

Research Article

A case study on the risk of spread of citrus huanglongbing in family farming in São Paulo and Minas Gerais States, Brazil

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Abstract

Since its detection in Brazil in 2004, huanglongbing (HLB) has caused extensive damage to the citrus belt in São Paulo, Minas Gerais and Paraná states. The disease incidence is higher in small groves mainly related to family farming. As a case study, a multicriteria risk analysis was performed in two citrus regions in São Paulo and Minas Gerais with the objective of identifying the main factors associated with the introduction and spread of HLB in this farm profile. In 2017, a structured questionnaire was distributed comprising 27 closed questions with binary answers (0 or 1 as no or yes) to 39 citrus growers along 12 municipalities. The regions were selected according to the HLB incidence and relevance of citrus family farming, and farms were assessed by non-probabilistic and convenience sampling. The Analytic Hierarchy Process (AHP) was used to prioritize and weigh specific criteria related to the factors evaluated. Based on the answers, each farm was classified into four risk classes: low (0 to 0.25), intermediate (0.26 to 0.50), high (0.51 to 0.75) and very high (0.76 to 1). The introduction risks into the sampled farms were very high due to the disease occurrence in neighboring areas. However, factors that most contributed to the spread risk within groves were different between the two regions evaluated. In South MG, lack of basic knowledge about the HLB pathosystem and the low uptake of control measures were major issues, whereas in East SP the spread was more related to grove age, productivity and density, and absence of area-wide management.

Keywords: *Citrus* spp., '*Candidatus Liberibacter* spp.', *Diaphorina citri*, decision support, dissemination, production system, quarantine pest.

Introduction

In Brazil, citrus cultivation is concentrated in the São Paulo and Minas Gerais states' citrus belts, which comprise about 80 % of the national production (IBGE 2022). Sweet orange for juice processing is the main crop in 84 % of the cultivated area (Fundecitrus 2022), even though more than 500 thousand tons of mandarins are produced for the domestic fresh fruit market, comprising 54 % of the Brazilian mandarin production (IBGE 2022).

Diseases are major causes of losses in Brazilian citriculture (Oliveira et al. 2018). Huanglongbing (HLB) is the most devastating due to the fast spread, cryptic nature, high damage to fruit production and quality, and reduced grove lifespan (Bové 2006; Bassanezi et al. 2020). In the country, HLB was first detected in 2004 in São Paulo

(Coletta Filho et al. 2004), then in 2005 in Minas Gerais (Castro et al. 2010) and in 2006 in Paraná (Nunes et al. 2010). It is associated with phloem-restricted bacteria, mainly *Candidatus Liberibacter asiaticus*, transmitted by grafting and naturally by the psyllid *Diaphorina citri* Kuwayama (Belasque et al. 2009). There are no resistant citrus varieties or curative measures, therefore the management of HLB is preventive based on the use of healthy nursery trees grown in insect-proof environments, scouting and eradication of symptomatic trees and alternative vector hosts, such as orange jasmine (*Murraya* spp.), and the vector control by chemical, biological and physical methods (Bové 2006; Belasque et al. 2009). The disease control is more efficient when area-wide management is carried out (Bassanezi et al. 2013).

In spite of these recommendations, the HLB incidence has been increasing in the citrus belt in São Paulo and Minas Gerais up to an average of 44.35 % of trees in 2024

(Fundecitrus 2024). However, farms with less than 10,000 trees (< 21 ha) had a mean incidence of 60.5 %, while farms with more than 200,000 trees (> 420 ha) presented 36.23 % of mean HLB incidence. Such a difference may be explained by the difficult and expensive management notably for family growers (Bernardi et al. 2019), but mainly because the incidence of HLB is concentrated at the farm edge, that is, 70-80 % of symptomatic trees are within 200 m from the edge, since invading infective psyllids are a primary source of infection in farms that adopt control measures (Bassanezi et al. 2013). Consequently, smaller farms have a higher proportion of edge/total area compared with larger farms and, therefore, are more vulnerable to the disease. In 2022, small farms represented only 13 % of the citrus belt area with oranges, but comprised 76 % of the number of farms, counting 3,906 growers with less than 50 ha (Fundecitrus 2022).

Risk analysis of HLB invasion in the disease-free state of Rio Grande do Sul (RS) allowed mapping of priority regions for surveillance and identified factors potentially favorable to the disease introduction in 163 sampled farms throughout the state (Sulzbach et al. 2018). The risks would raise substantially for more than 90 % of the farms where HLB was detected in a given region of the state. Since family farming is prevalent in RS, and this production profile is more subject to HLB damage, the risk analysis proved to be an auxiliary tool to direct public policies on plant defense and rural extension (Petrini et al. 2016).

In this work, we performed a case study using multicriteria risk analysis in two citrus regions located in São Paulo and Minas Gerais states, Brazil, with the objective to identify the main factors related to HLB introduction and spread within small family farms with a history of disease incidence.

