol, only onethird of the facilities reported implementing sanitation procedures. This contrast suggests that identification and response activities are more established than daytoday preventive practices.

The results indicate that the Consolidation Units have made greater progress in recognition and response initiatives than in preventive actions integrated into daily operations. The higher training level for citrus canker compared to HLB, combined with the nearuniversal adoption of communication protocols with agricultural defense authorities, suggests an institutional surveillance framework that is already partially embedded. However, literature indicates that knowledge gaps, resource constraints, and communication barriers remain frequent obstacles to the consistent implementation of sanitary practices in packinghouses (Hamilton et al., 2025). This is particularly critical because high employee turnover tends to compromise training consistency, thereby reducing the standardization of risk recognition in daily operations (Hamilton et al., 2025). Therefore, while the 60% rate for HLB and 80% for citrus canker reflect a considerable investment in capacity building, it remains insufficient for a scenario where phytosanitary action must be rapid and wellcommunicated (Hamilton et al., 2025).

On the other hand, the low adoption rate of vehicle and equipment sanitation reveals a vulnerability in what represents the most preventive link in terms of operational biosecurity. Prelogistical sanitization in citrus packinghouses is a mandatory step, and experimental investigations demonstrate that appropriate sanitizers can eliminate Xanthomonas citri from infected fruit, mitigating the risk of citrus canker (Dilarri et al., 2020). Regular application of standardized operating procedures for cleaning and sanitization in fruit facilities reduces environmental microbial load; however, efficacy varies across surfaces and decreases in areas with residue buildup, such as wax, requiring more rigorous procedures and continuous verification (Rolon et al., 2024). Thus, the fact that only onethird of the units perform sanitation highlights that the main obstacle lies not merely in identifying symptoms or reporting suspected cases, but in translating that knowledge into consistent operational preventive measures (Hamilton et al., 2025).

Unsellable fruit and waste disposal:-

Figure 23 illustrates the handling of plant residues and unsellable fruit generated in the Consolidation Units. Open dumps were the most frequently cited destination, reported by 73.3% of the facilities. Composting was mentioned by 20%, while burial and animal feed utilization were cited by 13.3% each. No unit reported burning these materials. These percentages are not mutually exclusive, as the survey allowed respondents to select multiple options. The modes of transportation used to haul these residues are illustrated in Figure 24. Own transportation and municipal public waste collection were cited by 53.3% of the units each, while 13.3% utilized thirdparty services. Multiple options could also be selected for this question.

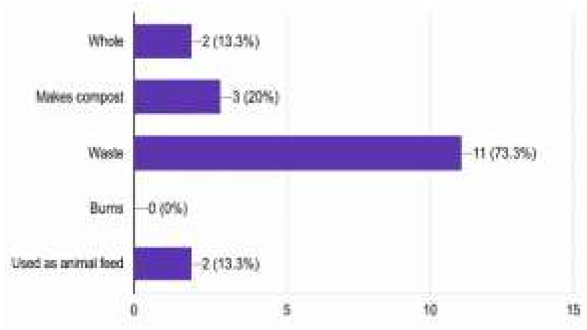


Figure 23. Frequency of final disposal methods for plant residues and unsellable fruit generated in the consolidation units across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

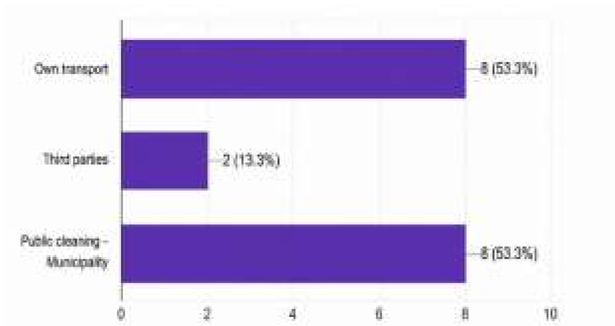


Figure 24. Frequency of transport modes utilized for the disposal of plant residues and unsellable fruit generated in the consolidation units across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

The results indicate that plant residue management in the Consolidation Units still relies on traditional disposal methods, given that open dumps were the most common destination, whereas composting and alternative recycling practices were sparsely adopted. According to the literature, landfilling and disposal at final disposal sites remain the most common alternatives for solid waste management due to their ease of implementation; however, they entail high land consumption, leachate generation, gas release, and other environmental damages, particularly when disposal occurs in open, poorly controlled dumps (Peng et al., 2023; Siddiqua et al., 2022). Regarding fruit and vegetable waste, this situation becomes even more critical, as this organic fraction possesses high potential for valorization through composting, bioinput production, or other recycling methods. This indicates that the predominant disposal in open dumps reflects low management circularity (Esparza et al., 2020; Russo et al., 2021; Campos et al., 2020).

This low frequency of composting among the facilities contrasts with literature reviews identifying composting as one of the most widely applied alternatives for organic waste recyclinga tool capable of diverting a significant portion of the biodegradable fraction from landfills, returning nutrients to the soil, and mitigating the environmental pressure of final disposal (Oviedo-Ocaña et al., 2023; De Souza & Drumond, 2022; Pajura, 2023). Transportrelated data demonstrate that sanitary and environmental risks reside not only at the final disposal destination, but across the entire removal, collection, and transport chain offsite. Literature highlights that waste management operates as an integrated systemspanning from source identification to final Destination and that failures at any stage can increase emissions, loss of control, and environmental exposure (Peng et al., 2023; Oviedo-Ocaña et al., 2023; Mehta et al., 2024). Given that private transport and municipal public collection were the most frequently cited transport modes, it can be inferred that multiple, likely nonstandardized logistical flows coexist, making welldefined procedures for residue segregation, packaging, and traceability up to final disposal even more critical.

This aspect is crucial because fruit and vegetable residues are highly perishable, high in moisture, and decompose rapidly, promoting foul odors, insect attraction, microbial activity, and processing issues in the absence of prompt and efficient handling (Nenciu et al., 2022; Lee et al., 2024). Consequently, the vast majority of facilities still depend on offsite disposal in open dumps, demonstrating that the primary challenge lies not merely in waste removal, but in developing a management system that integrates logistical control, environmentally adequate disposal, and greater utilization of a biomass that, to date, is largely treated as waste (Chirumamilla, 2026; Mehta et al., 2024).

Inspection and corrective capacity:-

Figure 25 shows official inspection visits conducted by the Bahia Agricultural Defense State Agency (ADAB), while Figure 26 illustrates inspection visits by the Ministry of Agriculture and Livestock (MAPA). These visits serve to verify compliance with phytosanitary and documentary requirements applicable to Consolidation Units. According to Figure 27, 46.7% of the units reported recorded noncompliances, whereas 53.3% indicated receiving no notices of noncompliance. Figure 28 categorizes the types of failures: 26.7% pertained to load inflow and outflow logging, 13.3% to outdated logbooks, and 13.3% to the absence of required documentation such as CFO, PTV, or PTIV. These noncompliances are significant, particularly in facilities that receive fruit from multiple origins and distribute products to broader markets. Figure 29 presents how the identified noncompliances were resolved. This outcome allows for evaluating not only failure occurrence, but also whether facilities possess the operational capacity to implement corrective actions mandated by inspection authorities. In other words, official inspection mitigates risk when it detects noncompliance, outlines required corrective actions, and subsequently verifies their effective implementation.

