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Mexican banana at risk!... The main quarantine threats to Musaceae

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Enrique Ibarra-Zapata[1]
enrique.zapata@uaslp.mx

Carlos Arturo Aguirre-Salado[2]
carlos.aguirre@uaslp.mx

Gustavo Mora-Aguilera[3]
morag@colpos.mx

1 School of Agronomy and Veterinary Medicine, Universidad Autónoma de San Luis Potosí, México

2 School of Engineering, Universidad Autónoma de San Luis Potosí, México

3 Colegio de Postgraduados, Campus Montecillos, Texcoco, Estado de México

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— Abstract—

The objective of this study was to show the phytosanitary status in a spatial context of the main quarantine threats to Mexican bananas. The characteristics and phytosanitary status of Fusariosis of Musaceae (FocR4T), Banana Bacterial Wilt (BXW), and Banana Bunchy Top (BBTV), as priority diseases identified by the National Service of Health, Safety and Agrifood Quality (SENASICA), were considered. Under the approach of "Tobler's Second Law", the area/production of bananas in the world was analyzed, the phytosanitary status (present) of the quarantine threats for the Mexican Republic and, on a larger scale (at the municipal level), the spatial condition of the area sowed and the banana production in Mexico was demonstrated. A scenario of the productive condition of the banana-producing countries (planted area and production) was obtained. On a regional scale, the existence of two territories close to Mexico with the presence of FocR4T at 1,800 and 2,500 km of distance was determined, and a third one with BBTV official status present at 4,200 km was determined. In addition, the spatial distribution of municipalities with the presence of economically important hosts was obtained. It is concluded that Mexico maintains technically and scientifically supported preventive activities against the possible entry of FocR4T, BXW, and BTTV, through the Phytosanitary Epidemiological Surveillance Program for banana quarantine pests. The results allow us to place the phytosanitary risk posed by quarantine threats to the banana product system on a spatial and current level and are considered an input that allows us to assist in strategic decision-making in the face of phytosanitary risks such as the pathogens described above.

Keywords:

Banana; Mexico; Quarantine threats.

Bananas (Musa paradisiaca) are a crop of economic and social importance in Mexico, even, according to García-Mata *et al* (2013), due to their high level of consumption they can be considered a necessary good. The banana product system is under the latent threat of different pests of quarantine interest. According to the National Service of Health, Safety and Agrifood Quality (SENASICA), the main threats are Fusariosis of Musaceae (*Fusarium oxysporum* f. sp. *cubense* (E.F. Sm.) W.C. Snyder & H.N. Hansen Raza 4 Tropical) (FocR4T) (SENASICA. 2019a), Banana Bacterial Wilt (*Xanthomonas vasicola* pv. *musacearum* (Yirgou & Bradbury, 1968; *Dye 1978*) (BXW) (SENASICA. 2019b) and Banana Bunchy Top Virus (BBTV) (SENASICA. 2019c).

In Mexico, these diseases have an absent categorization of quarantine pests; since there are no records of their presence in the country, however, according to the International Standard for Phytosanitary Measures No. 5 (FAO-IPPC-NIMF, 2009), can potentially cause economic losses in host crops. They are considered phytosanitary risks with the potential to cause significant reductions in the crops' national production since they are considered "devastating pests"; providing direct effects on the fourth most important food in the world, after rice, wheat, and corn (Shankar & Mondal, 2016). Plantains are viewed as one of the most important products for food security, as well as an important source of job creation (García-Bastidas *et al*, 2020).

The spatial condition involves the interrelationship between elements that develop in a context defined by geographical entities. That is, the spatial properties are established through division relationships and proximity measurements, which allows quantifying the distance between disjoint parts of the related geographic objects (Nedas *et al*, 2007), in this case: Phytosanitary status "*present*" vs. plantain farming areas in Mexico. Theoretically, this association process was based on the approach of the Second Geographical Law proposed by Tobler (1999), which states that "*every phenomenon external to an area affects what happens inside*", which allows highlighting the interaction between the events that occur in a certain space that can affect other nearby or distant territories. Therefore, the study's objective was to demonstrate the main quarantine threats' phytosanitary condition in a spatial context to the cultivation of Mexican bananas, supported by a review of specialized literature.