Materials and Methods

In 2017, 39 growers were interviewed in farms located in 12 municipalities that were selected due to the socioeconomic importance of local citrus production, family farming and occurrence of HLB: Aguaf (1 sampled farm), Amparo (1), Itatiba (1), Limeira (1), Mogi Guaçu (1), Socorro (7) and Tremembé (1), in the East of São Paulo State (SP); and Cambuquira (2), Campanha (14), Conceição do Rio Verde (2), Monsenhor Paulo (2) and Três Corações (6) in the South of Minas Gerais State (MG). Production was mainly for the fresh fruit market, 'Ponkan' mandarin (*C. reticulata* Blanco) being the most cultivated variety, and the average farm area was 50 ha. Growers were selected by non-probabilistic and convenience sampling. The number of respondents in each municipality/region was related to the amount of local production of mandarin, as Campanha (representing the main area in South MG) produces about 3-fold more fruit than Socorro (representing the main area in East SP) (Bernardi et al., 2019). The number and cultivated area of interviewed growers represented only 0.4 % of both total citrus growers and cultivated area in the citrus belt, but 0.99 % and 3.9 %

within small farms number and area, respectively (Fundecitrus 2022). Although general inferences for the two states are not feasible due to the bias in the sample size used in this study, the sampling provided a good case study for HLB dissemination within citrus family farming or small farms in a given region.

A structured questionnaire was distributed comprising 27 pre set closed questions with binary answers, based on criteria on HLB epidemiology, adapted from Sulzbach et al. (2018). The questionnaire was divided into two sections with 12 and 15 questions related to the introduction and spread risks, respectively (Table 1). Each affirmative answer (*yes*) counted one (1) point, related to a higher risk of either introduction or spread of HLB within the sampled farm, while each negative answer (*no*) counted zero (0).

Each criterion was weighed through the Analytic Hierarchy Process (AHP), which is used to prioritize and weigh the relative importance of the criterion in the risk composition (Appendix). AHP is a tool for decision making based on multicriteria risk analysis, in which the problem is structured in hierarchical levels and the corresponding comparison between criteria allows consistencies to be identified (Saaty, 2013).

For the risk analysis of HLB spread in the sampled regions, three hierarchical levels were structured: the problem itself (level 1), the two basic risks that lead to the problem – introduction in the farm and spread within the farm or global priorities (level 2), and the criteria that compose each basic risk (level 3). Twelve criteria were related to the introduction risk and 15 to the spread risk in SP and MG (Table 1). For levels 2 and 3, experts in HLB management were asked to make pairwise comparison using a scale ranging from 1 (criteria are equally important) to 9 (one criterion is extremely more important than the alternative). The comparisons were used to generate a comparison matrix paired with the chosen intensities, and the matrix was used to calculate the autovector of the criteria in each hierarchical level (Saaty, 2013). Each one of the five experts compared each pair of criteria based on their relative importance, using a numerical scale provided by the AHO-OS system. These comparisons were compiled into individual pairwise comparison matrices for each expert. The individual pairwise comparison matrices were aggregated into a group pairwise comparison matrix by averaging the corresponding values across experts. This matrix represents the collective judgment of the group regarding the relative importance of the criteria.

The weights and the consistency rate (CR) were estimated for each criterion, with $CR = CI / RI$, where CI is the consistency index of the cases matrix and RI is the consistency index of a random matrix of the same size. Values lower than 10 % (0.1) are classified as very consistent, while $CR > 90$ % (0.9) indicates that the process is almost random (Saaty 2013). All calculations were performed using the Online AHP System (bpmsg.com) (Goepel 2018). For each pairwise comparison matrix (individual and group), the Consistency Ratio (CR) was

calculated to assess its consistency. The CR compares the consistency of the matrix to a random one. A CR value less than 10% indicates a consistent matrix. If the CR is too high, the pairwise comparisons should be revised to improve consistency. The consensus is an estimate of the agreement on the priorities between experts. It ranges from 0% (not at all) to 100% (full consensus). According to Goepel (2018), it derives from the concept of diversity based on Shannon alpha and beta entropy. The consensus indicator measures the homogeneity between experts' evaluations. A combination of CR analysis and the consensus indicator ensures a robust AHP analysis.

The contribution of each criterion (relative importance) to the HLB introduction and spread risks was calculated by the proportion of affirmative answers from the applied

questionnaires, multiplied by the criterion weight obtained from the AHP. The 'HLB global risk' was calculated by (introduction risk x introduction weight) + (spread risk x spread weight). All estimated risks were classified into four categories: low (0 to 0.25), intermediate (0.2501 to 0.50), high (0.5001 to 0.75) and very high (0.7501 to 1.0). Farms from SP and MG were evaluated separately to compare the two regions.

Data were analysed using Statistica 7 (StatSoft). The non-parametric Kolmogorov-Smirnov two-sample test was used to compare the distribution of HLB introduction, spread, and global risks of independent samples (citrus farms) with variable sizes (number of sampled farms in each evaluated region).

Table 1

Structured questionnaire comprising 27 pre set closed questions divided into two sections, huanglongbing (HLB) introduction and spread risks, assessed for 39 citrus growers located in 12 municipalities in the East of São Paulo (Socorro region) and South of Minas Gerais (Campanha region), Brazil, and criteria weighed according to the Analytical Hierarchy Process (AHP). Adapted from Sulzbach et al., 2018.