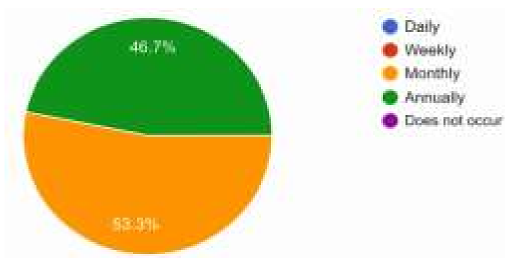


Figure 25. Frequency distribution of inspection visits by the state agricultural defense agency (ADAB) to consolidation units across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

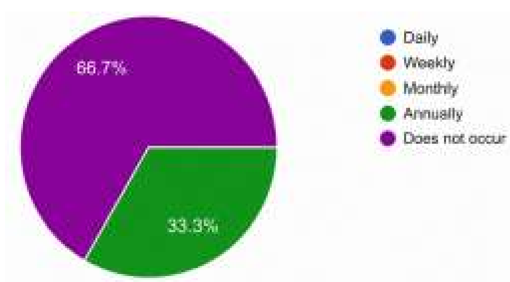


Figure 26. Frequency distribution of inspection visits by the federal agricultural defense agency (MAPA) to consolidation units across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

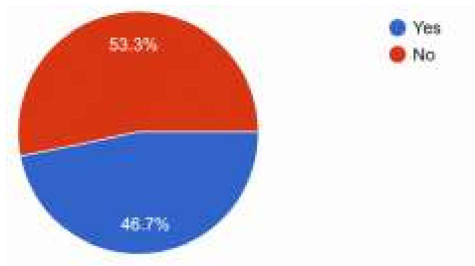


Figure 27. Proportion of consolidation units with recorded noncompliances during agricultural inspections across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

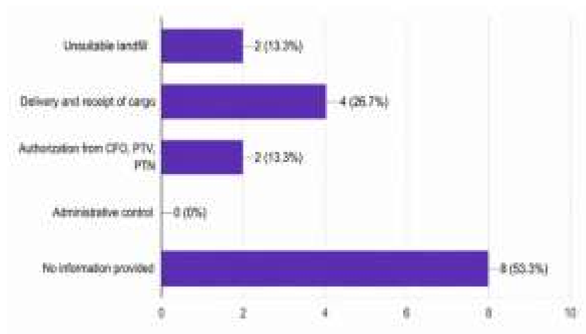


Figure 28. Frequency of noncompliance types recorded in consolidation units during agricultural inspections across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

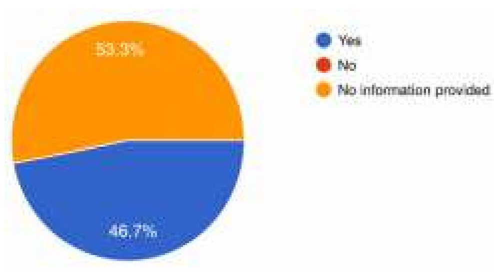


Figure 29. Distribution of consolidation units according to the resolution of noncompliances recorded during agricultural inspections across 15 fruit consolidation units in five municipalities of the Recôncavo region of Bahia. Data collected via structured questionnaire during 2024, 2025, and through June 2026.

The findings indicate that inspections carried out by ADAB and MAPA play a crucial regulatory role, as regular surveillance actions, alongside the existence of formal response and contingency plans, are fundamental to effective sanitary control (Rodrigues et al., 2019). Fault detection is most efficient in Brazilian agricultural supply chains when institutional resources and frequent interactions between inspection agencies and inspected facilities are present, particularly in scenarios where facilities are diverse and exhibit varying levels of operational organization (Rodrigues et al., 2019; Bezerra et al., 2019). Therefore, the fact that 46.7% of the facilities reported noncompliances should not be interpreted as a lack of control, but rather as evidence that inspection is successfully identifying critical areas related to traceability and documentary compliance. This is significant because official inspection systems generate valuable data by recording noncompliances and their operational impacts (Leite et al., 2022; Bidone et al., 2021).

The identified failures demonstrate that the primary challenge lies in controlling inflows and outflows, as issues regarding load movement tracking, uptodate logbooks, and valid documentation compromise the traceability of products moving across diverse origins and destinations. Studies on agricultural transport inspection indicate that documentary and operational irregularities stem from noncompliance with legislation, requiring increased inspection frequency, particularly because transport without proper sanitary certification elevates regulatory and sanitary risks (Bezerra et al., 2019). Furthermore, the significance of Figure 29 lies in demonstrating that inspection is not limited to identifying noncompliances; it also guides corrective actions and enables subsequent verification of their implementationan approach aligned with institutional integrity and compliance enhancement frameworks in the agricultural sector (Novacki & Machado, 2020; Bidone et al., 2021). Consequently, the data reveal that risk within Consolidation Units (Packinghouses) decreases when inspection is continuous, thorough, and documented, complemented by the actual corrective capacity of inspected facilities.

Integrated classification and implications for agricultural defense:-

Figure 30 combines the orthomosaics of the 15 Consolidation Units with their spatial distribution and final phytosanitary risk classification, an analytical approach aligned with literature citing drones as essential tools for precision agriculture and phytosanitary monitoring (Kouadio et al., 2023; Olson & Anderson, 2021). Specifically, Unmanned Aerial Vehicles (UAVs) capture highresolution spatial and temporal imagery at controllable altitudes and angles, enabling standardized digital documentation over timehighly beneficial for comparative surveys across facilities (Kouadio et al., 2023). The generation of georeferenced orthomosaics is equally technically grounded, as they result from photogrammetric processing that corrects imagery distortions to produce a uniformscale spatial representation ideal for territorial analysis and Decision making (González-García et al., 2020; Ding et al., 2023).

These products are not merely illustrative; they allow detailed observation of internal facility layouts and their immediate surroundings, including access roads, structures, surrounding vegetation, and adjacent agricultural areas (Ding et al., 2023; Olson & Anderson, 2021; Vélez et al., 2023). Literature indicates that orthomosaics and other UAVderived products can surpass single pointbased field observations in detailed mapping, biotic stress detection, spatial reconstruction, and critical area identification (Kouadio et al., 2023; Vélez et al., 2023; Su et al., 2021). Thus, integrating these products with structured questionnaires, direct observations, and documentary records strengthens phytosanitary assessments by merging spatial and operational evidence into a unified analytical baseline (Olson & Anderson, 2021; Rao et al., 2026).

The concentric buffer zones of 0 to 200 m, 200 to 400 m, and 400 to 600 m should be understood as analytical proximity zones rather than automatic risk classifications, as supported by spatial modeling literature (Nanny lugo Eguchi et al., 2026; Shih et al., 2021; Guerrero-Cabrera et al., 2020). Buffer analyses are valuable for estimating exposure and delineating priority areas according to spatial epidemiology studies, although proximity effects depend on the scale of the process, density of connected facilities, and the considered pathway of dissemination (Shih et al., 2021; Guerrero-Cabrera et al., 2020; Mastin et al., 2019). Regarding HLB, this precaution is especially critical because its spatial dynamics result from concurrent multiscale processes: vector transmission occurs across local to long distances, heavily influenced by citrus orchard density and transportation corridors (Gottwald, 2010; Galvan et al., 2023).

