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RESEARCH ARTICLE

Possible economic losses on the oranges production chain of Peru due to introduction of Huanglongbing (HLB): Simulation of prospective scenarios to 2045

Waldemar Mercado[1, *]; Katherine Guadalupe[1]; Karla Vega Alegre[1]

[1] Universidad Nacional Agraria La Molina, UNALM, Apartado postal 12-056, La Molina, Lima, Perú.

* Corresponding author: wmercado@lamolina.edu.pe (W. Mercado).

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Abstract

Huanglongbing (HLB) is a citrus disease known for causing significant production losses, and its potential introduction into Peru looms on the horizon. The aim of this study was to assess the potential economic losses within the Central Jungle's orange production chain, specifically in the Region Junín. This assessment involved simulating the spread of HLB under prospective scenarios spanning from 2026 to 2045, aiming to estimate the cost-benefit of preventing these losses through the implementation of a national phytosanitary program (PNF). The methodology employed in this study comprised administering questionnaires to local growers and estimating economic losses across three scenarios. The first scenario assumed a baseline production trend without HLB presence, while the second scenario considered an epidemiological situation with HLB but without the implementation of a PNF. The third scenario factored in HLB with varying degrees of adoption among PNF-affiliated growers. The findings highlight several risk factors contributing to the potential spread of HLB in Junín. The epidemiological model reveals that HLB can swiftly render young trees unproductive. Cumulatively, economic losses from 2026 to 2045 could reach a staggering US$ 371,146 thousand if no intervention takes place. However, this figure could be significantly reduced to US$ 44,890 thousand if 100% of growers embrace the PNF. Such public policy measures would not only prevent production losses but also generate substantial social benefits. These scenarios underscore the stark negative impacts HLB could inflict on the local orange production chain. The implementation of the PNF proves to be a critical intervention, preventing production losses, preserving jobs, and safeguarding related economic activities. Without timely public intervention, the economic losses at stake could render the agribusiness sector unsustainable.

Keywords: *Citrus*; *Citrus Greening*; Cost-benefit; *Diaphorina citri*; Epidemiological model; Prospective.

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1. Introduction

Huanglongbing (HLB), also known as "Yellow Dragon" or "Citrus Greening," is a bacterial disease that affects citrus trees. The causative agent is a gram-negative, persistent, and propagative bacteria (Aidoo et al., 2023; Darolt et al., 2021; Nguyen et al., 2023; Stover et al., 2018). In the Americas, the *Candidatus Liberibacter americanus* strain is prevalent (Bové et al., 2006; Clarke & Brown, 2018; De Chaves et al., 2023; Hansen et al., 2022). It is transmitted by the psyllid insect *Diaphorina citri* (Aubert, 1987; Garnier & Bové, 1996; Li et al., 2022; Liu et al., 2022; Pan et al., 2023). This psyllid primarily prefers grapefruit trees (*Citrus paradisi*) (Phuyal et al., 2020; Santiago et al., 2023) and the curry leaf tree (*Murraya paniculata*) (Hernández-Landa et al., 2018; Kalile et al., 2023; Meng et al., 2022; SENASICA, 2017) as hosts. Psyllid adults are not strong fliers, and their dispersion occurs through wind or human movement (Aidoo et al., 2023; Chen et al., 2022; Kalile et al., 2023). When the vector feeds on an infected plant, it acquires the pathogen and subsequently spreads the disease (Grafton-Cardwell et al., 2013; Oke et al., 2020; Setamou et al., 2022). HLB leads to the development of small, deformed fruits with bitter juice, fruit drop, and shrinkage. Symptoms may not become apparent until two years after infection, and the affected tree is no longer economically viable between five and eight years (Bové et al., 2006; Lin et al., 2017; Pandey et al., 2022; Spreen & Baldwin, 2013; Thakuria et al., 2023).

The disease was first reported in Brazil, specifically in the State of São Paulo in 2004 (De Carvalho et al., 2019; Zorzenon et al., 2021), followed by cases in Minas Gerais in 2005 (Alves et al., 2022; Sulzbach et al., 2018) and Paraná in 2006 (Cruz et al., 2021; Sauer et al., 2015). In the United States, it emerged in Florida in 2005 (Lin et al., 2023; Lopez & Durborow, 2014; Zapien-Macias et al., 2022) and California in 2008 (McRoberts et al., 2019; Nguyen et al., 2023). Cuba reported cases in 2007 (Bertaccini et al., 2019; Paredes-Tomás et al., 2023), and it entered Yucatán, Mexico, in 2009 (López-Collado et al., 2013; Pérez-Valencia et al., 2019). The Dominican Republic experienced its first cases in 2010 (Luis-Pantoja et al., 2021), followed by Belize in 2011 (Petri & Jorge, 2015) and Argentina in 2012 (Badaracco et al., 2017, 2022; Petri & Jorge, 2015). Paraguay documented occurrences in 2013 (COSAVE, 2017), while Colombia faced its first cases in 2015 (Ramírez-Godoy et al., 2018; Wang et al., 2021). In Ecuador, the presence of the vector has been noted since 2013 (Chavez et al., 2019).

The mapping analysis reveals that the United States, China, and Brazil stand out as prominent countries in these research areas. Scientists have established connections between HLB and citrus cultivation, insect vectors, and disease control. Additionally, research has delved into the relationship between HLB and parasitology, as well as microorganisms. Notably, the themes of "prevention and control" have gained increasing attention since 2018 (Supplementary Material 1).

China, Brazil, and the United States, which are the major global citrus growers, have all grappled with the impacts of HLB (Cui et al., 2022; Da Silva et al., 2019; Ding et al., 2020; Gao et al., 2022; Hallman et al., 2023). This disease has had far-reaching consequences on the economy, the society, and the environment. For instance, Durborow & Lopez (2012) explored the economic repercussions of HLB on orange production in California. Their research reveals staggering losses totaling US$ 2.2 billion over a 20-year span. In Florida, the economic toll of HLB was estimated at US$ 9.3 billion over a three-year period (Lopez & Durborow, 2014). In Brazil, Miranda et al. (2012) observed that in the absence of HLB, the projected production after 20 years would reach 6.7 billion boxes of 40.8 kg each. However, without effective HLB control measures, this figure saw a significant 45.3% decline. Meanwhile, in the state of Paraná, Da Costa et al. (2021) estimated HLB-related losses amounting to US$ 11.8 million dollars for the period 2011–2013, coupled with additional losses of US 39.2 million attributable to reduced citrus plantation productivity. Salcedo et al. (2011) conducted an assessment in Mexico that indicated that total production would decrease by 25% in a scenario with low HLB impact and by 41% in a scenario with a high HLB impact.

Citrus farming plays a significant role in Peru, with the industry experiencing substantial growth, now ranking as the 19th largest global grower. It contributed 3.3% to the gross production value of the agricultural gross domestic product (GDP). Notably, from 2018 to 2022, the Region Junín alone contributed a remarkable 56% to the country's total orange production (SIEA, 2023).

In 2018, the HLB vector *Diaphorina citri* was detected in Tumbes (SENASA, 2018) due to the informal trade of ornamental plants, particularly *Murraya paniculata*. Subsequently, three more detections occurred in 2019. In response, the Servicio Nacional de Sanidad Agraria (SENASA) and Agrocalidad of Ecuador initiated collaborative surveillance efforts along the northern border of Peru (SENASA, 2020). Given the presence of HLB in neighboring countries like Colombia and Brazil, coupled with the vector's presence in Ecuador and Bolivia (Giancola et al., 2019), the entry of the disease in Peru is highly probable. Such an incursion could result in significant economic losses unless growers prepare to combat it. Without a national phytosanitary program (PNF) dedicated to prevention, control, and monitoring in place to address the contingency, the importance of prevention cannot be overstated, especially since there is no known cure for HLB (Bové et al., 2006; Mora-Aguilera et al., 2019; Ortiz-Isabel & Manzo-Ramos, 2019). Furthermore, in Latin American countries, there has been a lack of *ex ante* studies examining the economic impact of HLB prior to its introduction. This study aims to simulate scenarios of economic losses, considering the possibility of HLB entering the Central Jungle of Peru (Junín).

The Junín Region is the leading grower of oranges in Peru. As per the SIEA (2023), it boasts 13,897 hectares dedicated to orange production, with impressive yields of 21.8 tons per hectare. This thriving industry involves the participation of 2,433 small and medium-sized growers. The region's growth is primarily driven by substantial investments in orchards to meet market demands.

The aim of this study was to assess potential economic losses within the direct orange production chain in Peru's Central Jungle, specifically the Region Junín. This assessment involved simulating the introduction and spread of HLB through a range of plausible future scenarios spanning from 2026 to 2045. The core objective was to estimate the cost-benefit of implementing a PNF as a proactive measure to mitigate damages caused by HLB. The study's ultimate purpose was to provide empirical evidence that could inform and support evidence-based public policy decisions.

2. Methodology

The study focused on Agricultural Units (AU) engaged in orange production within the Region Junín. To gather data, questionnaires were administered using a stratified sampling approach, targeting a total of 345 growers from a population of 3,366 AU (Equation 1). This population was distributed across two provinces: Chanchamayo (comprising the districts of Perené with 99 questionnaires, Pichanaqui with 41, Chanchamayo with 25, San Ramón with 16, and San Luis de Shuaro with 14) and Satipo (encompassing the districts of Satipo with 61 questionnaires, Pangoa with 49, Mazamari with 20, and Río Negro with 20) as illustrated in Figure 1. Details are given in. the questionnaire (Annex 1).

$$n = \frac{\sum_{h=1}^{L} W_h p_h q_h}{\frac{e^2}{Z^2_{(1-\alpha/2)}} + \frac{1}{N}\sum_{h=1}^{L} W_h p_h q_h} \quad (1)$$

where n is sample size, N is the population, W_h is the weight of the stratum in the population, Z is the normal distribution, and e is the error; while p_h, and q_h are respectively the proportion of success and failure in stratum h.

Three scenarios were developed to assess the economic impact of HLB introduction. The business as usual (BAU) scenario represents the trend production of oranges in the absence of HLB, essentially the status quo. The epidemiological scenario assumed that HLB present without the implementation of a PNF for disease prevention, control, and monitoring. In the HLB entry with variable compliance scenario, HLB is introduced and various levels of compliance and adoption by orange growers are considered. Compliance rates include 25%, 40%, 50%, 75%, and 100%, which represent the extent to which growers adhere to the measures outlined in the PNF for HLB treatment and management.