THE BANANA CROPS CONTEXT IN THE WORLD

During 2020 there was a planted area of 5,493,932 hectares of banana crops in the world, distributed in 123 countries, of which a production of 113,212,452 tons of the crop was obtained. The countries that reported the largest area destined for banana cultivation were: India (846,000 ha), followed

by Brazil, Tanzania, the Philippines, and the People's Republic of China which have more than 430 thousand banana hectares each, it should be noted that Mexico was positioned in 15th place, with a planted area of 78,322 ha of banana crops (Figure 1a).

In addition, when considering banana production, countries like India stand out with 25.72% of production, followed by China with 11.77&, Indonesia (6.19%), Ecuador (5.77%), and Philipines (5.15%), the rest of the countries have less than 3.42% each, it is relevant to highlight that Mexico was considered 12th place with 2,384,778 tons equivalent to 2.11% of the registered production in the referenced year (Figure 1b).

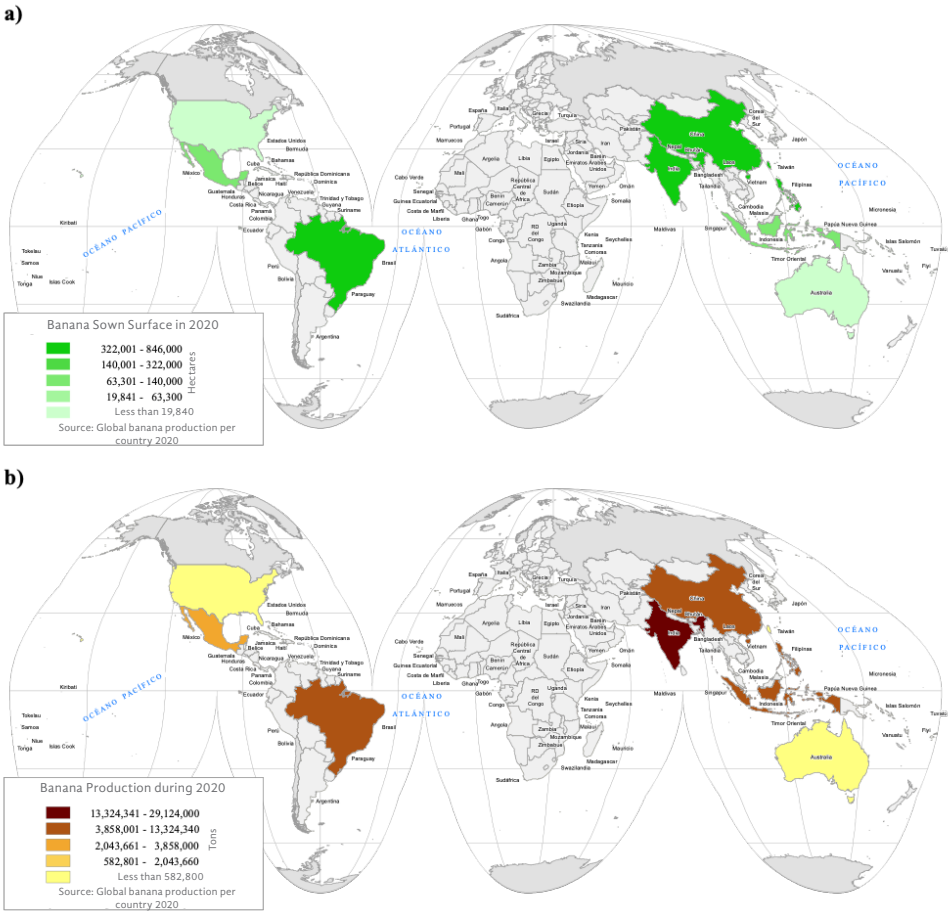


Figure 1. Global outlook for banana cultivation. a) Surface planted with bananas per country and b) Banana production per country. Source: https://www.atlasbig.com/es-es/paises-por-produccion-de-banano