The centrality of Cruz das Almas and intermunicipal connectivity are similarly supported by the concept that phytosanitary risk is not determined solely by facility location, but by inflow and outflow movements linking the unit to other production regions (Mastin et al., 2019; Rao et al., 2026). Within the citrus supply chain, traceability is a critical requirement for accessing product and path information across all stages from production to delivery (Cader et al., 2025; Tagarakis et al., 2021; Rashid et al., 2026). This is particularly true for facilities processing thirdparty fruit, as batch mixing and product transformation complicate traceability, necessitating rigorous linkages between physical lots and internal records (Qian et al., 2020).

Spatial exposure alone does not yield a definitive risk classification, as actual risk is governed by the presence and efficacy of operational and sanitary barriers. Phytosanitary management literature indicates that risk reduction cannot rely on a single strategy, requiring instead a combination of independent measures across production, harvest, certification, and postcertification phases (Mastin et al., 2019). For instance, in the case of citrus canker, postharvest sanitization is mandatory in Brazilian packinghouses and has been proven effective in significantly reducing bacterial populations on infected fruit; furthermore, packing line processing reduces lesion activity, rendering processed fruit an extremely unlikely pathway for pathogen dissemination (Gottwald et al., 2009). Regarding HLB, the primary epidemiological driver is the movement of vectors and infected plant material, making effective control dependent on largescale coordinated management rather than mere spatial distance (Gottwald, 2010; Galvan et al., 2023).

This underscores the critical role of waste management and documentary compliance. Fresh fruit supply chain traceability systems frequently lack coverage, interoperability, data quality, and rapid response capacity, hindering flow reconstruction during noncompliance events (Cader et al., 2025; Tagarakis et al., 2021; Rashid et al., 2026). As noted by Tagarakis et al. (2021) and Rashid et al. (2026), untreated or improperly disposed residues and effluents from processing facilities can transfer phytosanitary hazards beyond the controlled environment. Therefore, the final classification presented in Figure 30 results from integrating spatial exposure, logistical connectivity, traceability, sanitary barriers, and waste disposal—justifying targeted inspection efforts on highrisk facilities during periods of peak operational activity and epidemiological sensitivity (Kouadio et al., 2023; Rao et al., 2026).

Santo Antônio de Jesus: orthomosaic and proximity zones; integrated classification: low risk.

A - CU01

Santo Antônio de Jesus: orthomosaic and proximity zones; integrated classification: low risk.

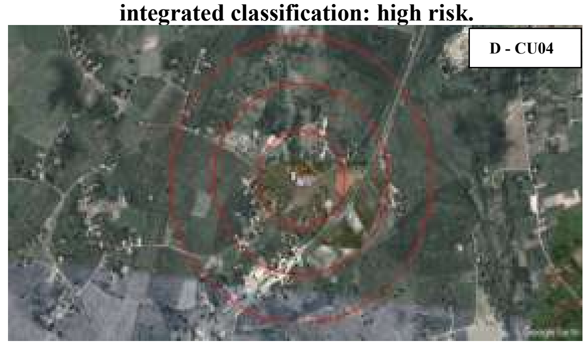
B - CU02

Sapeaçu: orthomosaic and proximity zones; integrated classification: high risk.

C - CU03

Cruz das Almas: orthomosaic and proximity zones; integrated classification: high risk.

D - CU04



Cruz das Almas: orthomosaic and proximity zones; integrated classification: high risk.

E - CU05

Cruz das Almas: orthomosaic and proximity zones; integrated classification: high risk.

F - CU06

Cruz das Almas: orthomosaic and proximity zones; integrated classification: high risk.

G - CU07

Cruz das Almas: orthomosaic and proximity zones; integrated classification: medium risk.

H - CU08

Cruz das Almas: orthomosaic and proximity zones; integrated classification: low risk.

I - CU09

Muritiba: orthomosaic and proximity zones; integrated classification: high risk.

J– CU10

Muritiba: orthomosaic and proximity zones; integrated classification: high risk.

K– CU11

Governador Mangabeira: orthomosaic and proximity zones; integrated classification: high risk.

L– CU12

Figure 30 (continued)

Cruz das Almas: orthomosaic and proximity zones; integrated classification: low risk.

Cruz das Almas: orthomosaic and proximity zones; integrated classification: high risk.

Governador Mangabeira: orthomosaic and proximity zones; integrated classification: high risk.

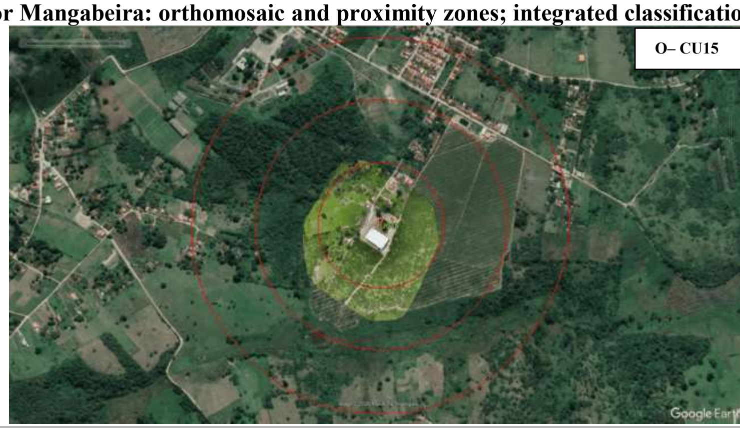


Figure 30 – Orthomosaics and proximity zones of the 15 citrus fruit consolidation units evaluated in the Recôncavo region of Bahia.The concentric buffer zones of 0–200 m, 200–400 m, and 400–600 m represent high, intermediate, and low levels of territorial exposure, respectively. Red = high risk; yellow = medium risk; blue = low risk.

Note: In each panel (A–O), the inset image corresponds to the orthomosaic generated from aerial photographs acquired by an unmanned aerial vehicle (UAV) and processed using open-source software

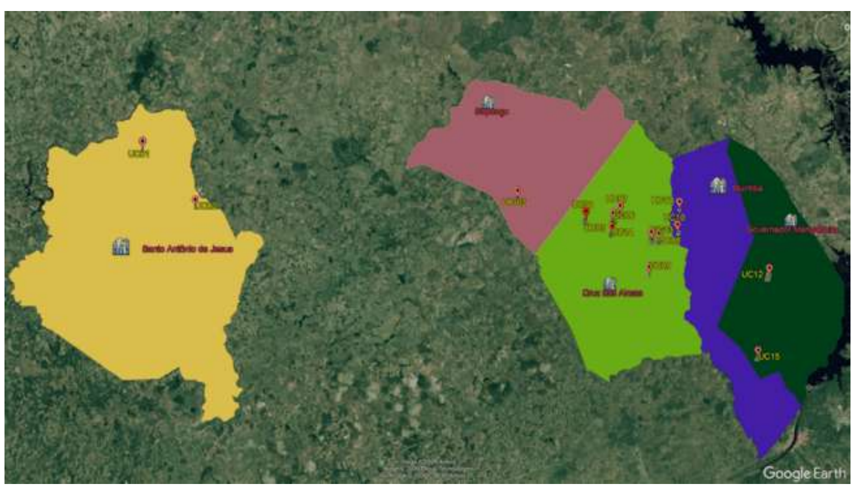


Figure 31 – Spatial distribution of the 15 Consolidation Units across the five municipalities evaluated in the Recôncavo region of Bahia.The colored polygons delineate the municipalities of Santo Antônio de Jesus, Sapeaçu, Cruz das Almas, Muritiba, and Governador Mangabeira; the markers indicate the locations of Consolidation Units CU01–CU15.
Source: Prepared by the author based on the georeferencing of the consolidation units and Google Earth base imagery.

