Soil, climate, and management practices associated with the prevalence of clubroot in Colombia

Suelo, clima y prácticas de manejo asociadas a la prevalencia de la hernia de las crucíferas en Colombia

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ABSTRACT

Clubroot disease caused by *Plasmodiophora brassicae* is a major constraint for cruciferous crops in Colombia; however, information regarding its spread and the relationship between environmental and crop management practices with its occurrence in the country is scarce. This research established clubroot prevalence in the main cruciferous productive areas in Colombia and the relation of its occurrence with crop management practices, soil, and climatic characteristics. In total, 127 fields were visited along eight departments. Clubroot infestation was determined either by direct inspection of roots of host plants for clubroot symptoms or by report of previous observation of the disease symptoms by the farmers. Soil samples were collected for physical and chemical analysis, climatic information was obtained, and farmers were surveyed on the management practices of the production systems. The survey confirmed the presence of the disease in 53.6% of the visited fields. The only department where the disease symptoms were not observed nor reported was Nariño. A negative correlation was found between the disease occurrence and the content of aluminum in the soil, the number of days with rain per year, and the cultivation of clubroot-resistant hybrids. Moreover, a positive correlation was observed with the inclusion of cruciferous crops in the rotation scheme, the effective cation exchange capacity of the soil, soil pH, and the content of phosphorus, calcium, boron, and copper in the soil.

Key words: pathogen spread, point biserial correlation, soilborne disease, epidemiology, *Plasmodiophora brassicae.*

RESUMEN

La hernia de las crucíferas, causada por *Plasmodiophora brassicae,* es una de las mayores limitantes para la producción de crucíferas en Colombia; no obstante, la información sobre su prevalencia, y la relación entre las condiciones ambientales y prácticas de manejo con su ocurrencia es escasa. Esta investigación estableció la prevalencia de la hernia de las crucíferas en las principales zonas productoras de crucíferas en Colombia y la relación entre su ocurrencia, las prácticas de manejo y algunas condiciones edafo-climáticas. En total se visitaron 127 lotes en ocho departamentos. La infestación por hernia de las crucíferas se determinó por inspección directa de raíces de hospederos susceptibles y por reporte de observación de síntomas por parte del agricultor. Se colectaron muestras de suelo para análisis fisicoquímicos; además se obtuvo información climática y se encuestó a los agricultores con respecto a sus sistemas de producción. La investigación determinó que el 53.6% de los lotes visitados estaban infestados. El único departamento donde no se observaron ni reportaron síntomas de la enfermedad fue Nariño. Se encontró una correlación negativa entre la presencia de la enfermedad y el contenido de aluminio en suelo, el número de días con lluvia al año y el cultivo de híbridos resistentes a la enfermedad. Además, se encontró una correlación positiva entre la presencia de la enfermedad y la inclusión de especies crucíferas en el esquema de rotación, la capacidad de intercambio catiónico, el pH del suelo y el contenido de fósforo, calcio, boro y cobre en el suelo.

Palabras clave: dispersión de patógenos, correlación biserial puntual, patógeno de suelo, epidemiología, *Plasmodiophora brassicae*.

Introduction

Clubroot disease is caused by *Plasmodiophora brassicae* Woronin, a soilborne protozoan. In Latin America, this disease has been reported from Mexico, Costa Rica, Guatemala, Bolivia, Venezuela, Ecuador, Peru, Chile, Brazil, and Colombia; however, studies reporting the disease severity and economic losses it causes are not available (Botero *et al.,* 2019). Clubroot reduces yield in vegetable crops of the *Brassicaceae* family that, in 2017 occupied 2600 ha in Colombia (3.5% of the cultivation area in vegetable crops in the country) (MADR, 2018). Disease symptoms are observed as galls in the plant roots that impede nutrients and water uptake and cause growth delay,

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wilting, chlorosis, and even plant death when symptoms are severe (Dixon, 2009).

The disease cycle is divided into three main stages. During the primary infection, resting spores in soil detect root exudates of a host plant and induces their germination into a primary zoospore that swims towards the plant root hairs. Once in the root hairs, penetration occurs; and a primary plasmodium develops. This plasmodium will later cleave into a zoosporangium that produces secondary zoospores that are responsible for the secondary infection. During the secondary stage, cells of the root cortex are infected; and the disease symptoms become visible. The last stage happens when resting spores are produced in the root galls to be later released into the soil. Those resting spores will serve as primary inoculum for future infections (Kageyama & Asano, 2009).