PRIORITY QUARANTINE THREATS TO MEXICAN BANANA CULTIVATION

Banana or plantain crops are susceptible to phytosanitary problems caused by pathogens such as FocR4T, BXW, and BTTV, which, according to the National Service of Health, Safety and Agrifood Quality SENASICA, are considered of quarantine interest. The dispersion and possible effects of these diseases depend to a large extent on the mobilization of infected or diseased vegetative material (seedlings, horns, offspring, etc.) however, there are some epidemic peculiarities specific to each pathogen that are listed below:

I. FocR4T is considered an extremely severe pathogen with the potential to affect a considerable group of Musaceae varieties of importance for food security (not only the Cavendish variety); that is, it can affect strategic crops for food security with repercussions for the generation of economic income in banana-producing regions (Dita *et al*, 2018).

   The causative agent of Fusariosis Musaceae is a soil fungus, and there are references that it can survive for up to more than 30 years in its resistance structures (mycelia and chlamydospores) (Stover, 1962). In Southeast Asia, there have been considerable effects, even, though it is present in large areas where it has caused millionaire losses with a high cost in management measures (OIRSA. 2020). FocR4T affects the root, stem, and other structures of the *Musa* genus, however, the fruit is not a carrier of the fungus, and there is no risk when consuming the fruit (ICA. 2021). Some characteristics of the pathogen can be seen in Table 1a.

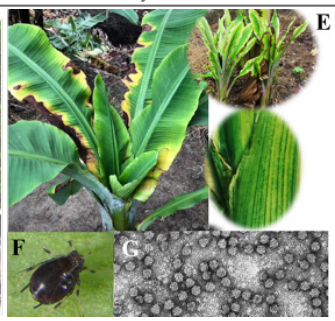
II. BXW is considered the most devastating banana disease in the Great Lakes region of Central and East Africa, where it caused total losses in the yield of infected plants (Ssekiowoko *et al*, 2006 & Tripathi *et al*, 2009). In sub-Saharan Africa, it is considered a highly limiting pathogen in the production of banana clusters, with estimated damage between 70% and 90% in affected areas (Kumar *et al*, 2015). This disease can infect all genotypes of bananas, so it is convenient to maintain a clear control measure, that is, restrict the movement of plant material from the territories where it is present since it spreads quickly and generally, field tools facilitate its transfer (Manzo-Sánchez *et al*, 2014). Its characteristics are shown in Table 1b.

III. BTTV In East Africa, in the Great Lakes region, it has destroyed entire plantations where losses are estimated at between 2000 billion and 8000 billion over a decade (Fresh-Plaza, 2021). Its control implies quarantine actions to avoid entry into free territories,

complemented by the eradication of infected plants that serve as a source of inoculum (Thomas, *et al*, 2000), its characteristics in culture are shown in Table 1c.

Table 1

Characteristics of the main quarantine threats to the Mexican banana. a) Fusariosis of Musaceae (Fusarium oxysporum f. sp. cuban (EF) Sm.) W.C. Snyder & H.N. Hansen Race 4 Tropical), b) Banana Bacterial Wilt (Xanthomonas vasicola pv. musacearum (Yirgou & Bradbury 1968; Dye 1978) and c) Banana Bunchy Top Virus

	a) FocR4T	b) BTTV	c) BXW
Culture Appearance	 Image: García-Bastidas, 2020	 Image: Betancourt Vásquez, 2020	 Image: Guy Blomme, 2021
	(A) External symptoms with extensive foliar yellowing, as well as the collapse of the leaves around the pseudostem and cracking of the pseudostem; (B-C) internal symptoms showing redness of the vascular bundles in the pseudostem and corm. (Photos: García-Bastidas, 2020).	(D) Infected banana and virus symptoms in foliage. (E) Banana thumb vector of the BTTV virus in bananas and (F) Babuvirus (Family Nanoviridae) (Betancourt Vásquez, 2020).	(H) Yellowing and wilting on the leaves, (I) Premature ripening of the fruit and (J) Bacterial exudate (Guy Blomme, 2021).
Dispersion media	Infected plant material, contaminated water, and tools/machinery with infested soil are the main means to disperse the pathogen (García-Bastidas, 2020).	It can propagate vegetatively through pacifiers or crop plants of infected tissues, causing a reduction in crop yield which triggers a barrier to international exchange (Kumar *et al*, 2015).	It is dispersed by mobilization of infected plant material and contaminated tools, and some insects favor dispersal (Family: Apidae), fruit flies (Family: Tephritidae) and grass flies (Family: Chloropidae) (SENASICA. 2019b).