CU Code	Municipality	Flight Request Date	Flight Date	Protocol	Latitude	Longitude	Maximum Authorized Flight Altitude (m)	Actual Flight Altitude (m)	Maximum Operation Radius (m)	Image Overlap (%)	Speed (m/s)	Flight Area (ha)	Perimeter (km)	GSD (cm/pixel)
UC01	Santo Antônio de Jesus	11/12/2024	12/12/2024	A39280DD	12°58'49.85"S	39°17'53.01"W	120	90	800	85/86	6	2,21	1,51	2,8
UC02	Santo Antônio de Jesus	09/05/2025	19/05/2025	EDBD7529	12°57'26.57"S	39°14'57.09"W	50	50	300	80/70	3,5	2,26	1,37	1,5
UC03	Sapeaçu	12/12/2024	13/12/2024	F6478641	12°44'28.98"S	39° 11'3.88"W	120	100	800	85/80	7	4,71	2,15	3,1
UC04	Cruz das Almas	12/12/2024	13/12/2024	7BAC5787	12°42'0.36"S	39°9'21.22"W	120	100	800	85/80	7	7,2	3,03	3,1
UC05	Cruz das Almas	12/12/2024	13/12/2024	275DCEE3	12°41'8.97"S	39°8'27.56"W	120	100	800	85/80	7	9,04	3,68	3,1
UC06	Cruz das Almas	13/03/2025	14/03/2025	E3015999	12°40'57.21"S	39°8'56.18"W	120	80	800	85/70	5	10,1	3,48	2,5
UC07	Cruz das Almas	13/03/2025	14/03/2025	39C3A00C	12°40'34.69"S	39° 9'7.71"W	120	100	800	85/75	5	10,5	3,42	3,1
UC08	Cruz das Almas	13/03/2025	14/03/2025	B4B60EDD	12°39'22.63"S	39° 7'30.07"W	120	80	800	85/70	5	11,7	3,98	2,5
UC09	Cruz das Almas	27/04/2025	30/04/2025	CB3C8A83	12°40'9.97"S	39°6'20.90"W	120	90	800	80/70	5	4,05	1,43	2,8
UC10	Muritiba	29/04/2025	29/04/2025	8F31C419	12°38'30.85"S	39° 7'38.37"W	120	90	800	80/70	5	7,42	2,52	2,8
UC11	Muritiba	27/04/2025	28/04/2025	1D616A86	12°38'9.94"S	39°8'30.19"W	120	90	800	80/70	5	4,12	1,52	2,8
UC12	Governador Mangabeira	14/05/2025	14/05/2025	D2224B18	12°35'23.06"S	39° 4'43.89"W	120	90	800	80/70	6	19,6	5,83	2,8
UC13	Cruz das Almas	12/07/2025	14/07/2025	352D35E9	12°39'39.39"S	39° 7'39.93"W	120	90	800	80/70	6	17,3	4,13	3,1
UC14	Cruz das Almas	25/05/2025	25/05/2025	F7T9FN45C	12°41'8.85"S	39°8'26.48"W	120	80	800	80/70	6	5,75	2,19	2,5
UC15	Governador Mangabeira	15/06/2026	15/06/2026	TF7PGQOEG	12°36'49.14"S	39° 1'37.84"W	120	80	800	80/70	6	9,51	3,29	2,5

Figure 32 – Technical flight parameters authorized by SARPAS/DECEA for the aerial survey of the Consolidation Units.The table presents the Consolidation Unit code, municipality, flight request and execution dates, protocol number, geographic coordinates, authorized and actual flight altitudes, maximum operation radius, image overlap, flight speed, surveyed area, perimeter, and GSD for the flights conducted between December 2024 and June 2026.

Note: GSD = Ground Sampling Distance, expressed in centimeters per pixel (cm/pixel).
Source: Prepared by the author based on records of flights authorized by SARPAS/DECEA.

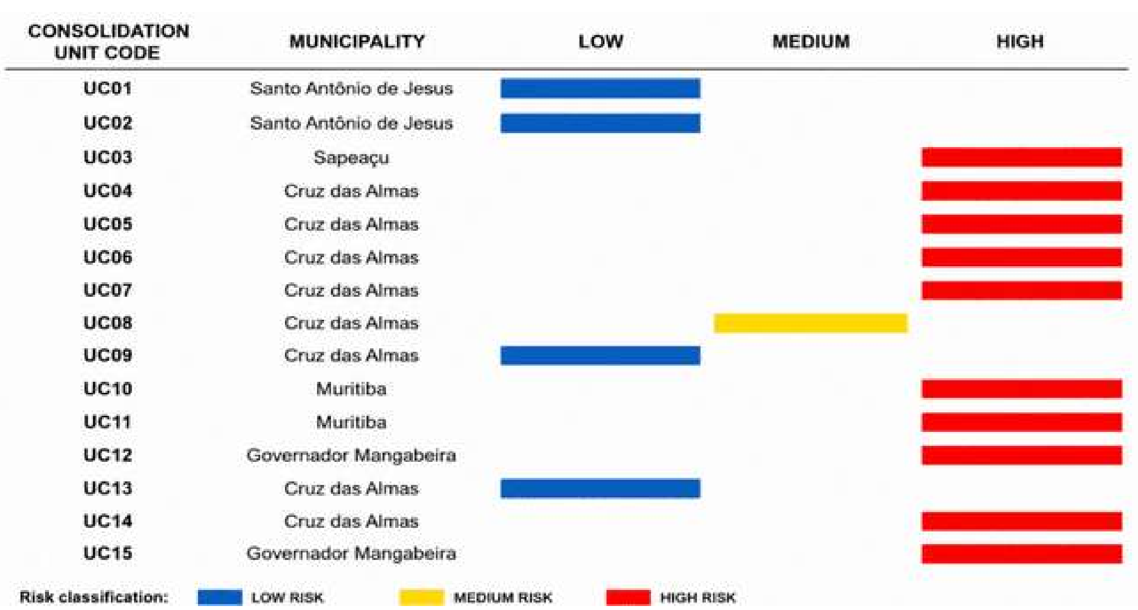


Figure 33 – Integrated phytosanitary risk classification of the 15 citrus fruit Consolidation Units.Blue = low risk; yellow = medium risk; red = high risk. The classification integrates the components of territorial exposure, operational and sanitary vulnerability, and the management of unmarketable fruits and waste.
Source: Prepared by the author based on the integrated phytosanitary risk classification matrix.