The first scenario (BAU) was built with the autoregressive integrated moving average (ARIMA) model that considers information on the value of orange production 1980–2022 (Xn), where α is the autoregression coefficient, εt is the error in time n and, θ is the coefficient of moving average part of the model (Equation 2).

$$Xn_{i=}\alpha X_{n-1} + \cdots + \alpha_p X_{n-p} + \varepsilon_n + \theta_1 \varepsilon_n + \cdots + \theta_q \varepsilon_{n-q} \quad (2)$$

In addition, growers were classified according to risk factors in the spread of HLB using the *Kprototypes* algorithm, and the cluster was segmented using the *ELBOW* method (Equation 3), considering the place of acquisition of seedlings, knowledge of symptoms, if there was pest control, the distance between the UA and the nearby populated center, associativity, training, movement of fruits in the UA and willingness to eliminate trees with HLB.

$$distorsion = \sum_i^N \frac{||Xi - centroid||^2}{N} \quad (3)$$

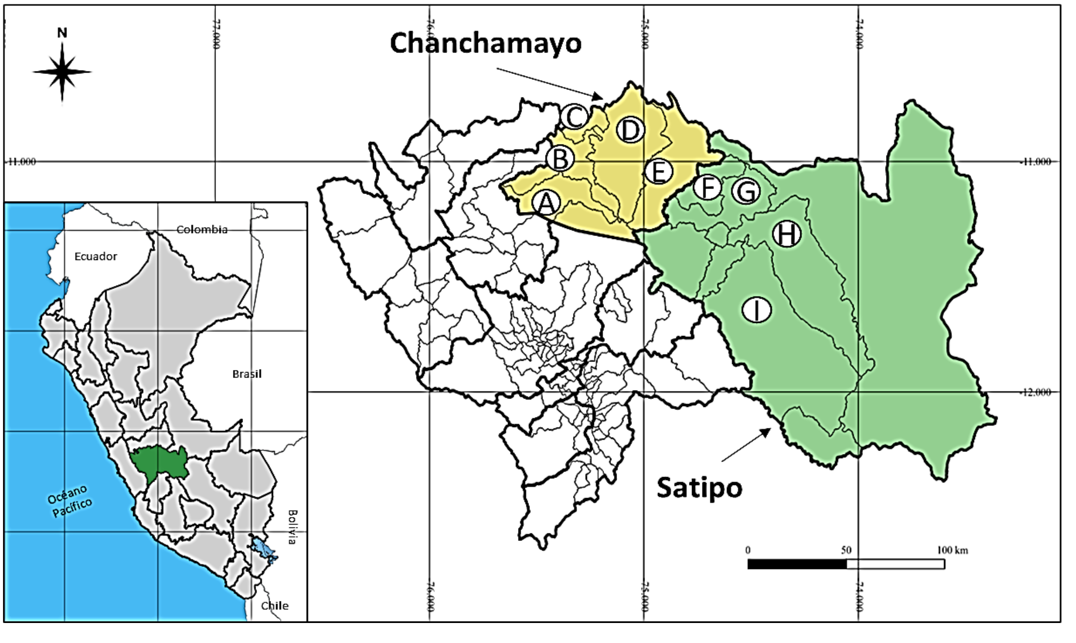

Figure 1. Region Junín and its main orange producing provinces and districts The Chanchamayo province in Region Junín and five of its districts producing oranges: (A) San Ramón, (B) Chanchamayo, (C) San Luis de Shuaro, (D) Perené, (E) Pichanaqui. The Satipo province including four districts producing oranges: (F) Río Negro, (G) Satipo, (H) Mazamari, (I) Pangoa. Source: INEI (2023).

The epidemiological model of Bassanezi & Bassanezi (2008) (Equation 4) allowed to estimate the severity curves, by considering *st* (proportion of tree crown area with HLB), age ranges of the trees (from 0 to 2 years, 3 to 5 years, 6 to 10 years, and more than 10 years), and the annual rate of severity progress by tree age (r_L) with values of 3.68, 1.84, 0.92 and 0.69; For the proportion of tree crown area with HLB in year zero (s_0), values of 0.2, 0.1, 0.05 and 0.025 were used per age range of the plantation; the values of r_L and S_0, the time in years (n) start at zero. Because there is no HLB disease in Peru, the parameters were field observations validated in orange production in São Paulo (Brazil), and the age of trees in plantations in Region Junín (Peru).

$$sn = 1/(1 + \left(\left(\frac{1}{s_0}\right) - 1\right).\exp((-r_L.n))) \quad (4)$$

Subsequently, disease incidence progress curves (represented by *yt*, which is the proportion of trees displaying HLB symptoms in the orchard) were estimated using the Gompertz model, with annual incidence progress rate (rG) values set at 1,300, 0.6500, 0.325, and 0.244, as per the methodology outlined by Bassanezi & Bassanezi (2008) (Equation 5). The initial values of y_0, indicating the proportion of trees with symptoms at year zero within different age ranges, were calculated using the inverse of the number of trees per hectare (1/number of trees). This method was adapted from Oliveira et al. (2013) and applied to the State of Bahia in Brazil. In this context, n represents the number of trees within each age category in the year 2024, with values of 38, 56, 98, and 63 corresponding to the categories spanning from 0 to 2 years, 3 to 5 years, 6 to 10 years, and more than 10 years, respectively.

$$yn = \exp(-(-\ln(yo)).\exp(-r_G.n)) \quad (5)$$

With the values obtained from equations 4 and 5, the total severity (Sn) of HLB in the orchard over time for each age range was calculated (Equation 6).

$$S_n = \sum_{j=0}^{j=n}(y_j - y_{j-1})S_{n-j} \quad (6)$$

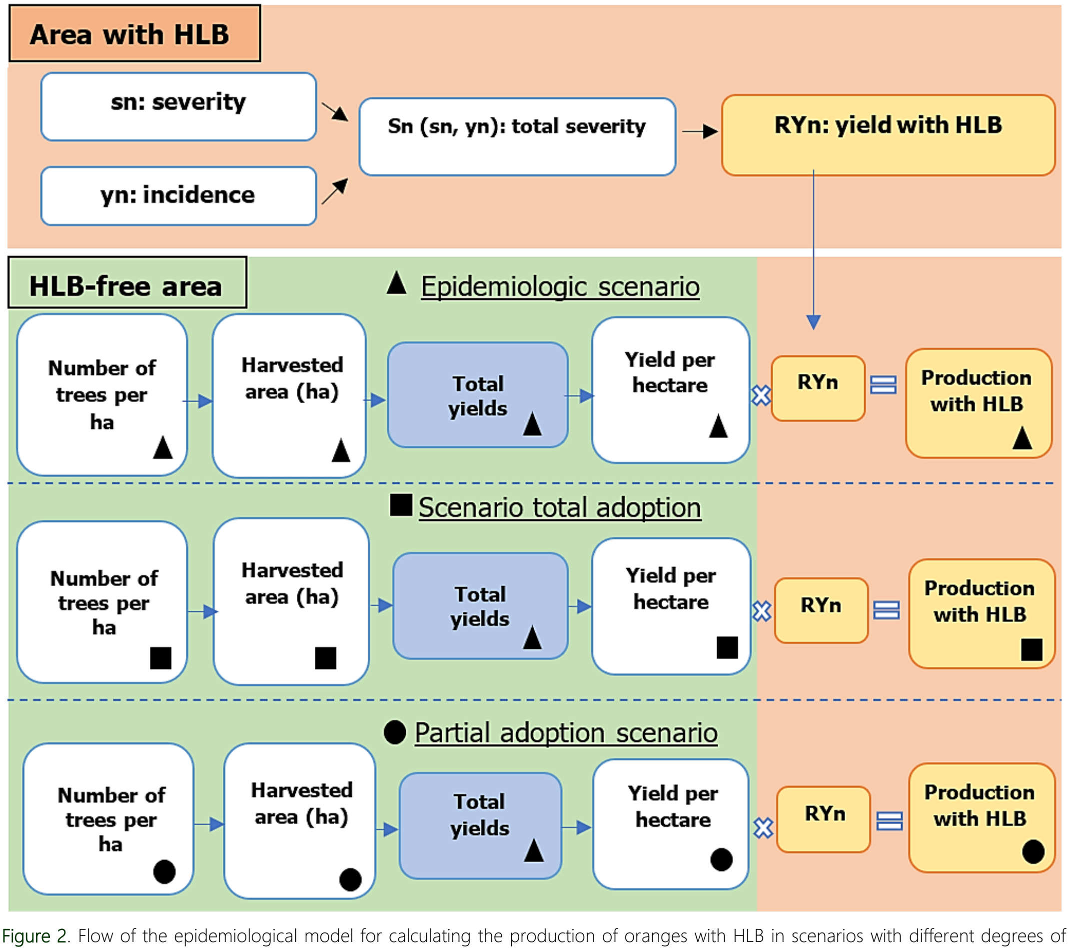

Figure 2. Flow of the epidemiological model for calculating the production of oranges with HLB in scenarios with different degrees of adoption of the growers to the PNF. Source: After Bassanezi & Bassanezi (2008). Note. In the HLB-affected zone, the total severity (Sn) is a function of both the severity (sn) and incidence (yn), which then determines the performance under HLB conditions (RYn). Production calculations involving HLB vary per hectare in terms of the number of trees, harvested area, and overall production. Meanwhile, yields remain consistent across all scenarios, as they are contingent on the age of the plantations rather than the number of trees.

Table 1
Number of trees in a hectare by age category over time

Year	n	wn (0–2 years)	xn (3–5 years)	yn (6–10 years)	zn (+ 10 years)
2026	0	w0	x0	y0	z0
2027	1	w0+7	x0	y0	z0-7
2028	2	w1+7-x1/4	x1+w1/4	y1	z1-7
2029	3	w2+7-x2/4	x2+w2/4-x2/4	y2+x2/4	z2-7
	:	.....	.....	.....	.....
	:	....	....	...	....
2044	18	q17+7-x17/4+z17/4	x17+w17/4-x17/4	y17+x17/4-y17/4	z17-7+y17/4
2045	19	w18+7-x18/4+z18/4	x18+w18/4-x18/4	y18+x18/4-y18/4	z18-7+y18/4

The production yields in the presence of HLB at time 'n' (RYn) were derived concerning both healthy and diseased trees, accounting for the severity of HLB symptoms (Sn) within each age range. These estimates were obtained through fitting to the negative exponential model as outlined in Bassanezi & Bassanezi (2008) (Equation 7).

$$RYn = \exp(-1.8.Sn) \quad (7)$$

Given that the epidemiological scenario involving HLB in the studies spans a 20-year period, the analysis assumes the detection of HLB in 2026, without the presence of a PNF. Consequently, the projected impacts extend until the year 2045. Insights were sought from experts affiliated with the Asociación de Productores de Cítricos del Perú (PROCITRUS) and the Universidad Nacional Agraria La Molina (UNALM), both actively engaged in the Junín region. Additionally, data from the administered questionnaires in Region Junín were incorporated. Figure 2 provides an overview of the impact within various scenarios as modeled epidemiologically.

Epidemiological scenario (HLB without PNF)

The production scenario in 2045, under the influence of HLB without the implementation of a National Phytosanitary Program (PNF), was based on several assumptions. It assumed that tree renewal occurred every 25 years, involving the removal of seven trees per hectare while planting the same number. A constant density of 255 trees per hectare was kept, with trees aged 0–2 years old not bearing fruit. Additionally, it was considered that HLB comes to Peru in 2026. The harvested area considered variation in the number of trees within each age category (as detailed in Table 1). Hence, the number of trees was determined by the initial values at time zero, with 34, 58, 114, and 49 trees respectively allocated to categories ranging from 0 to 2 years, 3 to 5 years, 6 to 10 years, and more than 10 years.