Nº	Question	Significance	Weight by question at AHP
Risk of HLB introduction (Global priority)			0.1000
1	Does HLB occur in the area and municipality?	The presence of HLB in the area favors a fast dissemination of the disease.	0.3280
2	Does <i>Diaphorina citri</i> occur in the area?	The presence of the HLB vector in the area increases the risk of disease introduction.	0.1210
3	Does HLB occur in a neighboring municipality?	<i>D. citri</i> has great mobility, either by flight or wind, and can move from the vicinity where HLB occurs.	0.1100
4	Is there a lack of official plant health actions in the area?	Official plant health actions play a major role for the prevention of quarantine pests.	0.0740
5	Are tree stocks produced in another location?	Movement of tree stocks among producing areas favors the introduction of HLB.	0.0530
6	Is the area of origin of the tree stocks affected by HLB?	The use of infected tree stocks is one of the main means of HLB introduction in new areas.	0.1060
7	Are tree stocks produced outside of a protected environment?	Insect-proof nurseries are mandatory for the production of healthy stocks.	0.0610
8	Are there orange jasmine plants in the area (farm, neighbors, city)?	Orange jasmine is the preferred host of <i>D. citri</i> .	0.0290
9	Is there incoming/outgoing movement of fruit at the location for areas affected by HLB?	<i>D. citri</i> can be carried within fruit loads moving between an infected area and the location.	0.0280
10	Is the citrus density in the neighborhood greater than ten production units?	Areas with more citrus growers in the neighborhood favor the risk of HLB introduction as a result of differentiated management and increased inoculum potential.	0.0310
11	Is the distance from other areas with citrus less than 1 km?	Closer groves favor the introduction of HLB once primary infection has occurred.	0.0320
12	Is the production center cut by federal/interstate access roads?	The presence of roads near the groves facilitates the introduction of both <i>D. citri</i> and HLB in new areas.	0.0290

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Risk of HLB spread (Global priority)			0.9000
1	Is the producer unaware of HLB and Asian citrus psyllid?	Lack of knowledge of the pathosystem and symptoms delays the identification of HLB in the field and the adoption of preventive measures.	0.1710
2	Does the producer use little or no chemicals to control citrus pests?	The chemical control of <i>D. citri</i> is essential to manage HLB spread, and growers used to this practice will promptly adopt.	0.1400
3	Are windbreaks absent?	The absence of windbreaks favors the dispersion of <i>D. citri</i> among orchards.	0.0400
4	Is cultivation limited to only one citrus cultivar?	Single cultivar groves present similar phenological stages which facilitates psyllid control; on the other hand, citrus monoculture increases the risk of HLB infection for the property.	0.0250
5	Is the average productivity per cultivar less than 30 tons per ha?	Low yields lead to decreased income which in turn reduces the potential of adoption of HLB control technologies.	0.0410
6	Does the producer have difficulties in pest monitoring?	Limitations in pest monitoring indicate that the citrus grower will be unlikely to identify the presence of <i>D. citri</i> .	0.1190
7	Is the planting density less than 600 plants per ha?	High citrus tree density increases HLB progress if there is no vector control. On the other hand, HLB resets are less important and yield decrease is lower as a result of the decreased production per tree.	0.0360
8	Is there use of irrigation?	Irrigation induces higher vegetative vigor in citrus trees which may attract <i>D. citri</i> .	0.0370
9	Are there groves aged less than or equal to 6 years?	Young citrus trees are more attractive to <i>D. citri</i> and are more sensitive to HLB, becoming unproductive very fast.	0.0840
10	Are there plants with symptoms of nutritional deficiencies?	HLB symptoms can be mistaken with several nutritional deficiencies.	0.0530
11	Is the property disassociated with cooperatives/associations?	Growers that are used to any level of associations are more likely to coordinate HLB management in an area-wide approach which is more efficient for the disease control.	0.0370
12	Are cooperatives/associations unavailable in the area?	Synchronized <i>D. citri</i> control and eradication of HLB symptomatic trees are more efficient if the neighboring orchards are associated.	0.0380
13	Does the property not go through a certification process?	Certified orchards are frequently audited for an improved integrated pest management program.	0.0370
14	Is technical assistance unavailable?	Available and trained technical assistance is critical for grower support in HLB identification, scouting and management.	0.0720
15	Is the citrus industry's economic return unsatisfactory for the producer?	The dissatisfaction with the economic return may lead to decreased use of control measures and even to abandoned orchards which highly increase inoculum sources and consequently HLB spread.	0.0690

Results

AHP multicriteria analysis

For the second hierarchical level, the specialists' consensus was very high (100%) with a CR of zero. The weights of level 2 (that is, the global priorities) were 0.10 for the introduction risk and 0.90 for the spread risk, because HLB is present in all selected municipalities. For the third hierarchical level, criteria were compared within the two basic risks. The pairwise comparison between introduction risk criteria had an intermediate consensus (73.3 %), and a very low group CR (1.5 %) (Appendix). The weights for each criterion varied from 0.028 to 0.328 (Table 1). For the spread risk criteria, consensus was of

64.4 % and CR equalled 1.4 % (Appendix). The weights for each criterion ranged from 0.025 to 0.171 (Table 1). Global consensus was high (82.6 %) and group CR was low (1.5%). Experts' CRs ranged from 6.4% to 9.3% (Appendix).

Kolmogorov-Smirnov non-parametric test

The statistical analysis enabled the HLB introduction, spread, and global risks to be compared between SP and MG regions, considering that the number of sampled farms per municipality varied within each region. There was no difference between the HLB introduction risks once the disease occurred in both regions ($p > 0.10$, Figure 1A).

However, the HLB spread risk ($p < 0.01$, Figure 1B) as well as the global risk ($p < 0.01$, Figure 1C) were higher for farms in MG.