Conclusion: -

The evaluated Consolidation Units functioned as critical nodes in thereceiving, processing, and redistribution chain of citrus production in the Recôncavo region of Bahia. The predominance of Tahiti acid lime, the reception of thirdparty fruit from other regions across 86.7% of the facilities, and the connectivity with various production areas and markets demonstrated that their functional domain extended far beyond municipal boundaries, heightening their economic, logistical, and phytosanitary relevance. Spatial analysis combining georeferenced data and orthomosaics enabled the mapping of facility locations, access roads, citrus orchards, and adjacent properties. The concentric distance buffers of 0–200 m, 200–400 m, and 400–600 m revealed varying levels of spatial proximity across the territory, though proximity alone was not a definitive risk classification criterion. Although the presence of orchards in surrounding areas suggested greater exposure, actual risk depended on fruit origin, operational intensity, and the efficacy of internal sanitary containment measures at each facility.

The integrated assessment identified ten highrisk units (66.7% of the total), four lowrisk units (26.7%), and one médium risk unit (6.7%). The coexistence of all three risk categories within Cruz das Almas confirmed that municipal location, orchard proximity, and facility size were not sole determining factors for classification. Rather, risk emerged from the dynamic interaction between territorial exposure, operational and sanitary vulnerability, and unsellable fruit management. Among the primary vulnerabilities identified, the sanitation of vehicles and equipment (implemented by only 33.3% of the units) and the disposal of plant residues and unsellable fruit in open dumps (reported by 73.3% of respondents) stood out. These vulnerabilities were further amplified during June and Julythe peak processing monthscharacterized by increased vehicle traffic, heightened batch movement, and greater waste generation. This classification does not imply the presence of HLB, citrus canker, or other regulated pests, but serves as a riskbased tool to guide phytosanitary surveillance. Priority should be given to highrisk units and peak processing periods, strengthening vehicle sanitation, batch segregation, traceability, inflow/outflow logging, phytosanitary documentation, and the oversight of waste transport, treatment, and disposal. The integration of structured questionnaires, official data, field observations, and geospatial products provided an effective analytical basis to support inspection, prevention, and monitoring actions by agricultural defense agencies.

References: -

1. Baležentis, T., Žičkienė, A., Volkov, A., Štreimikienė, D., Morkūnas, M., Dabkienė, V., & Ribašauskienė, E. (2023). Measures for the viable agri-food supply chains: A multi-criteria approach. Journal of Business Research. https://doi.org/10.1016/j.jbusres.2022.113417
2. Bassan, M. M., Filho, F. M., Caron, V., Couto, H. D., & Jacomino, A. P. (2013). The harvesting system affects the quality and conservation of the 'Tahiti' acid lime. Scientia Horticulturae, 155, 72–77. https://doi.org/10.1016/j.scienta.2013.03.008
3. Beshara, S., Kassem, A., Fors, H., & Harraz, N. (2024). A comprehensive review and mapping citrus supply chains from a sustainability perspective across the European Union, Middle East, and Africa. Sustainability. https://doi.org/10.3390/su16198582
4. Bezerra, N. P., Vargens, M. L., De Jesus Moreira, D., Santos, L. S. D., Coimbra, V. C. S., & Bezerra, D. C. (2019). Milk and dairy product interceptions due to agricultural product transport inspections carried out in Maranhão State. Acta Veterinaria Brno, 13, 204–209. https://doi.org/10.21708/avb.2019.13.4.8466
5. Bidone, N. D. B., Gonçalves, A. P., Bremm, C., Girotto, A. F., Girotto-Soares, A., Santos, P., Pinto, A., & Soares, J. (2021). Slaughter condemnation in bovine due to parasitic lesions and their economic impact in Federal Inspection System establishments in Brazil and in State inspection System in Rio Grande do Sul State. Revista brasileira de parasitologia veterinaria = Brazilian journal of veterinary parasitology: Orgao Oficial do Colegio Brasileiro de Parasitologia Veterinaria, 30 1, e022720. https://doi.org/10.1590/s1984–296120201079
6. Bosona, T., & Gebresenbet, G. (2013). Food traceability as an integral part of logistics management in food and agricultural supply chain. Food Control, 33, 32-48. https://doi.org/10.1016/j.foodcont.2013.02.004
7. Bragard, C., Dehnen-Schmutz, K., Di Serio, F., Gonthier, P., Jacques, M., Miret, J. J. A., Justesen, A., Magnusson, C., Milonas, P. G., Navas-Cortés, J., Parnell, S., Potting, R., Reignault, P., Thulke, H., Van Der Werf, W., Civera, A. V., Yuen, J., Zappalà, L., Kertész, V.,... MacLeod, A. (2021). Pest categorisation of Diaphorina citri. EFSA Journal, 19. https://doi.org/10.2903/j.efsa.2021.6357
8. Cader, A., Basson, A., Kruger, K., & Taylor, N. (2025). Requirements for a food traceability system in a fruit supply chain. Food Control. https://doi.org/10.1016/j.foodcont.2025.111403
9. Campos, D., Gómez-García, R., Vilas-Boas, A. A., Madureira, A., & Pintado, M. M. (2020). Management of Fruit Industrial By-Products—A Case Study on Circular Economy Approach. Molecules, 25. https://doi.org/10.3390/molecules25020320
10. Cavenaghi, M. G. L., Bruschi, L. T., & Santos, M. D. T. (2026). Design and optimization of supply chain for citrus biorefineries: A regional approach for waste valorization in Brazil. Systems and Control Transactions. https://doi.org/10.69997/sct.181146