To calculate the harvested area, the last three categories were considered, and being their sum kn at time n. Furthermore, an, bn, and cn denote the respective proportions of harvested area within each category (Table 2).

The calculation of harvested area per hectare considered an average yield of 22 t/ha (averaged over 2018–2022), with time (n) incrementing by 1 for each subsequent year. This calculation involved dividing the total production for year n (Pn) by 22 t, thereby resulting in the total harvested area over time (Spcn). Subsequently, this value was multiplied by an, bn, and cn to determine the area associated with each age category (for details, Annex 2, part a).

The calculations over time were resolved using Excel 2019 Solver. In this optimization process, the objective was to minimize α to achieve a value of zero. The variables considered include Pn (total production), PAn (production from 3 to 5 years), PBn (production from 6 to 10 years), and PCn (production over 10 years), as expressed in Equation 8 (for details, Annex 2, part b):

$$\alpha = \sum_{t=0}^{21}(\mathrm{Pn} - \mathrm{PAn} - \mathrm{PBn} - \mathrm{PCn}) \quad (8)$$

The total production under HLB conditions without the presence of a PNF was computed. PAn, PBn, and PCn, which represent the production by age range (without HLB), were multiplied by RYn, thus corresponding to yields under HLB for their respective categories. As a result, the total summation of the outcomes (δn + εn + θn) over time constituted the total production (Pn) under HLB conditions and in the absence of a PNF.

Table 2
Share of harvested area in one ha by age category over time

Year	n	an (3–5 years)	bn (6-10 years)	cn (+ 10 years)	kn (xn+yn+zn)
2026	0	x0/k0	y0/k0	z0/k0	k0
2027	1	x1/k1	y1/k1	z1/k1	k1
2028	2	x2/k2	y2/k2	z2/k2	k2
2029	3	x3/k3	y3/k3	z3/k3	k3
:	:	....	....	....	....
:	:	....	....	....	.....
2044	18	x17/k17	y17/k17	z17/k17	k17
2045	19	x18/k18	y18/k18	z18/k18	k18

Full adoption scenario (with HLB and 100% of growers applying the PNF)

This scenario was simulated using the methodology developed by Bassanezi & Bassanezi (2008), wherein all orange growers adopt the National

Phytosanitary Program (PNF). To estimate the trend production without HLB and under strict PNF implementation, several assumptions were made. Tree renewal was every 25 years, involving the removal of seven trees and the planting of seven new seedlings per hectare. A constant tree density of 255 trees per hectare was kept, with trees aged 0–2 years not bearing fruit. An annual removal rate of 2% of trees per hectare was used. Consequently, the harvested area varied, thereby leading to a change in the sequence presented in Table 1 (Annex 2, part c). However, the underlying variables remained consistent, and the number of trees within each category retained values of w_0 for 0 to 2 years, x_0 for 3 to 5 years, y_0 for 6 to 10 years, and z0 for more than 10 years. To determine the share of harvested area by age in the epidemiological scenario, the analysis calculated the new area by age category (PAn, PBn, and PCn). These areas were then multiplied by the yields without HLB, which were computed using the Solver, to obtain the total production. The total new production was derived by summing these three categories.

Partial adoption scenarios (with HLB and a percentage of growers complying with the PNF protocol)

For these cases, the harvested area was divided between adopters and non-adopters. The scenarios of 25%, 40%, 50% and 75% of growers adopting the PNF caused the removal of 3% of trees annually due to HLB. For growers who did not carry out any control and where the disease spread, the epidemiological scenario methodology was used. Finally, the production of both types of growers was added.

To estimate the production in the partial scenarios, the following assumptions were made. Tree renewal occurred every 25 years, involving the removal of 7 trees and the planting of 7 new seedlings per hectare. A constant tree density of 255 trees per hectare was maintained, with trees aged 0-2 years not bearing fruit. Additionally, 3% of trees per year per hectare were removed from growers who adopted the National Phytosanitary Program (PNF). The harvested area varied over time, reflecting the total adoption scenario as presented in Table 1 (Annex 2, part d). Consequently, the number of trees within each category changed over time, with initial values set at w0 for 0 to 2 years, x0 for 3 to 5 years, y0 for 6 to 10 years, and z0 for more than 10 years. At time zero, these values were 34, 58, 98, and 77 trees, respectively. The percentage of growers who did not adopt the PNF was equivalent to the harvested area not covered by the program, following the methodology of the epidemiological scenario. Finally, the sum of production from both adopting and non-adopting growers equated to the total production within these scenarios.

Cost-benefit analysis (CBA)

The costs and benefits associated with each proposed scenario were quantified in monetary terms using the formula employed by Miranda et al. (2012), Dahlui et al. (2021), and Kotchen & Levinson (2023), which is represented by Equation 9.

$$\frac{B}{C} = \frac{\sum_{j=0}^{n} R_j/(1+i)^j}{\sum_{j=0}^{n} C_j/(1+i)^j} \quad (9)$$

where, for the epidemiological scenario, Rj is benefits without adopting the PNF in the year j, and Cj is the costs without implementing PNF in year j; while for the scenarios with PNF Rj is benefits after adopting PNF in year j, Cj: is the cost of implementing PNF in year j. Likewise, relying on the direct orange production chain in the Central Jungle and the production simulations spanning from 2026 to 2045, we estimated the income losses attributable to HLB in each of the proposed scenarios. We also assessed their impacts on wages and profits, in conjunction with the application of CBA. Consequently, the disparities in production between the baseline scenario and scenarios with HLB allowed for a comparison of the disease's impact, thereby enabling the estimation of potential future economic losses. This assessment considered the net present value (NPV) in 2026 and the social discount rate (SDR) of 8%. The SDR signifies the opportunity cost incurred by the Government of Peru when allocating resources to finance its projects, as outlined in government documents (MEF, 2019; Seminario de Marzi, 2017).

3. Results and discussion

Cluster analysis

Table 3 presents the classification of orange growers in the Junín region, emphasizing the risk factors associated with the dissemination of HLB. Cluster one comprises 190 growers, constituting 55% of the total, with the majority from the province of Chanchamayo (97%). Meanwhile, cluster two consists of 155 growers (45%), with 93% of them originating from the province of Satipo.

The identified risks upon the entry of HLB into the region include: (i) limited acquisition of seedlings from certified nurseries; (ii) less than 50% of farmers possessing the knowledge to identify HLB symptoms, (iii) infrequent pest control efforts, with most growers dedicating less than one day per year to this task.; (iv) inadequate levels of grower association, involving less than a third of the growers; and (v) proximity of Agricultural Units (UAs) to populated areas or main roads, which is a known factor in HLB transmission, as the disease is primarily transported by humans. This transmission occurs through infected fruits, cuttings, seedlings, or ornamental plants that contain the insect vector (Bassanezi et al., 2020; Zhang et al., 2020).

Table 3
Clusters of orange growers and risk attributes before the entry of Huanglongbing (HLB)

Risk factors	Cluster 1		Cluster 2	
1. Acquisition of orange tree seedlings from a nursery	Own 20%	Informal 80%	Own 65%	Informal 35%
2. Know symptoms of HLB	45%		30%	
3. Days spent performing pest control per year	0		1	
4. Distance between Agricultural Units (UA) and the town or road	38 minutes		27 minutes	
5. Belong to a citrus association	13%		32%	
6. Participate in pest control training	97%		79%	
7. There is entry and exit of citrus fruits in the UA	4%		90%	
8. Willing to remove diseased plants	95%		100%	

Source: After a questionnaire survey of 345 growers in Junín (2021).

These risks closely align with those noted by Sulzbach et al. (2018) in the State of Rio Grande do Sul, Brazil, where HLB has not yet been detected. In this region, orange cultivation is predominantly done by small growers with limited phytosanitary knowledge. Moreover, the proximity of the disease to neighboring Paraguay and Argentina poses an additional threat. These authors emphasize that the primary preventive measure against the disease is quarantine, aiming to prevent the introduction of citrus trees infected with HLB and *Murraya paniculata* carrying *Diaphorina citri*, which is the vector of this disease. Rigorous inspection is crucial, as the vector can also be transported via infected fruit (Halbert et al., 2010; Hall & McCollum, 2011).

Scenarios with HLB

Following the epidemiological model (Equations 4, 5, 6, and 7), Figure 3a reveals that the severity of HLB increases more rapidly in young trees. Consequently, by the year 2026, following the entry of HLB, the crown infection rate in 0–2-year-old trees may reach 20%, while for other age categories, it may remain at 10% or lower.

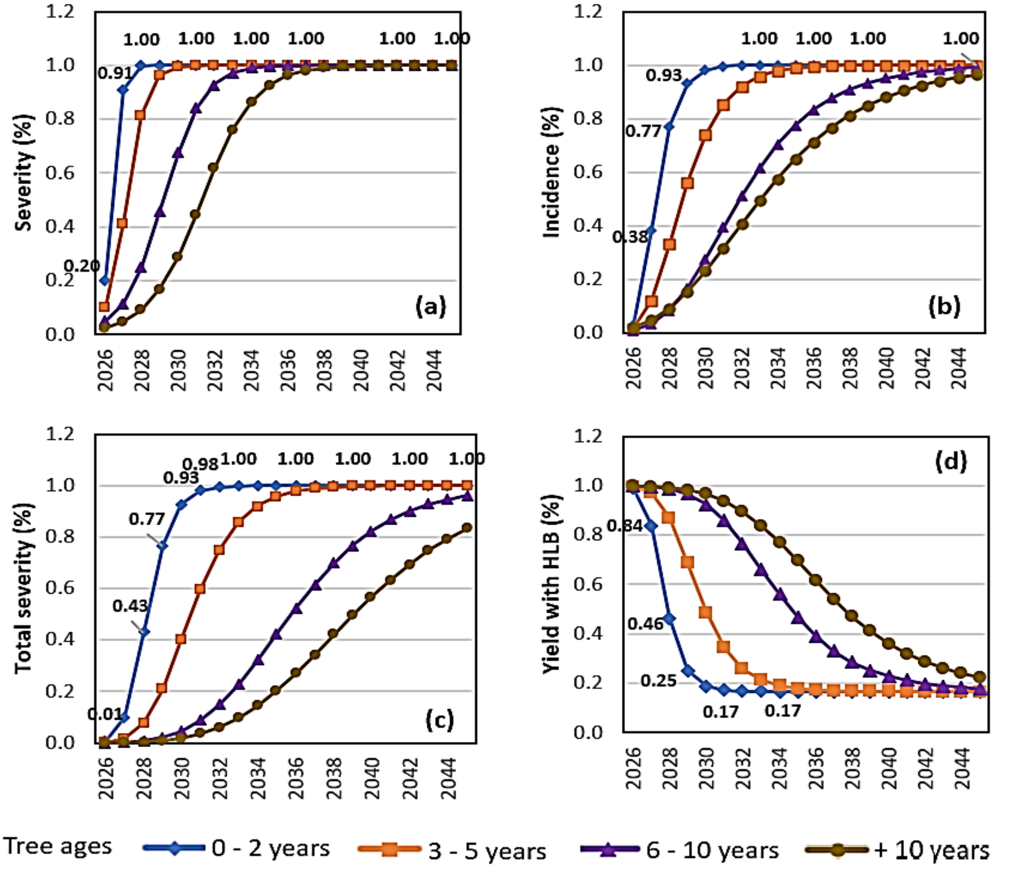

Figure 3. Percentage of severity, incidence, total severity and production yields with Huanglongbing (HLB) depending on the age of the trees in Region Junín. These curves represent the impact of HLB from 2026 to 2045.