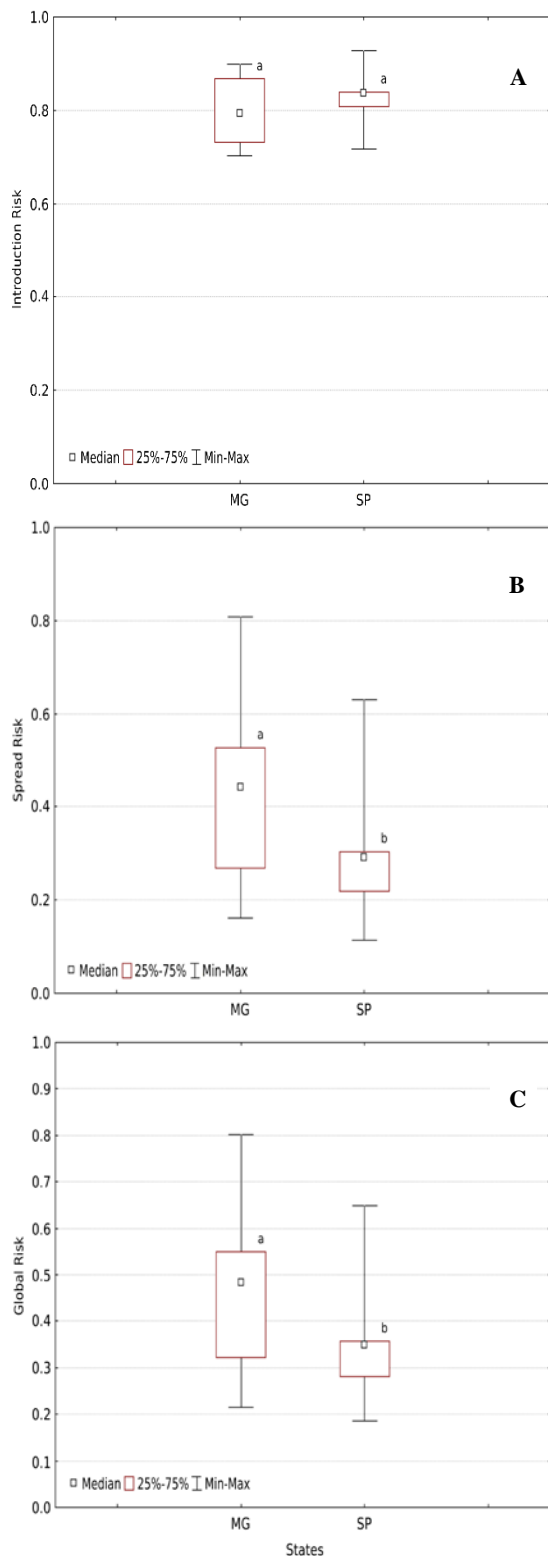


Fig. 1. Box-plot of huanglongbing (HLB) introduction (A), spread (B), and global (C) risks in Minas Gerais (MG) and São Paulo (SP) States, Brazil, compared by the Kolmogorov-Smirnov test ($p > 0.10$).

HLB introduction risk into farms

According to the questionnaire answers and weighing of the introduction criteria, 26 farms were classified as having very high risk (69 % of farms in SP and 62 % in MG), and 13 farms with high risk (31 and 38 % in SP and MG, respectively). For both regions, the occurrence of HLB in the neighboring areas contributed the most to the introduction risk into the farm. The presence of the insect vector, *D. citri*, ranked second in the risk of introducing HLB, followed by the HLB occurrence in neighboring municipalities. The fourth factor most associated with the disease introduction into the farm was the use of nursery trees from locales with HLB occurrence. However, in MG the use of nursery stocks grown outside insect-proof protected environment ranked fifth, which in turn was at eleventh position in SP, where the use of nursery trees from other states was as important (fifth position) as in MG (sixth position). The top five factors contributed to 84 % of the HLB introduction risk in both regions (Figures 2A and 2C).

HLB spread risk within farms

Eleven farms were classified as having low spread risk, 20 with intermediate risk, seven with high risk and only one with very high risk. The HLB spread risk was different between farms located in SP and MG regarding both the relative number of farms with high and very high risks and the relative importance of the spread risk criteria. Based on the AHP, the most important factor in the South of MG was the lack of knowledge on the HLB pathosystem, followed by the absence or low use of insecticides, the presence of young groves in the farm (≤ 6 years-old), the reduced income due to low fruit yield (≤ 30 t/ha) and the unavailability of technical assistance (Figure 2B). In the East of SP, the five most important factors were, in descending order: the presence of young groves, the reduced income due to low fruit yield, the absence of certification programs, the low tree density (< 600 trees/ha) and the lack of area-wide coordinated management through growers associations or cooperatives (Figure 2D). In the two regions, the top five factors contributed to about 60 % of the HLB spread risk.

HLB global risk

The combined risks of HLB introduction and spread, that is, the 'global risk', varied from 0.186 to 0.648 in 13 farms located in SP (mean of 0.349 ± 0.11) and from 0.215 to 0.802 in 26 farms located in MG (mean of 0.456 ± 0.15), therefore, being classified as intermediate (Figure 3). The HLB introduction risk was very high and high in 67 and 33 % of the sampled farms (Figure 4A), whereas the HLB spread risk was low to intermediate in 79 % of the farms (Figure 4B). Moreover, in MG about a quarter of the sampled farms were classified as having high to very high HLB spread risk (Figure 4C), even though in SP only 8 % were within the same classification range (Figure 4D).