Source: Adapted according to the indicated references

THE SITUATION OF THE BANANA PRODUCT SYSTEM IN MEXICO

According to the Agricultural and Fisheries Information Service (SIAP) in 2020, the Mexican Republic had 80,546.74 hectares of the planted area. with bananas distributed in 16 states, it should be noted that Chiapas, Veracruz, and Tabasco contributed the largest estimated territorial extension with

63.45% of the sown area, which is equivalent to 51,112 ha. In addition, the states of Quintana Roo, Yucatan, Campeche, Mexico, Hidalgo, and Morelos only contributed 1,183 ha; overall, this represented 1.46% of the national banana area in Mexico (Figure 2).

At the municipal level, the largest area planted with bananas was grouped into Teapa, Tabasco (7,439 ha); Suchiate, Chiapas (5,503); Coahuayana, Michoacán (4,589 ha); and Tecomán, Colima (4,158 ha) which together contributed 26.92% of the national planted area. In addition and with the smallest extensions are Atenango del Río, Guerrero; Malinalco, Mexico; Huetamo, Michoacán; Soledad Doblado, Veracruz and Muna and Cantamayec in the state of Yucatán, with an extension of fewer than two hectares of sown area each (Figure 2).

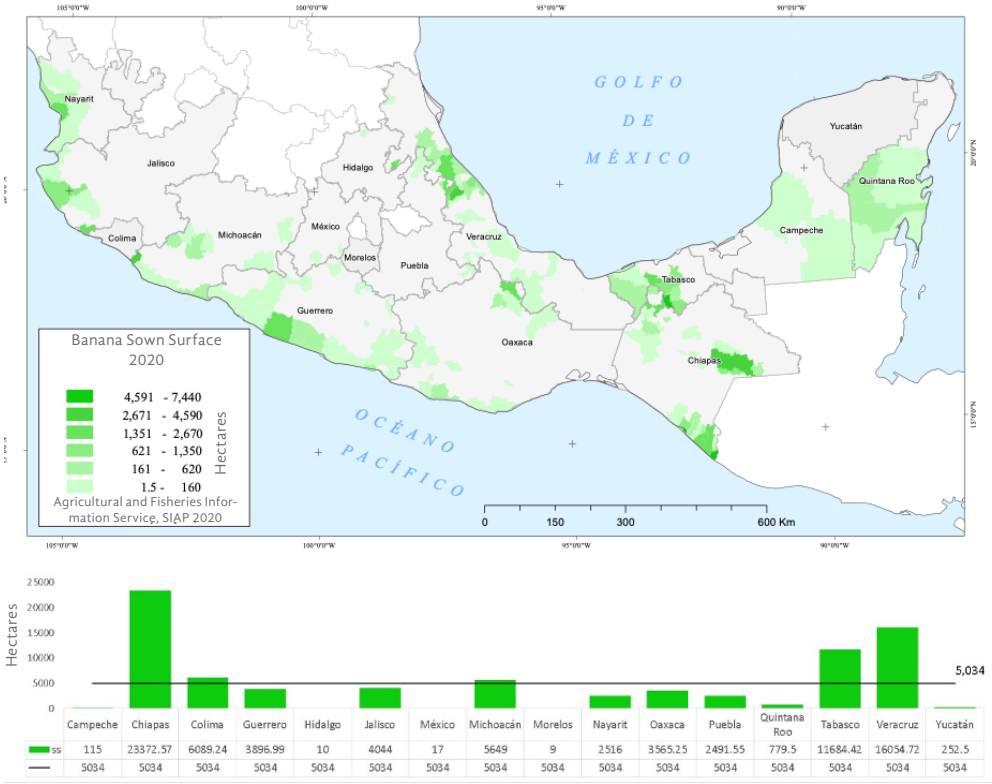


Figure 2. Sown area of the banana product system in Mexico, 2020. Source: Agricultural and Fisheries Information Service, SIAP-AGRICULTURA. 2020