Figure 3b shows the proportion of trees displaying HLB symptoms per hectare (incidence). In 2026, all age categories may exhibit infection rates of at least 1%. By 2027, the infection rate for 0–2-year-old trees could rise to 38%, while for 3–5-year-old trees, it may be 12%. In comparison, the last two categories may maintain infection rates below 3%. Figure 3c provides curves depicting the total severity per hectare, considering both the production of diseased trees and the ratio of healthy ones. It also shows the severity of HLB in relation to the age of the trees when the first symptom appears. The contagion and spread of the disease may occur most rapidly in 0–2-year-old trees, reaching 100% infection by 2033. Subsequently, 3–5-year-old trees may attain full infection by 2039, while the last categories may reach 96% and 83% infection rates in 2045, respectively. Figure 3d presents the returns with HLB. The reduction in returns appears to be most pronounced in the 0–2-year age category, quickly plateauing at 17% by 2031. For 3–5-year-old trees, returns may also stabilize at 17% by 2036, whereas 6–10-year-old trees could reach 18% in 2044. In the case of trees older than 10 years, returns may stand at 22% by 2045.

Figure 4 displays a range of prospective scenarios for orange production in Region Junín up to the year 2045. In the baseline scenario (BAU, without HLB), production is projected to increase at an average annual rate of 2%. Conversely, in the epidemiological scenario, the production of oranges affected by HLB may initially experiences minimal growth until 2025, after which it could undergo a significant annual decline of -6% until 2045, given the uncontrolled nature of the disease. The full adoption scenario, where production follows an annual growth rate of 2%, shows an increase that is somewhat lower compared to the trend production (BAU, without HLB). By 2045, this scenario anticipates a production loss of 4% in comparison to the BAU scenario (without HLB). For the partial adoption scenarios involving HLB, with varying percentages of growers adopting the PNF program (25%, 40%, 50%, and 75% of the total), the results demonstrate that a higher number of growers embracing the program leads to a reduced production loss over time. It's worth noting that in Region Junín, intermediate scenarios are considered more plausible because most orange growers (60% of respondents) are characterized as small and unorganized.

The introduction of the HLB disease would result in losses spanning the entire direct production chain. These losses encompass not only reduced income for growers but also a decrease in wages across various sectors, including production, transporttation, processing, and both internal and external trade. These losses are quantified in terms of decreased production, the reduction in the number of wages, and unrealized monetary gains. This quantitative data is integral to the prospective evaluation of the cost-benefit analysis (CBA), Detailed information is given in Annex 3 and Annex 4.

By the year 2045, in the presence of HLB and without the implementation of the PNF as per the epidemiological scenario, the citrus production would only reach 20% of what is expected in the BAU trend scenario, with a production of 89,839 tons compared to 457,022 tons. However, if 25% of producers were to adopt the PNF, production would increase to 38% of the expected output. Remarkably, with 100% adoption of the PNF, the losses would be limited to just 4%, as depicted in Figure 4. These findings align with research by Vera-Villagrán et al. (2016) on lime production in Colima, Mexico, in the presence of HLB, and Miranda et al. (2012) on citrus production in the State of São Paulo, Brazil. Both investigations underscore that without the implementation of a comprehensive phytosanitary program to control the disease, production experiences significant reductions. For Vera-Villagrán et al. (2016), the scenario with effective HLB control results in production totaling 227,446 thousand tons, whereas the scenario limited to vector control alone only achieves 123,578 thousand tons. Similarly, Miranda et al. (2012) show that a phytosanitary program significantly curbs production losses compared to scenarios without this critical element. These outcomes collectively emphasize the effectiveness of phytosanitary programs in curbing the spread of HLB disease and mitigating losses in citrus production.

Cost-benefit analysis (CBA)

The CBA for the scenario involving HLB and partial adoption of PNF by 25% producers, along with the HLB control costs within the direct productive chain of Junín orange, cumulatively assessed from 2026 to 2045, yields a NPV of S/ 1,224,531.6 thousand by the year 2026. This NPV is attributed to production losses, equivalent to US$ 368,345.1 thousand using the exchange rate of the year 2023. Additionally, there is an unrealized gain of S/ 224,713.2 thousand soles (Table 4). Considering the incremental costs incurred by various entities, the government's expenditure for implementing the PNF stands at S/ 25,781 thousand, while PROCITRUS contributes S/ 5,024.2 thousand. Furthermore, factoring in the additional expenses that producers will need to bear due to HLB, amounting to S/ 44,458.8

thousand (which include costs related to the removal of diseased plants, replanting, enhanced sanitary control, increased use of chemical inputs, among others), the simulation accounts for the impact of high HLB-related costs as referenced in Miranda et al. (2012). Consequently, the total incremental costs across these three entities sum up to S/ 75,264 thousand. These figures translate into a benefit-to-cost ratio (B/C) of 6.25 for growers, 10.78 for the government, and 9.02 for the combined efforts of the Government of Peru and PROCITRUS.

For every S/ 1 invested by growers to prevent and manage HLB in their crops, they would avoid the loss of S/ 5.25. In the case of the Government of Peru, for every S/ 1 it invests it would avoid losses of S/ 9.78 in the productive chain. direct production of oranges from Junín, and the three agents together (Government of Peru, PROCITRUS and growers) would avoid a loss of S/ 2.69 (Table 4), with the public intervention ratios being positive.

The results of the CBA and associated ratios are presented across a range of scenarios involving the adoption of the PNF by growers, including adoption rates of 25%, 40%, 50%, 75%, and 100%. It is evident that as the level of acceptance and adherence to the disease control guidelines by producers increases, losses diminish, and the B/C ratios improve. This underscores the potential for greater success in preventing, managing, and controlling the disease, ultimately resulting in reduced losses across production, income, jobs, and the broader economic activity. These outcomes emphasize that, from the government's perspective, the PNF remains viable even when only 25% of producers adopt it, as the B/C ratios consistently surpass the 8% threshold (TSD) typically used to assess the feasibility of financing public projects. Consequently, to enhance the effectiveness of public policy, it is imperative to concurrently promote the acceptance of the PNF among growers. Furthermore, to assess the feasibility of implementing the PNF, variations in producer prices and production costs are considered, with fluctuations of +/- 10%. Even under these dynamic conditions, the B/C ratio remains viable in all scenarios, consistently exceeding the 8% TSD (Annex 5).

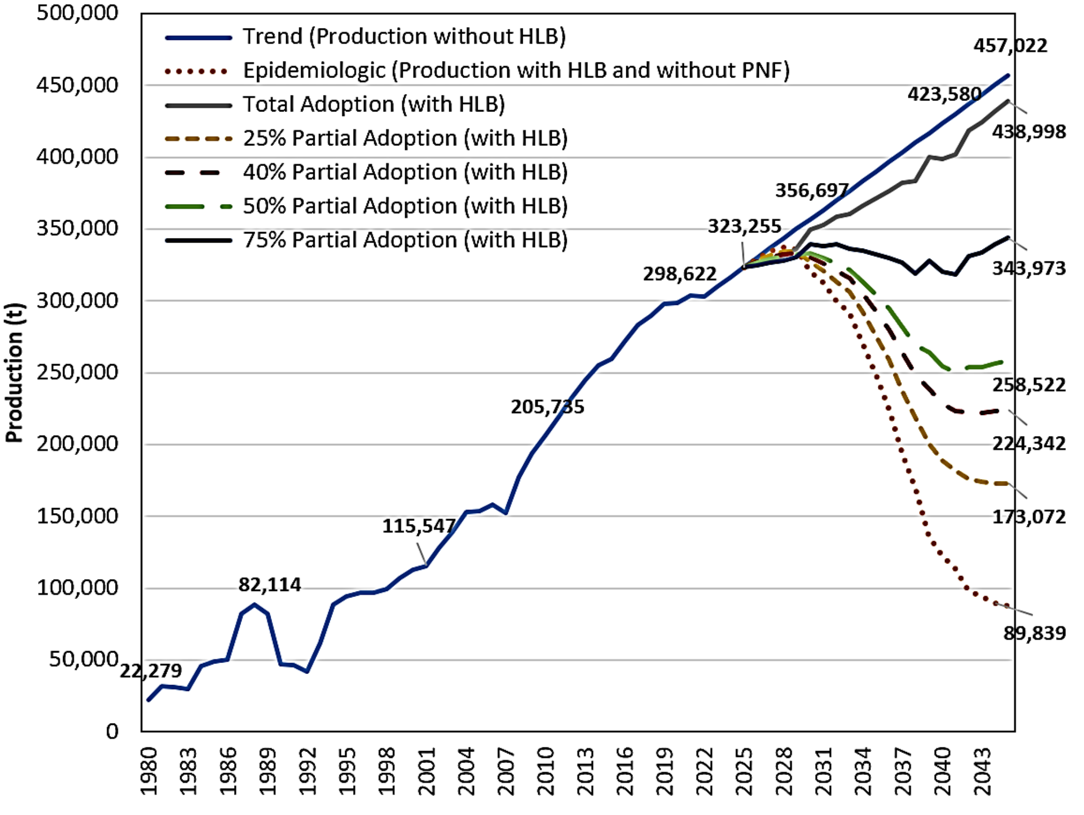

Figure 4. Orange production projection (2023–2045) in Region Junín (t), trend scenario (without Huanglongbing [HLB]), epidemiological scenario (with HLB), total adoption (with HLB and national phytosanitary program [PNF]), and scenarios with HLB and partial adoption of PNF growers (25%, 40%, 50% and 75%). Note. The orange production projection from 2023 to 2045 (in t) in Junín considers the trend scenario (BAU, without HLB), the epidemiological scenario (with HLB), total adoption scenario (with HLB and PNF), and various scenarios with existence of the HLB and partial adoption of the PNF by growers (at 25%, 40%, 50% and 75% adoption). To estimate the effects of HLB on production, it is considered that the *Diaphorina citri* vector enters in 2024 or 2025 and in 2026 the existence of HLB is formally declared in the country (although the disease may not be declared in 2026, the analysis It is valid from the year HLB is detected and a PNF is implemented).