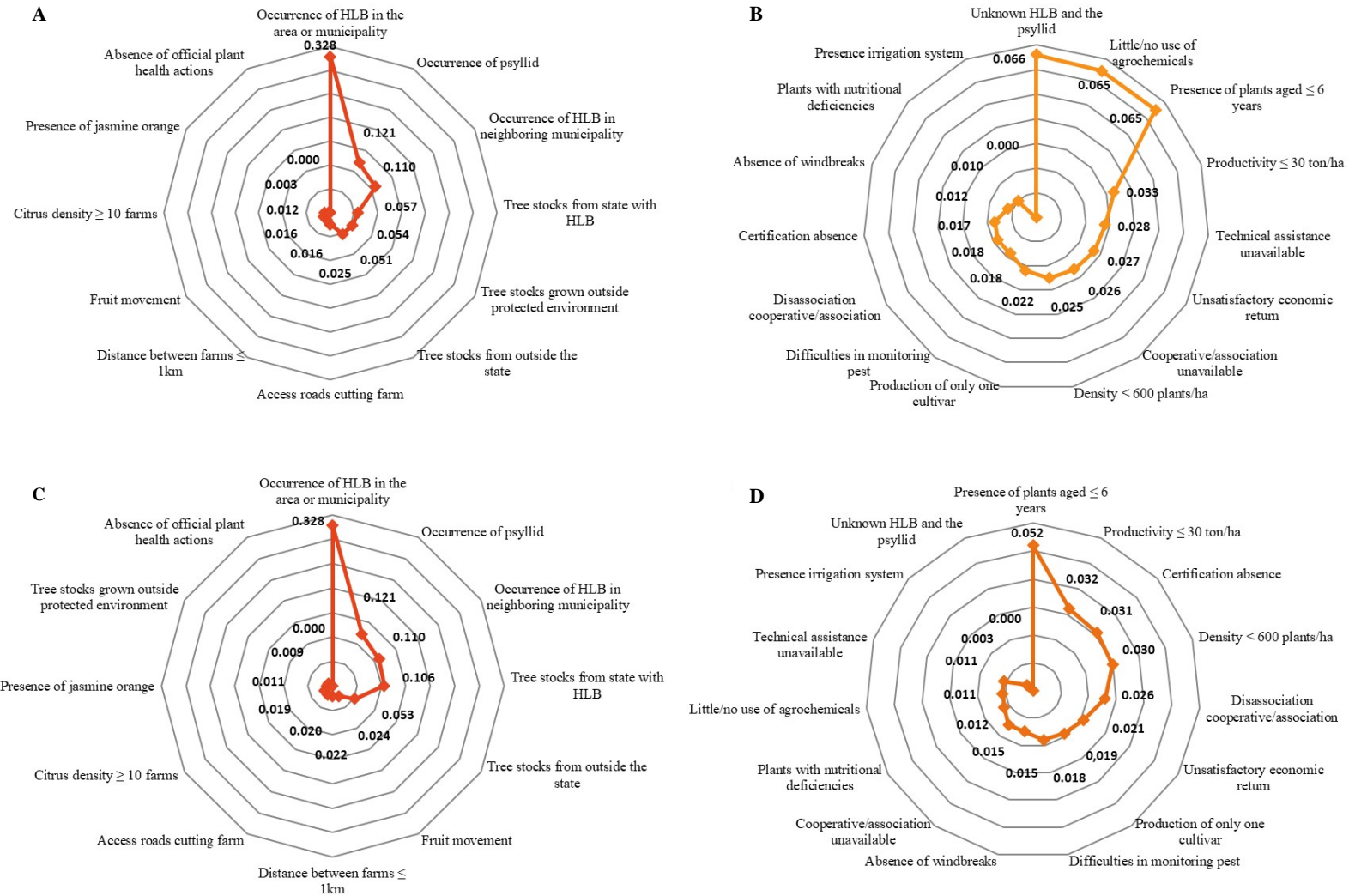


Fig. 2. Relative importance of the questionnaire criteria for calculating the introduction risk (A and C) and spread risk (B and D) of huanglongbing (HLB) into farms in the South of Minas Gerais and East of São Paulo State, Brazil. The relative importance is the average value of affirmative answers from the sampled farms to the questionnaire and multiplied by the criteria weights calculated by the Analytical Hierarchy Process (AHP) (Table 1).