11. Cheng, M.-T., Wu, J., Li, C., Jia, Y., & Xia, X. (2023). Tele-connection of global agricultural land network: Incorporating complex network approach with multi-regional input-output analysis. Land Use Policy. https://doi.org/10.1016/j.landusepol.2022.106464
12. Chirumamilla, V. (2026). Waste disposal and management practices in fruit and vegetable processing plants in Gujarat. Discover Sustainability. https://doi.org/10.1007/s43621–026–02964-w
13. Da Silva, T. L., De Sousa, S. V., Cruz, R., Da Costa, F. B., De Andrade Silva, L., Sales, G. N., Brito, M., Ribeiro, W. S., Soares, L., & Filho, W. D. S. S. (2023). Fruit quality of 'Tahiti' lime grafted onto different rootstocks grown under salt stress. Arid Land Research and Management, 38, 447–463. https://doi.org/10.1080/15324982.2023.2292999
14. De Oliveira, G. S., Fancelli, M., Silva, S. X., & Carvalho, S. (2021). Participatory survey of citrus in the "Recôncavo Baiano region" with emphasis on the threat of huanglongbing. Revista Brasileira de Fruticultura. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1134716/1/Oliveira-et-al-2021-Participatory-survey.pdf
15. De Oliveira, G. S., Fancelli, M., Silva, S. X., & Carvalho, S. (2021). Participatory survey of citrus in the "Recôncavo Baiano region" with emphasis on the threat of huanglongbing. Revista Brasileira de Fruticultura. https://doi.org/10.1590/0100-29452021168
16. De Souza, A. J. B., Cristofani-Yaly, M., Da Conceição, P. M., Devite, F. T., Bastianel, M., Romero, P. V. S., Padilha, P., & De Azevedo, F. A. (2025). Physiological and productivity responses of Tahiti acid lime grafted onto dwarfing rootstocks under different planting and mulching practices. Frontiers in Sustainable Food Systems. https://doi.org/10.3389/fsufs.2025.1489291
17. De Souza, L. C. D., & Drumond, M. A. (2022). Decentralized composting as a waste management tool connect with the new global trends: a systematic review. International Journal of Environmental Science and Technology, 19, 12679–12700. https://doi.org/10.1007/s13762–022–04504–1
18. Dilarri, G., Zamuner, C., Mendes, C., Júnior, J. R. M., Morão, L. G., Montagnolli, R., Bidoia, E. D., & Ferreira, H. (2020). Evaluating the potential of electrolytic water for the disinfection of citrus fruit in packinghouses. Journal of the science of food and agriculture. https://doi.org/10.1002/jsfa.10888
19. Ding, R., Luo, J., Wang, C., Yu, L., Yang, J., Wang, M., Zhong, S.-H., & Gu, R. (2023). Identifying and mapping individual medicinal plant Lamiophlomis rotata at high elevations by using unmanned aerial vehicles and deep learning. Plant Methods, 19. https://doi.org/10.1186/s13007–023–01015-z
20. Esparza, I., Jiménez-Moreno, N., Bimbela, F., Ancín-Azpilicueta, C., & Gandía, L. M. (2020). Fruit and vegetable waste management: Conventional and emerging approaches. Journal of environmental management, 265, 110510. https://doi.org/10.1016/j.jenvman.2020.110510
21. Galvan, A., Bassanezi, R., Luo, W., Vanaclocha, P., Vicent, A., & Lázaro, E. (2023). Risk-based regionalization approach for area-wide management of HLB vectors in the Mediterranean Basin. Frontiers in Plant Science, 14. https://doi.org/10.3389/fpls.2023.1256935
22. Gardas, B. B., Raut, R. D., Cheikhrouhou, N., & Narkhede, B. (2019). A hybrid decision support system for analyzing challenges of the agricultural supply chain. Sustainable Production and Consumption. https://doi.org/10.1016/j.spc.2018.11.007
23. Ge, H., Goetz, S. J., Canning, P., & Perez, A. (2018). Optimal locations of fresh produce aggregation facilities in the United States with scale economies. International Journal of Production Economics, 197, 143–157. https://doi.org/10.1016/j.ijpe.2018.01.007
24. Glew, R., Hernández, M. P., & Mcfarlane, D. (2021). Analysing the effect of food supply chain traceability on product waste. Social Work. https://doi.org/10.36819/sw21.015
25. González-García, J., Swenson, R. L., & Gómez-Espinosa, A. (2020). Real-time kinematics applied at unmanned aerial vehicles positioning for orthophotography in precision agriculture. Comput. Electron. Agric., 177, 105695. https://doi.org/10.1016/j.compag.2020.105695
26. Goodarzian, F., Ghasemi, P., Santibanez Gonzalez, E. D., & Tirkolaee, E. B. (2022). A sustainable-circular citrus closed-loop supply chain configuration: Pareto-based algorithms. Journal of Environmental Management, 328, 116892. https://doi.org/10.1016/j.jenvman.2022.116892
27. Gottwald, T. (2010). Current epidemiological understanding of citrus Huanglongbing. Annual review of phytopathology, 48, 119–39. https://doi.org/10.1146/annurev-phyto-073009–114418
28. Gottwald, T., Graham, J., Bock, C., Bonn, G., Civerolo, E., Irey, M., Leite, R., McCollum, G., Parker, P., Ramallo, J., Riley, T., Schubert, T., Stein, B., & Taylor, E. (2009). The epidemiological significance of post-packinghouse survival of Xanthomonas citri subsp. citri for dissemination of Asiatic citrus canker via infected fruit. Crop Protection, 28, 508–524. https://doi.org/10.1016/j.cropro.2009.02.003
29. Gottwald, T., Taylor, E., Amorim, L., Bergamin-Filho, A., Bassanezi, R., Silva, G. J., Fogliata, G., Fourie, P., Graham, J., Hattingh, V., Kriss, A., Luo, W., Magarey, R. D., Schutte, G. C., & Spósito, M. B. (2021). Probabilistic risk-based model for the assessment of Phyllosticta citricarpa-infected citrus fruit and illicit plant material as pathways for pathogen introduction and establishment. Crop Protection, 142, 105521. https://doi.org/10.1016/j.cropro.2020.105521
30. Guerrero-Cabrera, L., Olivera, B., Villavicencio-Pulido, J. G., & Ortiz Luna, R. J. (2020). Proximity and density of neighboring farms and water supply, as risk factors for bacteriosis: A case study of spatial risk analysis in tilapia and rainbow trout farms of Oaxaca, Mexico. Aquaculture, 520, 734955. https://doi.org/10.1016/j.aquaculture.2020.734955
31. Hamilton, A. N., Chandran, S., Gibson, K. E., & Moreira, J. (2025). Thematic Analysis of Produce Packinghouse Sanitation: Challenges and Recommendations based on Operator and Educator Insights. Journal of food protection, 100587. https://doi.org/10.1016/j.jfp.2025.100587