Table 4
Economic evaluation of Region Junín orange production under various cost-benefit scenarios considering wage losses and foregone profits due to HLB-induced production decline, simulated costs (in thousands of S/ and thousands of US$) Accumulated from 2026 to 2045, and net present value (NPV) as of 2026

BENEFITS AND COSTS		Epidemiologic (S/)	25% (S/)	40% (S/)	50% (S/)	75% (S/)	Total adoption (S/)	Total adoption (in thousands of US$) (*)
I. Benefits								
A. Production value		1 224 531.60	1 355 509.90	1 434 096.90	1 486 488.30	1 617 466.60	1 789 550.80	486 291.00
B. Production loss		641 058.20	510 079.90	431 492.90	379 101.50	248 123.20	76 039.00	20 662.80
C. Reduction of employment		724 761.30	577 912.10	489 802.60	431 063.00	284 213.80	89 156.10	24 227.20
C.1. Production days		249 138.90	198 659.10	168 371.20	148 179.20	97 699.40	30 647.70	8 328.20
C.2. Rest of chain wages		193 808.90	154 539.90	130 978.40	115 270.80	76 001.80	23 841.30	6.478.60
C.3. Unrealized benefit		281 813.50	224 713.20	190 453.00	167 612.90	110 512.60	34 667.10	9 420.40
D. Total loss	D = B + C	1 365 819.60	1 087 992.00	921 295.50	810 164.50	532 337.00	165 195.00	44 890.00
E. Benefits (avoided losses scenario B)			277 827.50	444 524.10	555 655.10	833 482.60	1 200 624.50	326.256.70
II. Costs								
F. Government Peru (Gov.)			25 781.00	26 296.60	27 070.09	29 648.10	32 226.20	8 757.10
G. PROCITRUS			5 024.20	5 024.20	5 024.20	5 024.20	5 024.20	1 365 30
H. Gov. + PROCITRUS	H = F + G		30 805.10	31 320.80	32 094.20	34 672.30	37 250.40	10 122.40
I. Growers (additional costs)			44 458.80	60 141.70	66 016.80	64 673.80	26 971.40	7 329.20
J. Total costs	J = H + I		75 264.00	91 462.40	98 110.90	99 346.10	64 221.80	17 451.60
K. Net costs	J = H + I		75 264.00	91 462.40	98 110.90	99 346.10	64 221.80	17 451.60
L. Net losses avoided (avoided costs)			202 563.60	353 061.00	457 544.10	734 136.50	1 136 402.70	308 805.10
M. Ratio B/C Growers			6.25	7.39	8.42	12.89	44.51	
N. Ratio B/C (Government, PROCITRUS and Growers)			3.69	4.86	5.66	8.39	18.69	
Ñ. Ratio B/C (Government)			10.78	16.90	20.53	28.11	37.26	
O. Ratio B/C (Government + PROCITRUS)			9.02	14.19	17.31	24.04	32.23	

(*) The conversion from soles (S/) to US dollars (US$) is with reference to the exchange rate of S/ 3.68 per US$ 1 dated 8th Nov. 2023. Source: BCRP (2023).

The findings from Oliveira et al. (2013) in Brazil indicate that the implementation of disease control measures would yield a significant net benefit, totaling 1,002 billion reais. Over a 20-year horizon, this translates into a net present value gain of 685 million reais. Similarly, Miranda et al. (2012) provide B/C indicators for 20-year timeframe. In their study, they report a B/C ratio of 4.6 for the Government of Brazil, Fundecitrus, and growers, which closely aligns with the results observed at a 40% adoption rate of PNF in Peru (B/C of 4.86). However, it is noteworthy that in Brazil, the Government and Fundecitrus achieve an exceptionally high B/C ratio of 57.3, which significantly surpasses all scenarios examined in the case of Peru, with the highest reaching 32.23.

The findings of Vera-Villagrán et al. (2016) regarding HLB management in diverse citrus settings in Colima, Mexico, present various production scenarios. These encompass a scenario devoid of HLB (BAU), another involving an epidemiological model, and several intermediate scenarios, thereby reflecting varying degrees of HLB control and tree eradication. Notably, one of these intermediate scenarios –when government intervention is factored in– yields a benefit-cost (B/C) ratio of 10.9 monetary units, akin to the B/C return observed in Junín with a 25% adoption rate among producers (10.78). Moreover, the study by IICA et al. (2019), which investigated the impact of phytosanitary strategies against HLB in Brazil, revealed a B/C ratio of 2.28 for society over a decade. This figure is lower than the one obtained for Region Junín in Peru (B/C of 3.69 with a 25% adoption rate). Furthermore, the production scenarios and their associated B/C indicators consider the possibility that, in response to the incursion of HLB into the Central Jungle, investors may opt to halt the expansion of production and instead aim to maintain production levels by 2030. The representation of this simulation and its corresponding ratios are presented in Supplementary Material 2.

4. Conclusions

The presence of HLB disease poses a substantial threat to the citrus agribusiness, potentially rendering it economically unviable. In Peru, while swift vector control efforts have successfully contained detections on the North Coast, the risk of HLB introduction still looms over orange growers in the Central Jungle region. These growers remain susceptible to significant losses, given their lack of preparedness to combat the disease. As a result, prospective scenarios for the year 2045 consider the growth of orange production under different circumstances: the baseline scenario without HLB (BAU), scenarios with HLB alongside full compliance with the PNF by all growers, and the epidemiological scenario without the PNF. In the latter scenario, HLB is projected to lead to an annual production decline of -6%.

The benefit-cost (B/C) ratio for scenarios involving HLB and varying levels of PNF adoption by growers, accumulated up to 2045, reflects the benefits arising from the prevention of production losses. However, it is important to note that the incremental costs associated with these scenarios are expected to be borne jointly by the Government of Peru, PROCITRUS, and the growers themselves. From the government's perspective, the B/C ratio ranges from 10.8 with 25% adoption among growers to 37.3 when 100% of growers adopt the PNF, thus making the PNF economically viable in all cases. For growers, a positive B/C ratio under scenarios with HLB and the PNF is beneficial because it not only prevents production losses but also safeguards income and jobs within the direct productive chain. Moreover, when considering potential interactions with other sectors of the economy, the benefits become even more significant.

The implementation of effective public policies is strongly recommended to mitigate economic losses for the country's citrus growers. Failure to do so could result in losses throughout the entire production chain. Consequently, public policy should encompass not only the management of the disease itself but also the preparation of growers to effectively confront it.

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ORCID

W. Mercado https://orcid.org/0000-0001-7167-9581
K. Guadalupe https://orcid.org/0009-0004-3764-1087
K. Vega Alegre https://orcid.org/0000-0003-3702-4279

References

Aidoo, O. F., Ablormeti, F. K., Ninsin, K. D., Antwi-Agyakwa, A. K., Osei-Owusu, J., et al. (2023). First report on the presence of huanglongbing vectors (Diaphorina citri and Trioza erytreae) in Ghana. *Scientific Reports*, *13*(1).

Alves, K. S., Rothmann, L. A., & Del Ponte, E. M. (2022). Linking Climate Variables to Large-Scale Spatial Pattern and Risk of Citrus Huanglongbing: A Hierarchical Bayesian Modeling Approach. *Phytopathology*, *112*(1), 189-196.

Aubert, B. (1987). Le greening, une maladie infectieuse des agrumes, d'origine bactérienne, transmise par des homoptères psyllides. Stratégie de lutte développée à l'île de la Réunion. Circonstances epidemiologigues en Afrique/Asie et modalités d'intervention. *Circonstances épidémiologiques en Afrique/Asie et modalités dÕintervention. IFRA/CIRAD, Nairobi, Kenya*.

Badaracco, A., Redes, F. J., Bustamente, K. M., Bloch, N., Schapovaloff, M. E., & Agostini, J. P. (2022). First detection of positive 'Candidatus Liberibacter asiaticus' Diaphorina citri in Argentina. *Australasian Plant Pathology*, *51*(1), 9-12. https://doi.org/10.1007/s13313-021-00817-w

Badaracco, A., Redes, F., Preussler, C., & Agostini, J. (2017). Citrus huanglongbing in Argentina: Detection and phylogenetic studies of Candidatus Liberibacter asiaticus. *Australasian Plant Pathology*, *46*(2), 171-175. https://doi.org/10.1007/s13313-017-0473-4

Bassanezi, R. B., & Bassanezi, R. C. (2008). An approach to model the impact of Huanglongbing on citrus yield. *Proceedings of the International Research Conference on Huanglongbing*, *1*.

Bassanezi, R. B., Lopes, S. A., De Miranda, M. P., Wulff, N. A., Volpe, H. X. L., & Ayres, A. J. (2020). Overview of citrus huanglongbing spread and management strategies in Brazil. *Tropical Plant Pathology*, *45*(3), 251-264. https://doi.org/10.1007/s40858-020-00343-y

Bertaccini, A., Satta, E., Luis-Pantoja, M., Paredes-Tomás, C., Yuneau, Y., & Myrie, W. (2019). 'Candidatus Phytoplasma' and 'Candidatus Liberibacter' species detection in citrus. *Phytopathogenic Mollicutes*, *9*(1), 187-188. https://doi.org/10.5958/2249-4677.2019.00094.X

Bové, J. M., López, M. M., & Durán-Vila, N. (2006). Evitar el huanglongbing (HLB), un reto para la supervivencia de la citricultura española. *Levante agrícola*, *383*, 385-390.

Chavez, Y., Castro, C., González, G. F., Castro, J., Peñarrieta, S., Perez-Almeida, I., Chirinos, D. T., & Kondo, T. (2019). Population fluctuation of Diaphorina citri Kuwayama (Hemiptera: Liviidae) and survey of some natural enemies in Ecuador. *Revista de Investigaciones Agropecuarias*, *45*(3), 449-453. Scopus.

Chen, X. D., Qureshi, J. A., & Stelinski, L. L. (2022). Monitoring of Diaphorina citri populations from Florida reveals reduced susceptibility to cyantraniliprole and thiamethoxam. *Journal of Applied Entomology*, *146*(6), 725-733. https://doi.org/10.1111/jen.13011

Clarke, S. K. V., & Brown, S. E. (2018). Identification and distribution of haplotypes of diaphorina citri (Hemiptera: Liviidae) in Jamaica and the Caribbean. *Journal of Economic Entomology*, *111*(5), 2401-2408. https://doi.org/10.1093/jee/toy194

COSAVE. (2017). *HLB: Regional Program of Control and Prevention*.