In addition, Mexican banana production relies upon the states of Chiapas with 701,501 tons, Tabasco with 601,608 tons, Veracruz with 324,733 tons, and Colima with 207,433 tons, which altogether represent 74.47% of the crop's national production (SIAP, 2020). On the contrary, the states of Quintana Roo (9,881 tons), Yucatán (1,474 tons), Campeche (1,249 tons),

Morelos (277 tons), México (225 tons), and Hidalgo (56 tons) altogether contribute only to 0.53%, which corresponds to 13,163 tons (Figure 3).

The main municipal producers consolidate 50.88% of the banana national production, out of which Teapa, Tabasco with 453,612 tons; Suchiate, Chiapas with 205,605 tons; Coahuayana, Michoacán with 142,747 tons; Tecomán, Colima with 137,024 ton; Cihuatlán, Jalisco with 128,251 ton; Tapachula, Chiapas with 96,416 ton; and San Rafael, Veracruz with 90,132 tons stand out. It should be noted that 63 municipalities had a production lower than 200 tons each and together contribute only 0.27% of the total banana production (SIAP. 2020).

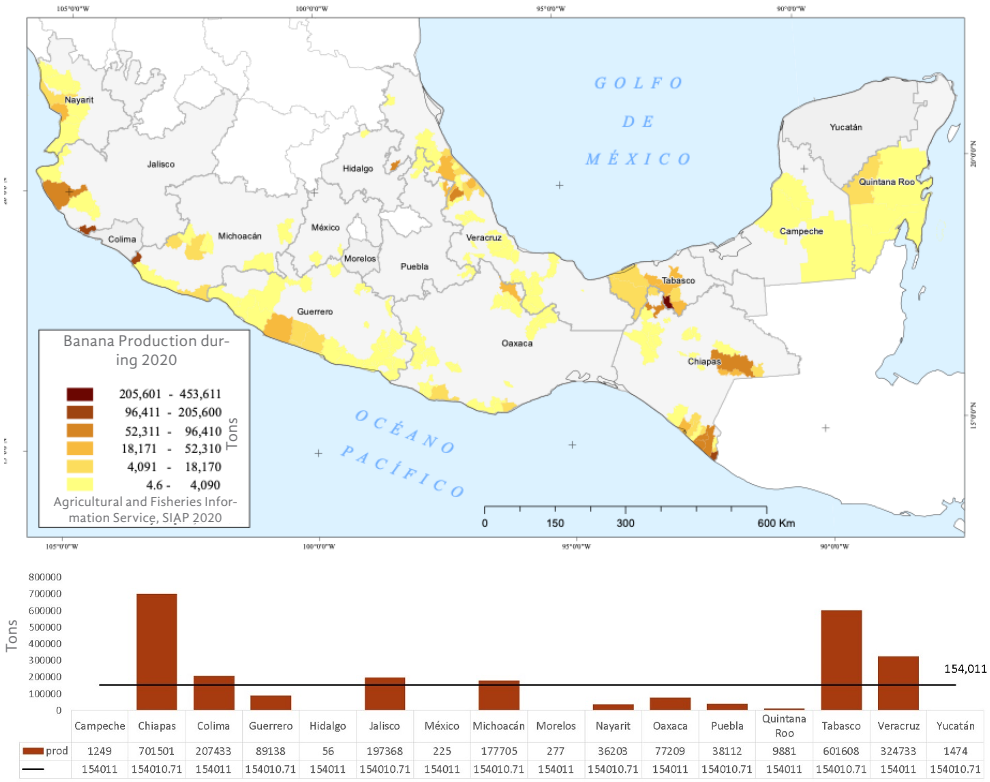


Figure 3. Banana production in Mexico, 2020. Source: Agricultural and Fisheries Information Service, SIAP-AGRICULTURA. 2020

The spatial representation of the sown area and the banana production (Figures 2 and 3, respectfully) allow obtaining spatial distribution patterns of the main FocR4T, BTTV, and BXW hosts, which allows creating scenarios that make it possible to direct preventive actions before the possible entry of any of the pathogens analyzed, that is, the regions where the largest/smallest banana producers in the country are concentrated.