32. Hattingh, V., Moore, S., Kirkman, W., Goddard, M., Thackeray, S., Peyper, M., Sharp, G., Cronjé, P., & Pringle, K. (2020). An improved systems approach as a phytosanitary measure for Thaumatotibia leucotreta in export citrus fruit from South Africa. Journal of Economic Entomology, 113, 700–711. https://doi.org/10.1093/jee/toz336
33. Khezev, A., Vasilev, V., Ostapchuk, T. V., Snegirev, D., & Aleshkina, A. (2025). International trade in lemons and limes: Volumes, countries, trends. International Agricultural Journal. https://doi.org/10.55186/25876740_2025_68_7_939
34. Khumalo, G., Goedhals-Gerber, L., Cronjé, P., & Berry, T. (2021). The non-conformance of in-transit citrus container shipments to cold protocol markets: A systematic literature review. Food Control. https://doi.org/10.1016/j.foodcont.2021.107947
35. Kouadio, L., Jarroudi, M., Belabess, Z., Laasli, S., Roni, M. Z. K., Amine, I. D. I., Mokhtari, N., Mokrini, F., Junk, J., & Lahlali, R. (2023). A Review on UAV-Based Applications for Plant Disease Detection and Monitoring. Remote. Sens., 15, 4273. https://doi.org/10.3390/rs15174273
36. Lee, A., Lan, J. C.-W., Jambrak, A., Chang, J.-S., Lim, J. W., & Khoo, K. S. (2024). Upcycling fruit waste into microalgae biotechnology: Perspective views and way forward. Food Chemistry: Molecular Sciences, 8. https://doi.org/10.1016/j.fochms.2024.100203
37. Leite, J. S., Passos, R. S. F. T., Da Matta Pires Cruz, T., Barreto, B. G., Silva, M. C. A. D., & Cavalheiro, C. (2022). Main causes of cattle slaughter condemnation under the state sanitary inspection in Bahia, Brazil. Semina: Ciências Agrárias. https://doi.org/10.5433/1679–0359.2022v43n1p61
38. Li, X., Jiang, J., & Cifuentes-Faura, J. (2023). The impact of logistic environment and spatial spillover on agricultural economic growth: An empirical study based on east, central and west China. PLOS ONE, 18. https://doi.org/10.1371/journal.pone.0287307
39. Liu, X., Zhao, J., Zhang, Y., & Shu, W. (2025). Bridging the urban-rural divide: How urban agriculture enhances food security in high-urbanized regions in Guangdong, China. Rural and Regional Development. https://doi.org/10.70322/rrd.2025.10019
40. Macdonald, J. (2020). Tracking the consolidation of U.S. agriculture. Applied Economic Perspectives and Policy, 42, 361–379. https://doi.org/10.1002/aepp.13056
41. Mastin, A., Gottwald, T., Van Den Bosch, F. C., Cunniffe, N., & Parnell, S. (2019). Optimising risk-based surveillance for early detection of invasive plant pathogens. PLoS Biology, 18. https://doi.org/10.1371/journal.pbio.3000863
42. Mehta, A., Yadav, A., Kumar, A., & Kumari, K. (2024). Waste Utilization in Horticulture: An Overview. Journal of Experimental Agriculture International. https://doi.org/10.9734/jeai/2024/v46i52427
43. Meyer, M. A., Früh-Müller, A., Lehmann, I., & Schwarz, N. (2023). Linking food and land system research in Europe. Land Use Policy. https://doi.org/10.1016/j.landusepol.2023.106692
44. Muñoz Torres, M. J., Fernández-Izquierdo, M. A., Ferrero-Ferrero, I., Escrig-Olmedo, E., & Rivera-Lirio, J. (2022). Transitioning the agri-food system. Does closeness mean sustainability? How production and shipping strategies impact socially and environmentally. Comparing Spain, South Africa and U.S. citrus fruit productions. Agroecology and Sustainable Food Systems, 46, 540–577. https://doi.org/10.1080/21683565.2022.2039835
45. Naseer, M. A. R., Razzaq, A., Ashfaq, M., Mehdi, M., Karim, S., & Naseer, M. S. (2023). Beyond subsistence: Linking citrus smallholders to high-value markets for sustainable supply chain development in Pakistan. Journal of Economic Impact. https://doi.org/10.52223/econimpact.2023.5310
46. Nenciu, F., Stănciulescu, I., Vlad, H., Gabur, A., Turcu, O., Apostol, T., Vlăduț, V., Cocârță, D., & Stan, C. (2022). Decentralized Processing Performance of Fruit and Vegetable Waste Discarded from Retail, Using an Automated Thermophilic Composting Technology. Sustainability. https://doi.org/10.3390/su14052835
47. NnanyelugoEgbuchiem, A., Egbubine, L., Ugorji, H. O., & C., N. E. (2026). Agrochemical Exposure and Chronic Disease Risk among U.S. Farmers Using Spatial Modeling: A Review of GIS-Based Epidemiological Approaches. Journal of Disease and Global Health. https://doi.org/10.56557/jodagh/2026/v19i110200
48. Novacki, E. R., & Machado, A. C. M. (2020). Compliance na administração pública brasileira: o caso do pacto pela integridade no Ministério da Agricultura, Pecuária e Abastecimento. Revista ESMAT, 12(19), 129–144. https://doi.org/10.34060/reesmat.v12i19.351
49. Olson, D. O., & Anderson, J. (2021). Review on unmanned aerial vehicles, remote sensors, imagery processing, and their applications in agriculture. Agronomy Journal. https://doi.org/10.1002/agj2.20595
50. Oviedo-Ocaña, E. R., Abendroth, C., Dominguez, I., Sánchez, A., & Dornack, C. (2023). Life cycle assessment of biowaste and green waste composting systems: A review of applications and implementation challenges. Waste management, 171, 350–364. https://doi.org/10.1016/j.wasman.2023.09.004
51. Pajura, R. (2023). Composting municipal solid waste and animal manure in response to the current fertilizer crisis - a recent review. The Science of the total environment, 169221. https://doi.org/10.1016/j.scitotenv.2023.169221
52. Pan, L., Panichakarn, B., & Garin, M. E. (2024). The redesign of logistics network of fresh fruit in Guangxi Province of China. Journal of Information Systems Engineering and Management. https://doi.org/10.55267/iadt.07.14856
53. Peña Orozco, D. L., González-Feliu, J., Rivera, L., & Ramírez, C. (2021). Integration maturity analysis for a small citrus producers' supply chain in a developing country. Business Process Management Journal, 27, 836–867. https://doi.org/10.1108/bpmj-05–2020–0237
54. Peña-Orozco, D. L., González-Feliu, J., Salazar-Aguirre, L. T., & Arenas-Ruiz, M. A. (2023). Sustainability fruit supply chain design in the context of decentralized smallholders: Modelling framework and sensitivity analysis. LOGI—Scientific Journal on Transport and Logistics, 14, 43–54. https://doi.org/10.2478/logi-2023–0005