Cruz, M. A. D., Neves, C. S. V. J., Carvalho, D. U. D., Colombo, R. C., Bai, J., Yada, I. F. U., Leite Junior, R. P., & Tazima, Z. H. (2021). Five Rootstocks for "Emperor" Mandarin Under Subtropical Climate in Southern Brazil. *Frontiers in Plant Science*, *12*. https://doi.org/10.3389/fpls.2021.777871

Cui, X., Liu, K., Huang, J., Fu, S., Chen, Q., Liu, X., Zhou, C., & Wang, X. (2022). Population Diversity of 'Candidatus Liberibacter asiaticus' and Diaphorina citri in Sichuan: A Case Study for Huanglongbing Monitoring and Interception. *Plant Disease*, *106*(6), 1632-1638. https://doi.org/10.1094/PDIS-07-21-1539-RE

Da Costa, G. V., Neves, C. S. V. J., Bassanezi, R. B., Junior, R. P. L., & Telles, T. S. (2021). Economic impact of huanglongbing on orange production. *Revista Brasileira de Fruticultura*, *43*(3). https://doi.org/10.1590/0100-29452021472

Da Silva, P. A., Fassini, C. G., Sampaio, L. S., Dequigiovanni, G., Zucchi, M. I., & Wulff, N. A. (2019). Genetic Diversity of 'Candidatus Liberibacter asiaticus' Revealed by Short Tandem Repeats and Prophage Typing Indicates Population Homogeneity in Brazil. *Phytopathology*, *109*(6), 960-971. https://doi.org/10.1094/PHYTO-08-18-0295-R

Dahlui, M., Rochmah, T. N., & Chalidyanto, D. (2021). Economic evaluation for health advocacy and informed policy. *Indonesian Journal of Health Administration*, *9*(2), 202-209. https://doi.org/10.20473/jaki.v9i2.2021.202-209

Darolt, J. C., Bento, F. D. M. M., Merlin, B. L., Peña, L., Cônsoli, F. L., & Wulff, N. A. (2021). The Genome of "Candidatus Liberibacter asiaticus" Is Highly Transcribed When Infecting the Gut of Diaphorina citri. *Frontiers in Microbiology*, *12*. https://doi.org/10.3389/fmicb.2021.687725

De Carvalho, S., Girardi, E., Filho, F., Ferrarezi, R., & Filho, H. (2019). Advances in citrus propagation in Brazil. *Revista Brasileira de Fruticultura*, *41*(6). https://doi.org/10.1590/0100-29452019422

De Chaves, M., Morán, F., Barbé, S., Bertolini, E., de la Rosa, F., & Marco-Noales, E. (2023). A new and accurate qPCR protocol to detect plant pathogenic bacteria of the genus 'Candidatus Liberibacter' in plants and insects. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-30345-0

Ding, F., Peng, S.-A., & Hartung, J. S. (2020). Enhanced Serologically Based Detection of Liberibacters Associated with Citrus Huanglongbing. *Plant Disease*, *104*(6), 1584-1588. https://doi.org/10.1094/PDIS-12-19-2679-SC

Durborow, S., & Lopez, A. (2012). *An analysis of the potential economic impact of Huanglongbing on the California citrus industry*. Southern Agricultural Economics Association Annual Meeting, Orlando, Florida. https://doi.org/10.22004/ag.econ.142771

Gao, F., Wu, B., Zou, C., Bao, Y., Li, D., Yao, W., Powell, C. A., & Zhang, M. (2022). Genetic Diversity of "Candidatus Liberibacter asiaticus" Based on Four Hypervariable Genomic Regions in China. *Microbiology Spectrum*, *10*(6). https://doi.org/10.1128/spectrum.02622-22

Garnier, M., & Bové, J. M. (1996). Distribution of the huanglongbing (greening) Liberobacter species in fifteen African and Asian countries. *International Organization of Citrus Virologists Conference Proceedings (1957-2010)*, *13*(13).

Giancola, S., Aguirre, M., Di Masi, S., Bravo, G., Molina, N., & Alderete, S. (2019). *Control sustentable del vector del HLB en la Agricultura Familiar en Argentina, Uruguay, Paraguay y Bolivia*. Congreso Argentino de Citricultura, Tucumán, Argentina.

Grafton-Cardwell, E. E., Stelinski, L. L., & Stansly, P. A. (2013). Biology and management of Asian citrus psyllid, vector of the huanglongbing pathogens. *Annual Review of Entomology*, *58*(1), 413-432. https://doi.org/10.1146/annurev-ento-120811-153542

Halbert, S. E., Manjunath, K. L., Ramadugu, C., Brodie, M. W., Webb, S. E., & Lee, R. F. (2010). Trailers transporting oranges to processing plants move Asian citrus psyllids. *Florida Entomologist*, *93*(1), 33-38.

Hall, D. G., & McCollum, G. (2011). Survival of adult Asian citrus psyllid, Diaphorina citri (Hemiptera: Psyllidae), on harvested citrus fruit and leaves. *Florida Entomologist*, 1094-1096.

Hallman, L. M., Kadyampakeni, D. M., Ferrarezi, R. S., Wright, A. L., Ritenour, M. A., & Rossi, L. (2023). Uptake of micronutrients in severely HLB-affected grapefruit trees grown on Florida Indian River flatwood soils. *Journal of Plant Nutrition*. Scopus. https://doi.org/10.1080/01904167.2023.2221287

Hansen, A. K., Sanchez, A. N., & Kwak, Y. (2022). Divergent Host-Microbe Interaction and Pathogenesis Proteins Detected in

Recently Identified Liberibacter Species. *Microbiology Spectrum*, *10*(4). https://doi.org/10.1128/spectrum.02091-22

Hernández-Landa, L., Lopez-Collado, J., González-Hernández, H., Vargas-Mendoza, M., Osorio-Acosta, F., & Nava-Tablada, M. E. (2018). Fluctuation and synchronization of adults catches of Diaphorina citri Kuwayama (Hemiptera: Liviidae) in urban backyards and commercial citrus plantations. *Journal of Asia-Pacific Entomology*, *21*(3), 745-753. https://doi.org/10.1016/j.aspen.2018.05.005

IICA, John Snow Brasil Consultoría, SDA, COSAVE, & PSAICA. (2019). *Estudio de caso de evaluación de impacto de las medidas fitosanitarias del Huanglongbing en Brasil para producción de plantines en ambiente protegido*. Instituto Interamericano de Cooperación para la Agricultura (IICA). https://repositorio.iica.int/handle/11324/7902

INEI. (2023). *Censos Nacionales XII de Población y VII de Vivienda.* Instituto Nacional de Estadística e Informática. https://www.gob.pe/inei/

Kalile, M., Cardoso, A., Pallini, A., Fonseca, M., Ferreira-Junior, T., & Janssen, A. (2023). A predatory mite that suppresses Diaphorina citri populations on plants with pollen and oviposition sites. *Entomologia Experimentalis et Applicata*, *171*(8), 592-602. https://doi.org/10.1111/eea.13326

Kotchen, M. J., & Levinson, A. (2023). When Can Benefit-Cost Analyses Ignore Secondary Markets? *Journal of Benefit-Cost Analysis*, *14*(1), 114-140. https://doi.org/10.1017/bca.2022.22

Li, J., He, P., He, P., Li, Y., Wu, Y., Lu, Z., Li, X., Yang, Y., Wang, Y., Guo, J., Munir, S., & He, Y. (2022). Potential of citrus endophyte Bacillus subtilis L1-21 in the control of Candidatus Liberibacter asiaticus in Asian citrus psyllid, Diaphorina citri. *Pest Management Science*, *78*(12), 5164-5171. https://doi.org/10.1002/ps.7134

Lin, C.-Y., Batuman, O., & Levy, A. (2023). Identifying the Gut Virome of Diaphorina citri from Florida Groves. *Insects*, *14*(2). https://doi.org/10.3390/insects14020166

Lin, C.-Y., Tsai, C.-H., Tien, H.-J., Wu, M.-L., Su, H.-J., & Hung, T.-H. (2017). Quantification and ecological study of 'Candidatus Liberibacter asiaticus' in citrus hosts, rootstocks and the Asian citrus psyllid. *Plant Pathology*, *66*(9), 1555-1568. https://doi.org/10.1111/ppa.12692

Liu, T.-S., Sun, X.-L., Bin, M.-L., Yi, G.-J., & Zhang, X.-X. (2022). Functional Characterization of the Ryanodine Receptor Gene in Diaphorina citri. *Life*, *12*(12). https://doi.org/10.3390/life12122005

Lopez, J. A., & Durborow, S. L. (2014). Huanglongbing and the California Citrus Industry: A Cost Comparison of Do Nothing vs. Do Something Management Practices. *Texas Journal of Agriculture and Natural Resources*, *27*, 51-68.

López-Collado, J., López-Arroyo, J. I., Robles-García, P. L., & Márquez-Santos, M. (2013). Geographic distribution of habitat, development, and population growth rates of the Asian citrus psyllid, Diaphorina citri, in Mexico. *Journal of Insect Science*, *13*. https://doi.org/10.1673/031.013.11401

Luis-Pantoja, M., Paredes-Tomás, C., Uneau, Y., Myrie, W., Morillon, R., Satta, E., Contaldo, N., Pacini, F., & Bertaccini, A. (2021). Identification of 'Candidatus Phytoplasma' species in "huanglongbing" infected citrus orchards in the Caribbean. *European Journal of Plant Pathology*, *160*(1), 185-198. https://doi.org/10.1007/s10658-021-02234-7

McRoberts, N., Figuera, S. G., Olkowski, S., McGuire, B., Luo, W., Posny, D., & Gottwald, T. (2019). Using models to provide rapid programme support for California's efforts to suppress Huanglongbing disease of citrus. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374*(1776). https://doi.org/10.1098/rstb.2018.0281

MEF. (2019). *Directiva General del Sistema Nacional de Programación Multianual y Gestión de Inversiones. Anexo 11. Parámetros de Evaluación Social*. Diario El Peruano.

Meng, L., Xia, C., Jin, Z., & Zhang, H. (2022). Investigation of Gut Bacterial Communities of Asian Citrus Psyllid (Diaphorina citri) Reared on Different Host Plants. *Insects*, *13*(8). https://doi.org/10.3390/insects13080694

Miranda, S. H. G. de, Adami, A. C. de O., & Bassanezi, R. B. (2012). *Economic impacts of huanglongbing disease in São Paulo State*.

Mora-Aguilera, G., Acevedo-Sánchez, G., Guzmán-Hernández, E., Flores, E., Martínez-Bustamente, V., Coria-Contreras, J., & Robles-García, P. (2019). *El HLB de los cítricos en México: Epidemiología, Manejo e Impactos Productivos*.

Nguyen, V.-A., Bartels, D. W., & Gilligan, C. A. (2023). Modelling the spread and mitigation of an emerging vector-borne pathogen: Citrus greening in the U.S. *PLoS Computational Biology*, *19*(6). https://doi.org/10.1371/journal.pcbi.1010156

Oke, A. O., Oladigbolu, A. A., Kunta, M., Alabi, O. J., & Sétamou, M. (2020). First report of the occurrence of Asian citrus psyllid Diaphorina citri (Hemiptera: Liviidae), an invasive species in Nigeria, West Africa. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-66380-4

Oliveira, J. M. C. de, Nascimento, A. S. do, Miranda, S. H. G. de, Barbosa, C. de J., & Laranjeiras, F. F. (2013). Estimativa dos impactos econômicos decorrentes de eventual introdução do huanglongbing (HLB) no estado da Bahia. *Revista Brasileira de Fruticultura*, *35*, 755-762.