Clubroot management is quite difficult, mainly because of the production of resting spores that can survive in soil in the absence of a host for up to 17 years (Wallenhammar, 1996). However, their average lifespan is around five to six years (Hwang *et al*., 2015). This is one of the main features that makes clubroot disease one of the major threats to cruciferous crop production around the world, including Colombia (Jaramillo & Díaz, 2006; Dixon, 2009).

Incidence and severity of diseases are modulated by the disease triangle components (host, environment, and pathogen) (Agrios, 2005). Among the environmental conditions affecting clubroot development, the most important are temperature, soil moisture, and soil properties. The most studied are soil pH, boron, and calcium contents. The optimum pH range for clubroot development has previously been determined to be between 5 and 6.5 (Webster & Dixon, 1991b; Narisawa *et al*., 2005; Niwa *et al*., 2007, 2008; Gossen *et al*., 2013; Rashid *et al*., 2013). An increase of concentration of both the nutrients calcium and boron is related to a reduction in the primary infection of the pathogen and plasmodia dehiscence (Webster & Dixon, 1991a, 1991b). Soil moisture is regarded as one of the most important factors affecting clubroot development, with disease incidence and severity increasing together with moisture levels (Samuel & Garrett, 1945; Hamilton & Crête, 1978; Dobson *et al*., 1982; Narisawa *et al*., 2005). Finally, previous reports have found that the optimal conditions for clubroot development include a temperature between 20 and 25°C, a soil pH between 5 and 5.6, and an inoculum density of 10^6 resting spores per plant (Sharma *et al*., 2011; Gossen *et al*., 2012, 2013).

While the planting of resistant cultivars is the most efficient and convenient method for clubroot management, intensive cropping of clubroot resistant cultivars (CR) exerts significant selection pressure on the pathogen (Holtz *et al*., 2018). This pressure can result in shifts in the virulence of pathogen populations, favoring the emergence of pathotypes that can break or overcome resistance, as has already been observed in canola and Chinese cabbage in Japan, Canada, and Europe (Kuginuki *et al*., 1999; Diederichsen *et al*., 2014; Orgeur *et al*., 2016; Strelkov *et al*., 2016).

Understanding the spatial patterns of pathogen populations or diseased plants is crucial to design disease management strategies (Madden *et al*., 2007). In Colombia, clubroot research is scarce and has been focused mainly on disease management (Velandia *et al*., 1998; Botero *et al*., 2015; Botero-Ramírez *et al*., 2016). Furthermore, currently, clubroot prevalence in Colombia and the relationship of its occurrence in the main cruciferous crops (cabbage (*Brassica oleracea* var. *capitata)*, broccoli (*B. oleracea* var. *italica)* and cauliflower (*B. oleracea* var. *botrytis*)) with field management practices, soil properties and climatic characteristics are unknown.

Given the lack of knowledge on clubroot prevalence in Colombia and the relationship of the disease occurrence with soil properties, climate, and crop management strategies, this research sought to achieve two main objectives: i) to determine the disease prevalence in the most important regions where cruciferous crops are grown in Colombia; ii) to evaluate the correlation between the soil properties, climate characteristics, and crop management strategies with the disease occurrence. This knowledge is needed to understand the impact of production practices of cruciferous crops on clubroot disease to outline more accurate disease management strategies.

Materials and methods

In total, 127 fields were visited in February and March of 2017 to establish the prevalence of clubroot throughout the main productive regions of cruciferous crops in Colombia. The fields were located in the departments of Cundinamarca, Antioquia, Nariño, Boyacá, Valle del Cauca, Norte de Santander, Caldas, and Cauca. Caldas was included because it was the first department where clubroot was reported in 1969 (Torres, 1969). The number of samples collected in each department was defined based on the cropped area in cabbage, broccoli, and cauliflower in 2016 (MADR, 2016) (Tab. 1).

TABLE 1. Cultivated area of cruciferous crops in the most productive departments of Colombia and the number of fields visited in each department.

Department	Area in cruciferous crops in 2016* (ha)	Number of fields visited
Cundinamarca	731.7	33
Antioquia	831.3	29
Nariño	522.4	28
Boyacá	117.2	10
Valle del Cauca	221.9	10
Norte de Santander	233.4	9
Cauca	37.6	3
Caldas	51.9	3

*The data presented are based on statistics of production from the Ministry of Agriculture and Rural Development (MADR, 2018).