PREVENTION CULTURE IN MEXICO

Mexico holds preventive strategies against bananas quarantine pests in NOM-010-FITO-1995 (DOF. 1995) "*establishing preventive guidelines for the introduction, establishment, and dissemination of banana quarantine pests to national territory*" through so-called surveillance routes, sentinel plots, and exploration areas. Likewise, the culture of prevention is implemented in the mobilization of plant material legally based on the Mexican Official Standard NOM-008-FITO-1995 "*laying down phytosanitary requirements and specifications for fresh fruits and vegetables import*."

In addition, the National Plant Protection Organization, through the General Directorate of Plant Health, maintains the Phytosanitary Epidemiological Surveillance Programme, which operates with active surveillance in agricultural, wild, marginal, and urban areas (SENASICA. 2020). The active surveillance of quarantine pests is carried out in areas of potential risk before the possible entry of exotic pests such as FocR4T, BTTV, and BXW into Mexican territory (SENASICA, 2020a).

Currently, in Mexico, phytosanitary epidemiological surveillance is carried out through robust operational strategies such as surveillance routes in risk areas (backyards, tourist areas, collection centers, nurseries, and storage centers), the establishment of sentinel plots at-risk sites, as well as exploration in the production area. Derived from these actions FocR4T, BTTV, and BXW, maintain a phytosanitary status absent in Mexico, since there are no records of the pest's presence, as indicated by NIMF No. 8 (2017).

Finally, it is pertinent to note that according to the Mexican National Plant Protection Organization, the highest phytosanitary authority, through the "Directorate of Phytosanitary Regulation -SENASICA" in 2009, an amendment was made to the NOM-FITO-010-1995 Single Article (point 4.1's paragraph "Absolute quarantine products") stating that "*The introduction of fresh bananas, banana plants, and parts thereof and their packaging originating in or consigned from the countries concerned by the presence of banana pests of quarantine importance for the country is prohibited*" and only transit is allowed (no opening of containers). In addition, recently in 2019, as a result of the recent detections of FocR4T in Colombia, the "*Import of propagative plant material "In Vitro" of the genus Musa spp and Heliconia spp*" (Cueto-Espinoza, 2021) was suspended. That is, nowadays, as a preventive measure in Mexico, the import of propagative material, fruits, and by-products derived from bananas is prohibited, and transit through the national territory is only allowed under controlled or very specific conditions according to specifications of the National plant health regulation and its counterpart in trade negotiations.

SPATIAL CONDITION OF THE PRIMARY BANANA QUARANTINE THREATS FOR MEXICO

The spatial condition was based on the assumption that there is a phytosanitary risk for the production of Mexican bananas when considering the proximity to the countries/states that maintain the presence of at least one of the banana quarantine diseases (FocR4T, BTTV, or BXW).

The main phytosanitary risk was associated with Fusariosis of Musaceae that was detected in 2019 in the American continent: in the banana production area in the Las Flores and Pelucha roads located in Dibulla and Riohacha, La Guajira, Colombia (ICA, 2019), 1,800 km away. There is another priority area in the production area of the Querecotillo district, in the Sullana province, department of Piura, Peru (SENASA. 2021), located just over 2,500 km away from the Mexican Republic. And in third place, by geographical proximity, approximately 4,200 km away, is Hawaii USA, where they have a phytosanitary status present to the Banana Bunchy Top (Figure 4).