Ortiz-Isabel, B. E., & Manzo-Ramos, F. (2019). El programa Arco para el control del huanglongbing en Tecoman, Colima, y Axtla, San Luis Potosí, México. *AGROProductividad*, *12*(6), 25-31.

Pan, Q., Yu, S.-J., Lei, S., Li, S.-C., Ding, L.-L., Liu, L., Cheng, L.-Y., Luo, R., Lei, C.-Y., Lou, B.-H., Cong, L., Liu, H.-Q., Wang, X.-F., & Ran, C. (2023). Effects of Candidatus Liberibacter asiaticus infection on metagenome of Diaphorina citri gut endosymbiont. *Scientific Data*, *10*(1). https://doi.org/10.1038/s41597-023-02345-2

Pandey, S., Hendrich, C., Andrade, M., & Wang, N. (2022). Candidatus Liberibacter: From Movement, Host Responses, to Symptom Development of Citrus Huanglongbing. *Phytopathology*, *112*(1), 55-68. https://doi.org/10.1094/PHYTO-08-21-0354-FI

Paredes-Tomás, C., Luis-Pantoja, M., Contaldo, N., Bertaccini, A., & Pacini, F. (2023). Multigene characterization of 'Candidatus Phytoplasma palmae' strains infecting citrus species in Cuba. *Phytopathogenic Mollicutes*, *13*(1), 91-92. https://doi.org/10.5958/2249-4677.2023.00046.4

Pérez-Valencia, L. I., Michel, A. P., Moya-Raygoza, G., & Rodríguez, A. (2019). Genetic variation and structure of Diaphorina citri (Hemiptera: Liviidae) in populations from México. *Annals of the Entomological Society of America*, *112*(4), 379-387. https://doi.org/10.1093/aesa/saz016

Petri, G., & Jorge, N. (2015). *Evaluación del potencial impacto económico del Huanglongbing [HLB] en la economía argentina*. IICA.

Phuyal, D., Nogueira, T. A. R., Jani, A. D., Kadyampakeni, D. M., Morgan, K. T., & Ferrarezi, R. S. (2020). 'Ray Ruby' grapefruit affected by huanglongbing II. Planting density, soil, and foliar nutrient management. *HortScience*, *55*(9), 1420-1432. https://doi.org/10.21273/HORTSCI15128-20

Ramírez-Godoy, A., Puentes-Pérez, G., & Restrepo-Díaz, H. (2018). An evaluation of the use of calcium, potassium and silicon for the management of Diaphorina citri populations in Tahiti lime trees. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *46*(2), 546-552. https://doi.org/10.15835/nbha46211152

Salcedo, D., Mora, G., Covarrubias, I., Cíntora, C., Hinojosa, R., DePaolis, F., & Mora, S. (2011). *Assessment of the economic impact of Huanglongbing (HLB) disease on Mexico's citrus chain*.

Santiago, J. M., Kadyampakeni, D. M., Fox, J.-P., Wright, A. L., Guzmán, S. M., Ferrarezi, R. S., & Rossi, L. (2023). Grapefruit Root and Rhizosphere Responses to Varying Planting Densities, Fertilizer Concentrations and Application Methods. *Plants*, *12*(8). https://doi.org/10.3390/plants12081659

Sauer, A. V., Nocchi, P. T. R., Zanutto, C. A., Rinaldi, D. A. M. F., & Nunes, W. M. C. (2015). Monitoring «candidatus liberibacter asiaticus» in a commercial orchard of sweet orange and tahiti lime in the northwest of paraná state, Brazil. *Acta Horticulturae*, *1065*, 913-918. https://doi.org/10.17660/ActaHortic.2015.1065.113

Seminario de Marzi, L. (2017). *Actualización de la Tasa Social de Descuento*. Ministerio de Economía y Finanzas. https://www.mef.gob.pe/contenidos/inv_publica/docs/parametros_evaluacion_social/Tasa_Social_Descuento.pdf

SENASA. (2018). Piura: Monitoreo preventivo permite proteger cítricos del dragón amarillo (HLB). *SENASA Contigo*. https://www.senasa.gob.pe/senasacontigo/piura-monitoreo-preventivo-permite-proteger-citricos-del-dragon-amarillo-hlb/

SENASA. (2020). MINAGRI y productores citrícolas firmes para evitar ingreso del HLB. *SENASA Contigo*. https://www.senasa.gob.pe/senasacontigo/minagri-y-productores-citricolas-firmes-para-evitar-ingreso-del-hlb/

SENASICA. (2017). *Manual operativo de la campaña contra el Huanglongbing de los cítricos*.

Setamou, M., Tarshis Moreno, A., & Patt, J. M. (2022). Source or Sink? The Role of Residential Host Plants in Asian Citrus Psyllid Infestation of Commercial Citrus Groves. *Journal of Economic Entomology*, *115*(2), 438-445. https://doi.org/10.1093/jee/toab249

SIEA. (2023). *Estadística Agropecuaria*. Sistema Integrado de Estadística Agraria. https://siea.midagri.gob.pe/portal/

Spreen, T. H., & Baldwin, J.-P. (2013). *The impact of huanglongbing (HLB) on citrus tree planting in Florida*.

Stover, E., Hall, D. G., Grosser, J., Gruber, B., & Moore, G. A. (2018). Huanglongbing-related responses of 'valencia' sweet orange on eight citrus rootstocks during greenhouse trials. *HortTechnology*, *28*(6), 776-782. https://doi.org/10.21273/HORTTECH04137-18

Sulzbach, M., de Oliveira, R. P., Girardi, E. A., Bassanezi, R. B., Laranjeira, F. F., & Schwarz, S. F. (2018). Risk analysis of introduction and spread of huanglongbing in citrus groves in Rio Grande do Sul, Brazil. *Tropical Plant Pathology*, *43*(1), 49-58. https://doi.org/10.1007/s40858-017-0198-5

Thakuria, D., Chaliha, C., Dutta, P., Sinha, S., Uzir, P., Singh, S., Hazarika, S., Sahoo, L., Kharbikar, L., & Singh, D. (2023). Citrus Huanglongbing (HLB): Diagnostic and management options. *Physiological and Molecular Plant Pathology*, *125*(102016).

Vera-Villagrán, E., Sagarnaga-Villegas, L. M., Salas-González, J. M., Leos-Rodríguez, J. A., Galvão De Miranda, S. H., & Cristina De Oliveira Adami, A. (2016). Economic impact analysis for combating HLB in key lime citrus groves in Colima, Mexico, assuming the Brazilian approach. *Custos e Agronegocio*, *12*(4), 344-363.

Wang, Y., Kondo, T., He, Y., Zhou, Z., & Lu, J. (2021). Genome sequence resource of «Candidatus Liberibacter asiaticus» from Diaphorina citri Kuwayama (Hemiptera: Liviidae) in Colombia. *Plant Disease*, *105*(1), 193-195. https://doi.org/10.1094/PDIS-06-20-1249-A

Zapien-Macias, J. M., Ferrarezi, R. S., Spyke, P. D., Castle, W. S., Gmitter, F. G., Jr., Grosser, J. W., & Rossi, L. (2022). Early Performance of Recently Released Rootstocks with Grapefruit, Navel Orange, and Mandarin Scions under Endemic Huanglongbing Conditions in Florida. *Horticulturae*, *8*(11). https://doi.org/10.3390/horticulturae8111027

Zhang, F., Qiu, Z., Zhong, B., Feng, T., & Huang, A. (2020). Modeling citrus Huanglongbing transmission within an orchard and its optimal control. *Mathematical Biosciences and Engineering*, *17*(3), 2048-2069.

Zorzenon, F. P. F., Tomaseto, A. F., Daugherty, M. P., Lopes, J. R. S., & Miranda, M. P. (2021). Factors associated with Diaphorina citri immigration into commercial citrus orchards in São Paulo State, Brazil. *Journal of Applied Entomology*, *145*(4), 326-335. https://doi.org/10.1111/jen.12851

ANNEX

Annex 1. Questionnaire used in survey with orange growers

SECTION I. Identification of household

1. Province ________________________
2. District ________________
3. Town __________________________
4. Sector
5. Código GPS ____________________
6. Latitude (°) _____________
7. Longitude (°) __________
8. Altitude (masl) ________

The respondent must be the producer who grew citrus fruits in 2020

SECTION II. Agricultural

* The "extension" "Quantity Produced", and the "Sales Price" must have equivalent conversion units.
* Production refers to the last year (2020).
* The Agricultural Unit (UA) refers to the plot or farm that is all land, located within the same district, which does not have continuity with the rest of the plots or farms that it works or manages.

In multiple choice questions, only mark one option, the most important one.

Crops	UA			Trees					
	UA	Data only from the main farm or plot (UA)							
	1. # of farms or plots	2. Main AU surface (ha)	3. Crop extension in the main UA (ha)	4. # of trees per ha	5. # of seedlings planted in 2019 in one ha	6. # of seedlings planted in 2020 in one ha	7. # of trees removed last year (2020) in one ha	8. In what year the tree begins its production (harvest begins)	9. In what year does the tree stop producing (remove the seedling)
1. Orange									
2. Tangelo									
3. Other: _									

Crops	# Trees owned in one ha (Insert the data from point 4 of the table)	(a) Percentage of trees less than 2 years old per ha	(b) Percentage of trees 2 to 5 years old per ha	c) Percentage of trees 6 to 10 years old per ha	) Percentage of trees over 10 years old per ha
1. Orange					
2. Tangelo					
3. Other: ____					

Crops	Quantity produced (2020) per ha (kg)	Producer sale price, kg? (S/)	(a) Self-consumption percentage	(b) Storage percentage for future sale	(c) Percentage of sales at harvest to the collector	(d) Percentage destined for direct sales at fairs	(e) Pecertange to destination Others: _____
1. Orange							
2. Tangelo							
3. Other: _							

*(a) + (b) + (c) + (d) + (e) = 100% annual amount produced per crop (2021).

SECTION III. Risk factors

In multiple choice questions, only mark one option, the most important one.