Clubroot infestation

A field was determined as clubroot infested either by direct observation of typical symptoms (galling on roots) in cruciferous crops or weeds or after being reported by the farmer. When the field was with cruciferous crops at the time of the visit, plants were evaluated for the presence of symptoms; when a different crop was grown, cruciferous weeds were assessed.

When cruciferous crops were growing, twenty plants were extracted and assessed for the presence of root galls, ten were evaluated at the field entrance, and ten more following the "W" pattern sampling. When a different crop was growing, nine points were assessed following the "W" pattern sampling for the presence of cruciferous weeds, and when present, those were removed and evaluated for the presence of typical clubroot symptoms. In either case, once the disease symptoms were observed the sampling was stopped, and the field was set as clubroot infested. In those cases, were the farmer confirmed previous observations of the disease symptoms, plants were also evaluated at the patches where clubroot had been observed before.

Soil samples

At each sampling site, a composite soil sample of 500 g was collected from the top 20 cm of the soil profile. At the central point of the "W" a metal cylinder with unperturbed soil was collected for bulk and particle density estimation. Chemical and physical analyzes of the samples were performed at the Soil and Water Laboratory of the Faculty of Agricultural Sciences at the Universidad Nacional de Colombia.

Crop management information

Information regarding the management of the fields and clubroot disease was obtained by surveying the farmers in the visited fields. The farmers were interviewed if they were familiar with clubroot symptoms; if they were not familiar with clubroot symptoms, photographs of typical symptoms of the disease were shown, and they were asked again if they had observed them before.

On management strategies, farmers were asked about the period during which the farmer had been growing the field, the cultivated area, the rotation scheme, the cruciferous cultivars planted, the propagation strategy, the machinery used and its provenance, the type and application frequency of liming materials and compost, and harvest residue management. In total, 98 farmers were surveyed, since at some places it was impossible to contact the field owner or worker.

Climatic information

Climatic information was obtained from the closest IDEAM weather station to the sampling point. The dataset consisted in the historical normalized data from 1982 to 2010 (IDEAM, 2014). Analysis included average, maximum and minimum temperature, relative humidity, monthly precipitation, and number of rainy days per year.

Statistical analysis

Data analysis was performed using the SAS software (Version 9.4 for Windows, SAS Institute Inc., Cary, NC, USA). Point biserial correlation analysis were done to correlate continuous (climatic variables, soil properties) and dichotomic variables (crop management practices and disease infestation) (Kornbrot, 2014) using the CORR procedure.

Results

Description of cruciferous crops in Colombia

Cruciferous crops were grown in 80 of the 127 surveyed fields. In those the main identified crops included green cabbage (64 fields representing 80% of the fields grown in cruciferous crops), red cabbage (5 fields representing 6.25% of the fields grown in cruciferous crops), broccoli (6 fields representing 7.5% of the fields grown in cruciferous crops), and cauliflower (5 fields representing 6.25 % of the fields).

The most commonly grown green cabbage cultivars were the susceptible hybrids 'Delus' (Semillas Arroyave, 2006), and 'Globe Master' (Agroglobal S.A, 2022a), and the CR hybrid 'Tekila' (Syngenta, 2016). Those hybrids were grown in different regions, 'Delus' was cultivated mainly in Cundinamarca and Boyacá, while 'Globe Master' was mostly grown in Caldas and Norte de Santander. On the other hand, the CR hybrid 'Tekila' predominated in Antioquia.

In all other departments, farmers do not know the name of the variety they were growing.

None of the other cruciferous species showed a clear pattern in the department where they were grown. Of the 25% of farmers cultivating red cabbage, 67% of the farmers growing broccoli, and 60% of those growing cauliflower did not know the name of the variety they grew.

Half of the farmers cultivating red cabbage grew the hybrid 'Ruby King' (Agroglobal S.A, 2022b) and 25% of them grew the hybrid 'Sombrero' (Bejo Eurosemillas, 2022). For broccoli, 33% of the farmers cultivated the hybrid 'Legacy' (Bayer, 2022), and, for cauliflower, 40% of the farmers employed the hybrid 'Skywalker-F1' (Bejo, 2022). It must be pointed out that none of the cropped varieties of red cabbage, broccoli or cauliflower are clubroot resistant.