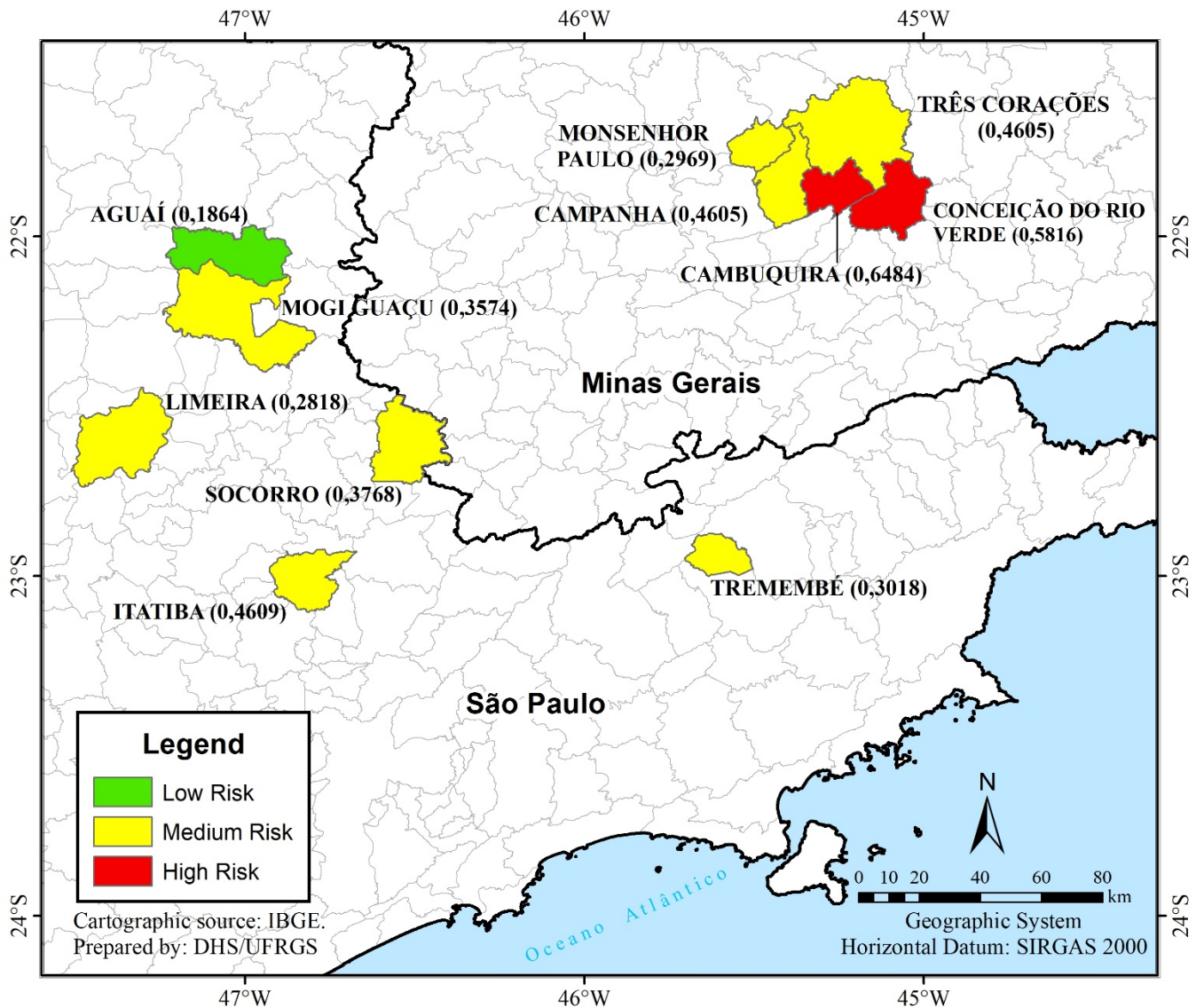


Fig. 3. Classification of 12 municipalities assessed in this survey regarding the huanglongbing (HLB) global risk of introduction and spread. Values in parenthesis correspond to the mean global risk within each municipality. The number of interviewed growers for each municipality is Aguai (1), Amparo (1), Itatiba (1), Limeira (1), Mogi Guaçu (1), Socorro (7) and Tremembé (1), Cambuquira (2), Campanha (14), Conceição do Rio Verde (2), Monsenhor Paulo (2) and Três Corações (6) (n = 39).

Discussion

The East of São Paulo (SP) and the South of Minas Gerais (MG) are contiguous regions that traditionally cultivate citrus for the domestic fresh fruit market, notably the ‘Ponkan’ mandarin (Ferreira 2014; Rocha and Cassino 2017), which is highly sensitive to HLB as ‘Cravo’ mandarin (Boscariol-Camargo et al. 2010). The citrus production is usually by family farming in groves with less than 50 ha, hence, it is an important income source in the municipalities of these regions. Nevertheless, after the detection of HLB in Brazil, its incidence increased significantly in both regions and, particularly, within smaller farms: from 0 to 68.62 % after 17 years in East SP (Fundecitrus 2022). Methods that assess more precisely factors related to the introduction and spread of the disease

are necessary to support the technology transfer focused on the sustainability of family farming, which could reduce withdrawal from the activity. From 2015 to 2022, the number of small citrus farms with oranges decreased 40 % in the citrus belt (Fundecitrus 2022). With this objective, we developed a case study to evaluate the risks associated with HLB spread on farms located in both regions.

The AHP is a multicriteria analysis that has been used to solve problems and direct decision making in several subjects, from public administration and environmental management to rural policies (Petrini et al. 2016).