1. Where do you obtain your citrus seedlings?
   1. Own 2. Other growers 3. From certified nurseries
   4. Informal nurseries. 5. Others ___________
2. Do you know what are the HLB symptoms?
   1. Yes 2. No
2. What is the number of times you evaluate and carry out pest control per year? ____________
3. What is the distance between your UA and the urban town or district capital (whichever is closest)? Distance in time (hours and minutes) and name of the populated center or capital of the district. Hours: ________; minutes: _______. Town/district capital: _______________
4. What is the distance in time (hours and minutes) between your UA and the main road? Also enter the name of the main road.
   Hours: ________; minutes: ________
   Main road: ________________________________
5. Do you belong to any citrus association? 1. Yes 2. No
6. Have you ever participated in a Yellow Dragon, HLB or Huanglogbing talk, training or event? 1. Yes 2. No
8. Is there movement in and out of citrus fruits (orange, tangerine, lemon) in the UA? 1. Yes 2. No
9. Knowing that a tree sick with HLB can continue producing, but there is no cure, if HLB is detected in a tree in your plantation, would you be willing to eliminate the diseased plant and the plants surrounding the diseased tree immediately?
   1. Yes 2. No

Nombre del encuestado (productor)			
Place of birth		Mobile phone number	
Email		Signature (optional)	

Annex 2. Tables detailing the study methodology

Anenx 2a. Total production, total harvested area and by age category over time

Year	n	Pn (production)	Spcn (harvested area)	dn (3–5 years)	en (6–10 years)	fn (+ 10 years)
2026	0	P0	P0/22	(Spc0)(a0)	(Spc0)(b0)	(Spc0)(c0)
2027	1	P1	P1/22	(Spc1)(a1)	(Spc1)(b1)	(Spc1)(c1)
2028	2	P2	P2/22	(Spc2)(a2)	(Spc2)(b2)	(Spc2)(c2)
2029	3	P3	P3/22	(Spc3)(a3)	(Spc3)(b3)	(Spc3)(c3)
	:	....	....	....	....	....
	:	....	....	....	....	....
2044	18	P18	P18/22	(Spc18)(a18)	(Spc18)(b18)	(Spc18)(c18)
2045	19	P19	P19/22	(Spc19)(a19)	(Spc19)(b19)	(Spc19)(c19)

Where dn, en, and fn represent the harvested area of the categories of 3–5 years, 6–10 years and more than 10 years.

Annex 2b. Performance and production by age category over time

Year	n	RAn (3–5 years)	RBn (6–10 years)	RCn (+ 10 years)	PAn (3–5 years)	PBn (6-10 years)	PCn (+ 10 years)
2026	0	RA0	RB0	RC0	(Spc0)(RA0)	(Spc0)(RB0)	(Spc0)(RC0)
2027	1	RA1	RB1	RC1	(Spc1)(RA1)	(Spc1)(RB1)	(Spc1)(RC1)
2028	2	RA2	RB2	RC2	(Spc2)(RA2)	(Spc2)(RB2)	(Spc2)(RC2)
:	:	....	....	....	....	....	....
:	:	....	....	....	....	....	....
2044	18	RA18	RB18	RC18	(Spc18)(RA18)	(Spc18)(RB18)	(Spc18)(RC18)
2045	19	RA19	RB19	RC19	(Spc19)(RA19)	(Spc19)(RB19)	(Spc19)(RC19)

RAn, RBn and RCn are the yields for each category, where 7 ≤ RAn≤ 14; 14 ≤ RBn ≤ 20; 26 ≤ RCn ≤ 45; αn = 0, only added when necessary.

Annex 2c. Number of trees in one hectare by age category over time, with 2% tree removal annually

Year	n	wn (0–2 years)	xn (3–5 years)	yn (6-10 years)	zn (+ 10 years)
2026	0	w0-μ(2%)/4+μ(2%)	x0-μ(2%)/4	y0-μ(2%)/4	z0-μ(2%)/4
2027	1	w0+7-μ(2%)/4+μ(2%)	x0-μ(2%)/4	y0-μ(2%)/4	z0-7-μ(2%)/4
2028	2	w1+7-x1/4-μ(2%)/4+μ(2%)	x1+w1/4-μ(2%)/4	y1-μ(2%)/4	z1-7-μ(2%)/4
2029	3	w2+7-x2/4-μ(2%)/4+μ(2%)	x2+w2/4-x2/4-μ(2%)/4	y2+x2/4-μ(2%)/4	z2-7-μ(2%)/4
	:	.....	.....	.....	.....
	:	....	....	...	....
2044	18	w17+7-x17/4+z17/4-μ(2%)/4+μ(2%)	X17+w17/4-x17/4-μ(2%)/4	y17+x17/4-y17/4-μ(2%)/4	z17-7+y17/4-μ(2%)/4
2045	19	w18+7-x18/4+z18/4-μ(2%)/4+μ(2%)	x18+w18/4-x18/4-μ(2%)/4	y18+x18/4-y18/4-μ(2%)/4	z18-7+y18/4-μ(2%)/4

μ represents 255 trees.

Annex 2d. Number of trees in one hectare by age category over time, with 3% tree removal annually

Año	n	wn (0-2 years)	xn (3-5 years)	yn (6-10 years)	zn (+ 10 years)
2026	0	w0-μ(3%)/4+μ(3%)	x0-μ(3%)/4	y0-μ(3%)/4	z0-μ(3%)/4
2027	1	w0+7-μ(3%)/4+μ(3%)	x0-μ(3%)/4	y0-μ(3%)/4	z0-7-μ(3%)/4
2028	2	w1+7-x1/4-μ(3%)/4+μ(3%)	x1+w1/4-μ(3%)/4	y1-μ(3%)/4	z1-7-μ(3%)/4
2029	3	w2+7-x2/4-μ(3%)/4+μ(3%)	x2+w2/4-x2/4-μ(3%)/4	y2+x2/4-μ(3%)/4	z2-7-μ(3%)/4
	:	.....	.....	.....	.....
	:	....	....	...	....
2044	18	w17+7-x17/4+z17/4 μ(3%)/4+μ(3%)	x17+w17/4-x17/4-μ(3%)/4	y17+x17/4-y17/4-μ(3%)/4	z17-7+y17/4-μ(3%)/4
2045	19	w18+7-x18/4+z18/4 μ(3%)/4+μ(3%)	x18+w18/4-x18/4-μ(3%)/4	y18+x18/4-y18/4-μ(3%)/4	z18-7+y18/4-μ(3%)/4

μ represents 255 trees.

Annex 3. Production flows of 10 t of orange from Region Junín throughout the direct productive chain

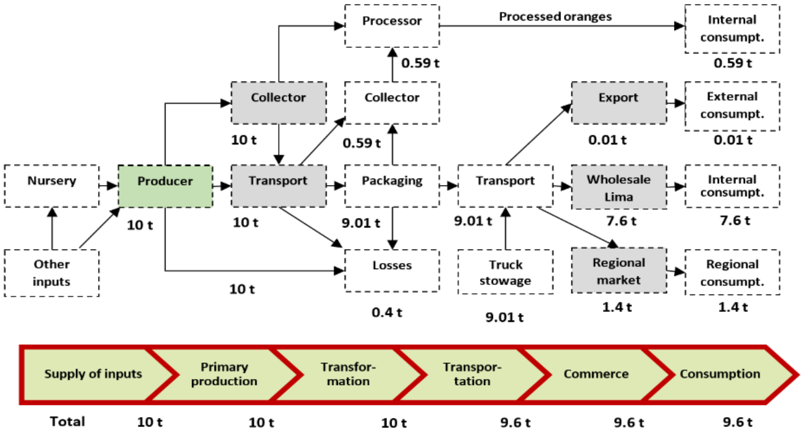

Figure A3.1. Production flows of 10 t of orange throughout the direct productive chain. The scheme indicates the flow that follows the production of 10 t of oranges and its interrelation with the actors of the direct productive chain that implies, in addition to the grower, the generation of wages in the collection, transformation, transportation, regional, national (Lima) and international trade.

Annex 4. Technical cost indicators for 10 t of orange production in Junín, generation of benefits and wages in the direct productive chain (in soles of 2022)

		Activity	t of fresh orange	Actor o agent in orange chain	Benefit margin (S/ per t)	Number of wages generated	Wage value (S/)	Total value (S/)
a.		Production (orange crop)	10.000	Day laborers		50.00	50	2500.00
b.		Fresh orange collection	10.000	Collector		5.33	50	266.50
c.		Rural transport	10.000	Conductor		0.66	60	39.60
d.		Packaging	9.010					
	d.1	Packaging (workers)	9.010	Wages		0.75	60	44 63
	d.2	Company packaging for the domestic market (90.01% total, 0.11 S/ per kg of trade margin)	9.000	Enterprise	110			990.00
	d.3	Company packaging for export (0.1% total, 0.04 US$ per kg, 0.13 S/ per kg trade margin)	0.010	Enterprise	130			13.00
	d.4	Processors (agribusiness, 0.20 as margin per trade)	0.590	Enterprise	200			118.00
	d.5	Processors (agribusiness, orange juice) (equivalence in 590 kg)	0.590	Wages		0.44	60	26.40
e.		Truck stowage (for 15 t it is 4 days)	9.600	Day laborers		2.56	50	128.00
f.		Transport Chanchamayo–Lima (for 15 t, 2 days) transfer to the Lima market (7.6), for export (0.01), for agroindustry (0.59), total 8.2 t for every 10 t	8.200	Conductor		1.09	143	155.87
g.		Unloading in Lima (for 15 t it is 3.5 wage days)	8.200	Day laborers		1.91	120	229.20
h.		Wholesale trade	7.600					
	h.1	Wholesaler's assistants (for 15 t they require two wage days)	7.600	Helpers		1.01	90	90.90
	h.2	Wholesale agent (margin 20% purchase value, 150 S/ per t) less cost of the assistant	7.600	Wholesaler	150			1140.00
i.		Export	0.010					
	i.1	Transport Lima to Puerto del Callao, fresh orange	0.010	Conductor		0.20	143	28.60
	i.2	Fresh orange exporting company (0.04 US$/kg, 0.13 soles/kg for trade margin).	0.010	Enterprise	130			1.30
j.		Regional market	1.400					
	j.1	Fresh orange destined for Region Junín market	1.400	Regional seller		4,00	40	160.00
	j.2	Transport of conditioner from Chanchamayo to the regional market	1.400	Conductor		0.50	143	71.50
		Total generated by 10 t of orange in wages and values (in S/)	10.000			68.45		5 958.87

Source: After interviews with direct actors in the orange production chain of Region Junín. The monetary values are updated to 2022 soles (S/).

Annex 5. Partial and total scenarios, with variation in grower's prices, variation in production costs and benefit/cost (B/C) indicator in the direct orange productive chain of Region Junín

	Adoption rate									
	25%		40%		50%		75%		100%	
Price Δ%	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10
Grower B/C	5.95	6.54	7.04	7.74	8.02	8.81	12.28	13.50	42.42	46.61
Goverment, PROCITRUS and grower B/C	3.52	3.87	4.63	5.09	5.40	5.93	7.99	8.79	17.82	19.57
Goverment B/C	10.27	11.28	16.11	17.70	19.56	21.49	26.79	29.44	35.50	39.01
Costs Δ%	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10	-0.10	+0.10
Grower B/C	6.94	5.68	8.21	6.72	9.35	7.65	14.32	11.72	49.46	40.47
Goverment, PROCITRUS and grower B/C	3.92	3.49	5.20	4.56	6.07	5.31	8.97	7.88	19.51	17.94
Goverment B/C	10.78	10.78	16.90	16.90	20.53	20.53	28.11	28.11	37.26	37.26