Globally, in Asia, Africa, and Australia, there are territories with the presence of at least one of the three diseases (FocR4T, BTTV, or BXW); however, not because they are in other continents does it mean that they do not represent a phytosanitary risk for banana producing countries in the Americas. Derived from the processes of globalization, such as commercial exchange, tourism, and human migration, the phytosanitary risk associated with banana quarantine pests continues to be a latent threat to the plantations of economic importance existing in 34 countries of the American continent, which together contributed 21.60% of the world's planted area of banana cultivation, which represents 24.9% of the 2020 production (Figure 4).

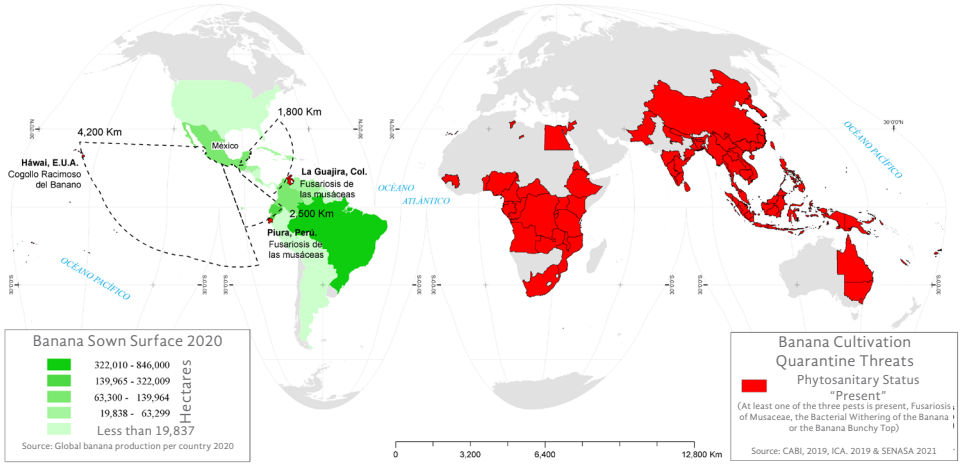


Figure 4. Spatial condition of the main quarantine threats to the banana system in Mexico. Source: CABI. 2019, EPPO. 2019, ICA. 2019 and SENASA 2020

CONCLUSIONS

The spatial diagnosis of the banana quarantine threats (FocR4T, BXW, and BBTV) based on a review of specialized literature, allows us to verify that we are facing priority regional phytosanitary risks and not only of risk for Mexico but for the 33 countries of the American continent where bananas are grown. Even the distance as a spatial condition of the presence of pathogens in other countries or continents does not represent an obstacle to its mobilization in our country since it is proven that the intercontinental distance did not impede the occurrence of two detections in different territories in America and with different temporality (Colombia and Peru).

In 2019, there was a first warning to strengthen epidemiological surveillance strategies with the first detection of FocR4T in the Americas, which implied restructuring the strategic plans for monitoring, acting, and containing banana pests, under a preventive approach. In this regard, it is important to strengthen phytosanitary research with trans and multidisciplinary approaches to strengthen national and regional phytosanitary epidemiology surveillance programs for banana quarantine pests, as well as to implement preventive actions jointly between phytosanitary protection agencies, research centers, producers, and final consumers. Today we all know the implications of health problems with a pandemic potential "*thanks to Covid-19*". Since, without a doubt, the pandemic potential associated with the Fusariosis of Musaceae, the Banana Bacterial Wilt or the Banana Bunchy Top is latent with direct implications for the fourth most important food in the world.

This type of analysis that involves the territorial component through the inclusion of spatial data, allows for territorialize of the phytosanitary risk and has the potential to be considered an essential input for decision-makers, since, although it can be considered a very brief analysis, it allows to identify locations or territories where it is feasible to perform a more robust geospatial analysis or modeling that integrates essential variables (environmental, epidemic, anthropic, economic, etc...) that favor the pathogen and its potential hosts (of economic and wild importance), which allows to obtain results with a greater spatial resolution (greater detail in the territory) to redirect risk mitigation strategies on the identified surfaces and, with this, give scientifical technical support to the decision-makers.

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