According to Bellver and Mellado (2005), AHP is a promising tool for evaluation of agricultural systems, since it can be applied on quantitative and qualitative data, or even when only the latter ones are partially available. Although AHP is a recognized tool for structuring complex

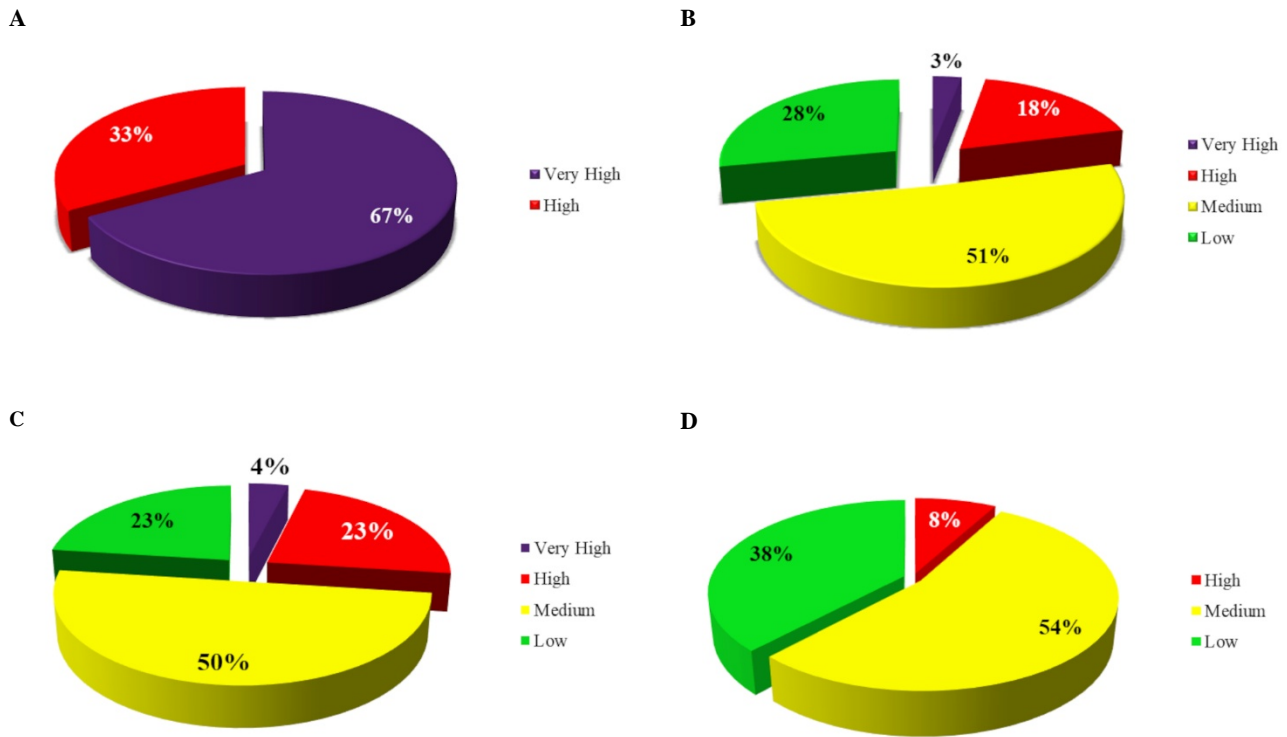


Fig. 4. Relative risks of introduction (A) and spread (B) of huanglongbing (HLB) in citrus farms located in the East of São Paulo (SP) and in the South of Minas Gerais (MG) States, Brazil, and relative spread risks within farms located in MG (C) and in SP (D).

decision problems and aiding analysis, it has limitations, particularly regarding inherent subjectivity. Nevertheless, it serves a distinct purpose compared to classical statistical analysis, because AHP acknowledges the role of subjective judgment on complex choices. Pairwise comparisons can be challenging, and achieving perfect consistency across decision-makers is an ongoing pursuit. However, AHP facilitates structured discussions and helps identify potential biases. The method's strength lies in its ability to break down a problem, prioritize criteria, and assess alternatives based on expert input. The consistency ratio is a valuable tool to identify and address inconsistencies in judgments, but it doesn't guarantee absolute correctness. By acknowledging these limitations, we could explore the association between perceived risks of introduction and spread (experts) and perceived existence of local risks (growers). By doing so, we can present a more nuanced understanding of the decision landscape aided by AHP.

In this work, the risk analysis based on the AHP allowed us to estimate the HLB 'global risk' (introduction + spread risks) as overall intermediate for a sample of 39 growers from 12 municipalities in the two regions, even though there was a wider variation in the spread risk within farms between SP and MG. The HLB introduction risk into farms was remarkably high, which corroborates the occurrence of the disease in the evaluated regions for at least ten years (Fundecitrus 2024; Castro et al. 2010). This reinforces that HLB is a serious threat to citrus production in small farms in the East of SP and South of MG.

However, regarding the HLB spread within farms, in MG there was a higher frequency of farms classified as having high to very high risks compared with those in SP. This condition may reflect a higher use of control technologies in SP, benefiting from more organized extension actions from Fundecitrus and other institutions. In fact, in East SP, unavailability of technical assistance and the lack of knowledge about HLB were negligible factors. Not knowing about HLB and its insect vector may explain why the disease spreads in MG because growers do not undertake any management actions. However, when the growers do know about HLB, this factor was irrelevant and other factors increase in relevance. This was the case in SP, where the dissemination of knowledge about HLB was faster and more effective than in MG. In future studies, it would be worth carrying out temporal comparisons as HLB and the knowledge on its control advances within a given region, to quantify the relevance of technology diffusion for disease management.