55. Peng, X., Jiang, Y., Chen, Z., Osman, A., Farghali, M., Rooney, D. W., & Yap, P. (2023). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review. Environmental Chemistry Letters, 1–37. https://doi.org/10.1007/s10311–022–01551–5
56. Phologane, S. A., Valentine, L., Yan, B., & Tambovceva, T. (2024). Towards effective integrated risk management: Enhancing compliance and competitiveness for sustainable access to the EU citrus market. Sustainability. https://doi.org/10.3390/su162410891
57. Porto, S., Arcidiacono, C., & Cascone, G. (2011). Developing integrated computer-based information systems for certified plant traceability: Case study of Italian citrus-plant nursery chain. Biosystems Engineering, 109, 120-129. https://doi.org/10.1016/j.biosystemseng.2011.02.008
58. Pristijono, P., Bowyer, M., Papoutsis, K., Scarlett, C., Vuong, Q., Stathopoulos, C., & Golding, J. (2019). Improving the storage quality of Tahitian limes (Citrus latifolia) by pre-storage UV-C irradiation. Journal of Food Science and Technology, 56, 1438–1444. https://doi.org/10.1007/s13197–019–03623-x
59. Pristijono, P., Bowyer, M., Scarlett, C., Vuong, Q., Stathopoulos, C., & Golding, J. (2017). The Effect of Postharvest UV-C Treatment and Associated with Different Storage Conditions on the Quality of Tahitian Limes (Citrus latifolia). Journal of Food and Nutritional Disorders, 6, 1–6. https://doi.org/10.4172/2324–9323.1000230
60. Qian, J., Dai, B., Wang, B., Zha, Y., & Song, Q. (2020). Traceability in food processing: problems, methods, and performance evaluations—a review. Critical Reviews in Food Science and Nutrition, 62, 679–692. https://doi.org/10.1080/10408398.2020.1825925
61. Rao, V. K., Higgs, R., Kingi, H., Radicchi, F., Fortunato, S., & Litvinova, M. (2026). Modeling plant disease spread via high-resolution human mobility networks. https://doi.org/10.48550/arxiv.2602.21491
62. Rashid, A., Ahmad, R. W., Nachouki, M., & Khan, A. U. R. (2026). Enhancing fruit supply chain traceability through blockchain and cryptographic protocols for achieving UN sustainable development goals. Scientific Reports, 16. https://doi.org/10.1038/s41598–026–37534–7
63. Ribeiro, C., Viana, C. M., Girão, I., Figueiredo, E., & Rocha, J. (2023). The spatiotemporal links between urban and rural regions through the sale and consumption of agri-food products. Sustainability. https://doi.org/10.3390/su151512038
64. Rodrigues, D., Teixeira, R., & Shockley, J. (2019). Inspection agency monitoring of food safety in an emerging economy: A multilevel analysis of Brazil's beef production industry. International Journal of Production Economics. https://doi.org/10.1016/j.ijpe.2019.03.024
65. Rolon, M., Méndez Acevedo, M., Sinclair, P., Macarisin, D., LaBorde, L. F., & Kovac, J. (2024). Impact of improved sanitation standard operation procedures on microbial populations at three tree fruit packing facilities. Journal of food protection, 100436. https://doi.org/10.1016/j.jfp.2024.100436
66. Romero-Barrera, Y., Botina-Azaín, B. L., García-Muñoz, M. C., Mateus-Cagua, D., Moreno-Rodríguez, J. M., & Henao-Rojas, J. C. (2022). O efeito do porta-enxerto e do local de produção do limão-taiti (Citrus latifolia Tanaka) na evolução das características de qualidade do fruto em condições de armazenamento. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4151264
67. Rovetto, E. I., La Spada, F., Aloi, F., Riolo, M., Pane, A., Garbelotto, M., & Cacciola, S. O. (2024). Green solutions and new technologies for sustainable management of fungus and oomycete diseases in the citrus fruit supply chain. Journal of Plant Pathology, 1–27. https://doi.org/10.1007/s42161–023–01543–6
68. Russo, C., Maugeri, A., Lombardo, G. E., Musumeci, L., Barreca, D., Rapisarda, A., Cirmi, S., & Navarra, M. (2021). The Second Life of Citrus Fruit Waste: A Valuable Source of Bioactive Compounds. Molecules, 26. https://doi.org/10.3390/molecules26195991
69. Schreiber, K., Hickey, G., Metson, G., Robinson, B. E., & MacDonald, G. (2020). Quantifying the foodshed: A systematic review of urban food flow and local food self-sufficiency research. Environmental Research Letters, 16. https://doi.org/10.1088/1748–9326/abad59
70. Shahsavani, I., Goli, A., & Hajiaghaei-Keshteli, M. (2024). A circular economy approach to design a citrus supply chain network. Annals of Operations Research. https://doi.org/10.1007/s10479–024–05829–5
71. Shih, P.-W., Chan, T., & King, C. (2021). Risk Mapping of Highly Pathogenic Avian Influenza H5 during 2012–2017 in Taiwan with Spatial Bayesian Modeling: Implications for Surveillance and Control Policies. Transboundary and emerging diseases. https://doi.org/10.1111/tbed.13991
72. Siddiqua, A., Hahladakis, J., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research International, 29, 58514–58536. https://doi.org/10.1007/s11356–022–21578-z
73. Spreen, T., Gao, Z., Fernandes, W., & Zansler, M. (2020). Global economics and marketing of citrus products. 471–493. https://doi.org/10.1016/b978–0–12–812163–4.00023–1
74. Strano, M. C., Altieri, G., Allegra, M., Di Renzo, G. C., Paterna, G., Matera, A., & Genovese, F. (2022). Postharvest technologies of fresh citrus fruit: Advances and recent developments for loss reduction during handling and storage. Horticulturae. https://doi.org/10.3390/horticulturae8070612
75. Su, J., Yi, D., Su, B., Mi, Z., Liu, C., Hu, X., Xu, X.-M., Guo, L., & Chen, W. (2021). Aerial Visual Perception in Smart Farming: Field Study of Wheat Yellow Rust Monitoring. IEEE Transactions on Industrial Informatics, 17, 2242–2249. https://doi.org/10.1109/tii.2020.2979237
76. Tagarakis, A., Benos, L., Kateris, D., Tsotsolas, N., & Bochtis, D. (2021). Bridging the Gaps in Traceability Systems for Fresh Produce Supply Chains: Overview and Development of an Integrated IoT-Based System. Applied Sciences. https://doi.org/10.3390/app11167596

77. Tongeren, F. V. (2021). Digital opportunities for Sanitary and Phytosanitary (SPS) Systems and the trade facilitation effects of SPS Electronic Certification. OECD Food, Agriculture and Fisheries Papers. https://doi.org/10.1787/cbb7d0f6-en
78. Van Klinken, R. V., Fiedler, K., Kingham, L., Collins, K., & Barbour, D. (2020). A risk framework for using systems approaches to manage horticultural biosecurity risks for market access. Crop Protection, 129, 104994. https://doi.org/10.1016/j.cropro.2019.104994
79. Vargas-Muñoz, J. C., Sanchez-Nitola, F. A., Jaimes, W. A., & Rios, R. (2025). Enhancing logistical performance in a Colombian citrus supply chain through joint decision making: A simulation study. Logistics. https://doi.org/10.3390/logistics9010030
80. Vélez, S., Ariza-Sentís, M., & Valente, J. (2023). Mapping the spatial variability of Botrytis bunch rot risk in vineyards using UAV multispectral imagery. European Journal of Agronomy. https://doi.org/10.1016/j.eja.2022.126691
81. Volkers, R., Van Doorn, B., Blom, N. I., Van De Bilt, J., Gorkink-Smits, P., Landman, M., Teunissen, M., Pel, M., Raaymakers, T., & Bergsma-Vlami, M. (2024). Xanthomonas citri pv. citri findings in citrus fruits imported in the Netherlands. Plant Health Progress. https://doi.org/10.1094/php-12-23–0107-sc
82. Wang, N. (2020). A perspective of citrus Huanglongbing in the context of the Mediterranean Basin. Journal of Plant Pathology, 1–6. https://doi.org/10.1007/s42161–020–00555-w
83. Yang, S., Li, Z., Zhou, J., Gao, Y., & Cui, X. (2023). Evolving patterns of agricultural production space in China: A network-based approach. Geography and Sustainability. https://doi.org/10.1016/j.geosus.2023.11.007
84. Younas, M., Zheng, Z., Atiq, M., Wei, T., & Li, Y. (2025). Insights into the Huanglongbing pandemic focusing on transmission biology, virulence factors and multifaceted management strategies. Pest Management Science, 81. https://doi.org/10.1002/ps.70073
85. Zacarías, L., Cronje, P. J. R., & Palou, L. (2020). Postharvest technology of citrus fruits. In M. Talón, M. Caruso, & F. G. Gmitter Jr. (Eds.), The genus Citrus (pp. 421–446). Elsevier. https://doi.org/10.1016/B978–0–12–812163–4.00021–8