The technological level of the sampled farms can be verified through the use of several best management practices and production indicators, such as planting healthy nursery trees grown in insect-proof screenhouses, varietal diversification, pest monitoring and control with appropriate insecticides, use of windbreaks, high fruit yield (≥ 30 t/ha), high tree density (≥ 600 trees/ha), adequate fertilization and the availability of technical assistance. In SP, 77% of the sampled farms used five to seven of those practices, whereas 80% of farms in MG used only three to

five practices. The use of nursery trees grown in the open field is particularly critical, because HLB infection is very likely (Bové 2006). This was the fifth and eleventh most important factor in the introduction risk in MG and SP, respectively, because protected nurseries have been mandatory in SP since 2003, though in MG their use has only been mandatory since 2008 in municipalities where HLB occurs (Carvalho et al. 2019). Furthermore, in both regions, the use of nursery trees from other HLB-affected areas/states was found to be an important factor for disease introduction, suggesting that clandestine stocks still pose a hazard to unwary growers.

The risk of introducing HLB was mainly linked to the presence of inoculum sources in the neighbouring areas and municipalities, whether they be host species in orchards or unprotected nurseries or insect vectors, as observed in the epidemiology of the disease in different regions of the world (Bové 2006). This information is important for identifying specific strategies to avoid recontamination where infected trees are eradicated, and farms are replanted. Although the eradication of HLB-symptomatic trees has been mandatory in Brazil since 2008 (MAPA, 2008), vector control was not regulated at that time, and the inoculum suppression is seldom achieved because of grower's reluctance to eliminate bearing trees, even if damaged by HLB, and the limitations of plant defense in some areas. In the State of RS, the AHP analysis indicated a low risk for the HLB introduction into farms across the state, which would more than double in the case the disease was detected in a given municipality (Sulzbach et al. 2018). In fact, the current study and the one of Sulzbach et al. (2018) were carried out in similar periods, but the risk perception of HLB introduction was notably different in RS compared to SP/MG, because the disease was already reported in the later states but still absent in RS to date. As a result, in RS the occurrence of HLB in neighboring countries and fruit movement from other states were the most relevant, but not mentioned in SP/MG questionnaires. Therefore, plant defense actions are fundamental to the prevention of HLB in unaffected regions. Interestingly, a similar composition of HLB spread risk was observed in RS compared to MG, because in these regions there was limited knowledge on the HLB pathosystem and little use of vector control measures.

In South MG, other factors relevant to HLB spread included the presence of young groves, reduced income due to low fruit yield (because low fruit yield leads to decreased income which in turn reduces the potential of adoption of HLB control technologies), and the limited availability of technical assistance. HLB spreads more rapidly in young groves, which are more susceptible to the disease, in the absence of vector control (Bassanezi et al. 2013, 2020). Low yields relate to low technification level being aggravated by the deficient agronomical support. This implies less investment potential that affects the disease management in a vicious circle. Conversely, in farms located in East SP, the HLB spread was more explained by some production indicators that influence on disease progress: grove age < 6 years, yield < 30 t/ha and

tree density < 600 trees/ha. Higher planting densities especially on the farm edge relate to lower HLB incidence in groves that control the psyllid, that is, where the primary infection is prevalent (Moreira et al. 2019). This practice also contributes to maintaining adequate productivity even with increasing disease severity and tree loss. Notwithstanding that citrus growers in East SP demonstrated better preparedness to manage the disease, the absence of certification programs or grower associations/cooperatives was also pointed out. This, in turn, is related to difficulties in optimizing income, monitoring the production system and, above all, implementing coordinated control measures by the farms in the same region. This is particularly of interest, because area-wide management of HLB is much more effective than only local control, and even large farms with rigorous control became economically unfeasible under the high pressure of external inoculum (Bassanezi et al. 2013, 2020).

Taken together, the results herein clearly demonstrate that any HLB management strategy that is designed for family farming will rely on specific public policies to support this group of growers, as well as innovations in control technologies (Oliveira et al. 2018).

Growing nursery trees mandatorily in protected environments across the state and training growers to recognize and manage the disease are especially important in MG, as indicated by the survey, aiming at decreasing the HLB spread within the state. However, it is important to note that HLB is a challenge not only for family farming, because its incidence is increasing in large industrial groves as well, irrespectively of the higher use of technology (Fundecitrus 2024; Rodrigues et al. 2016). HLB control measures increase the production costs and environmental impacts due to higher consumption of fuels and agrochemicals. On the other hand, alternative measures such as biological control and repellent substances, and coordinated actions to decrease inoculum in the vicinities of the farms, present potential for greater adoption (Rodrigues et al. 2016), and, ultimately, could contribute to sustainability of citriculture in the presence of HLB. Furthermore, considering that the presence of the pathogen in the neighborhood was the main factor in the composition of the risk of introducing the disease, it should be emphasized the urgent need to implement public policies that encourage the eradication of abandoned cultivation areas in both states, mainly to benefit family farmers in reducing the external pressure of the pathogen.

In conclusion, in this case study we found overall high risks of HLB introduction and spread within small farms located in the East of São Paulo and in the South of Minas Gerais, Brazil, which corroborates the high disease incidence in these regions. The AHP was useful to identify the main factors associated with HLB spread in this farm profile, and, consequently, to direct priority measures to manage the disease. As family farming prevails in these regions, the coordinated control by grower associations or cooperatives is strongly recommended, in addition to more effective training of growers on HLB management. The

use of insect-proof and healthy nursery trees is crucial to prevent disease introduction in unaffected areas. It is expected that this same problem will occur in other regions with a similar socioeconomic profile that either have or will face HLB epidemics.

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