Cruciferous crops are grown in small areas; the national average size of the fields was 3 ha. The size of the fields was different among departments. Antioquia, Cundinamarca, Valle del Cauca, and Nariño were the only departments with fields larger than 1 ha with average sizes of 7.1, 3.3, 1.8 and 1.6 ha, respectively.

Production of cruciferous crops in the country had high agroclimatic variability and these are allocated at altitudes between 1600 and 3000 m a.s.l. From the surveyed field, 10% of the fields were at altitudes between 1600 and 2000 m a.s.l., 20% were between 2000 and 2500 m a.s.l., and the remaining 30% were between 2500 and 3100 m a.s.l. In Cundinamarca, Boyacá, Nariño, and Norte de Santander (half of the visited crops) cruciferous crops were allocated at altitudes between 2500 to 3600 m a.s.l. In Antioquia and the Norte de Santander cruciferous crops were at altitudes between 2000 and 2500 m a.s.l. In Cauca, Valle del Cauca and Caldas, the fields were at altitudes between 1674 and 2343 m a.s.l.

Clubroot prevalence in Colombia

The prevalence of clubroot was established within the departments where most of the cruciferous crops are grown in the country (Fig. 1). Those fields where the disease symptoms were observed in any host plant or where the farmer reported its occurrence in previous cycles of cruciferous crops were reported as clubroot infested. Clubroot was present in 53.6% of the sampled fields; from these, 48.8% were fields where the disease was observed by the researchers. The remaining 4.8% were assumed as positives as the farmer reported to have observed the disease in previous crop cycles. The disease was observed in all visited departments with the exception of Nariño (Figs. 1 and 2).

In Nariño, Boyacá, and Caldas, most of the farmers were not familiar with the disease symptoms (data not shown). In the municipalities of Sogamoso (Boyacá) and Popayán (Cauca), plants with typical clubroot symptoms were observed in fields of farmers who were not familiar with the disease and could not recognize its symptoms. Furthermore, they attributed yield losses, and symptoms such as wilting and reduction in the crop (caused by plant death) to different stresses such as water deficit and nutritional deficiencies. In Antioquia, the disease symptoms were not observed in green cabbage.

According to the farmers, clubroot was observed the first time around 2001 in Cundinamarca, 2011 in Boyacá, and 2013 in Norte de Santander. It was impossible to determine the approximate year when the disease was observed for the first time in Antioquia, Caldas, Valle del Cauca, and Cauca.

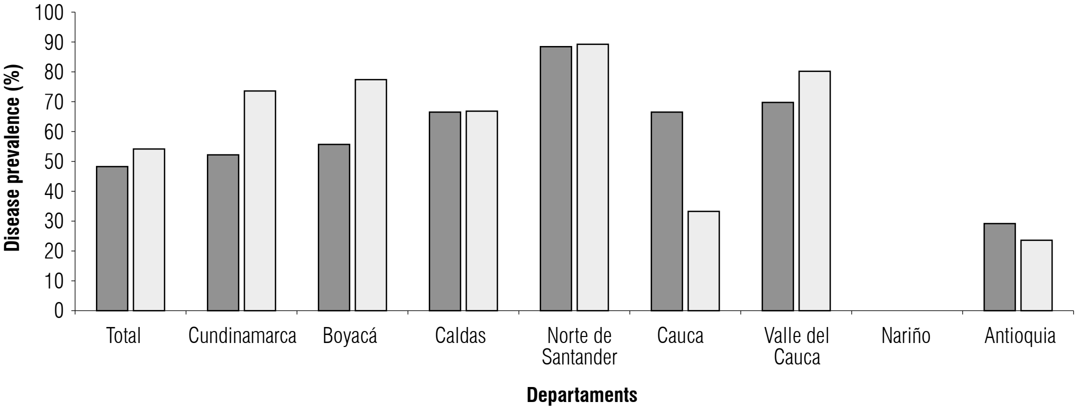

FIGURE 1. Clubroot prevalence in the main productive departments of cruciferous crops in Colombia. The graph shows the percentage of fields where clubroot symptoms were observed in any susceptible host (dark bars) or where farmers reported observation of clubroot symptoms in previous cycles of cruciferous crops (white bars). Percentages were estimated using a total of 127 fields visited in 2017.

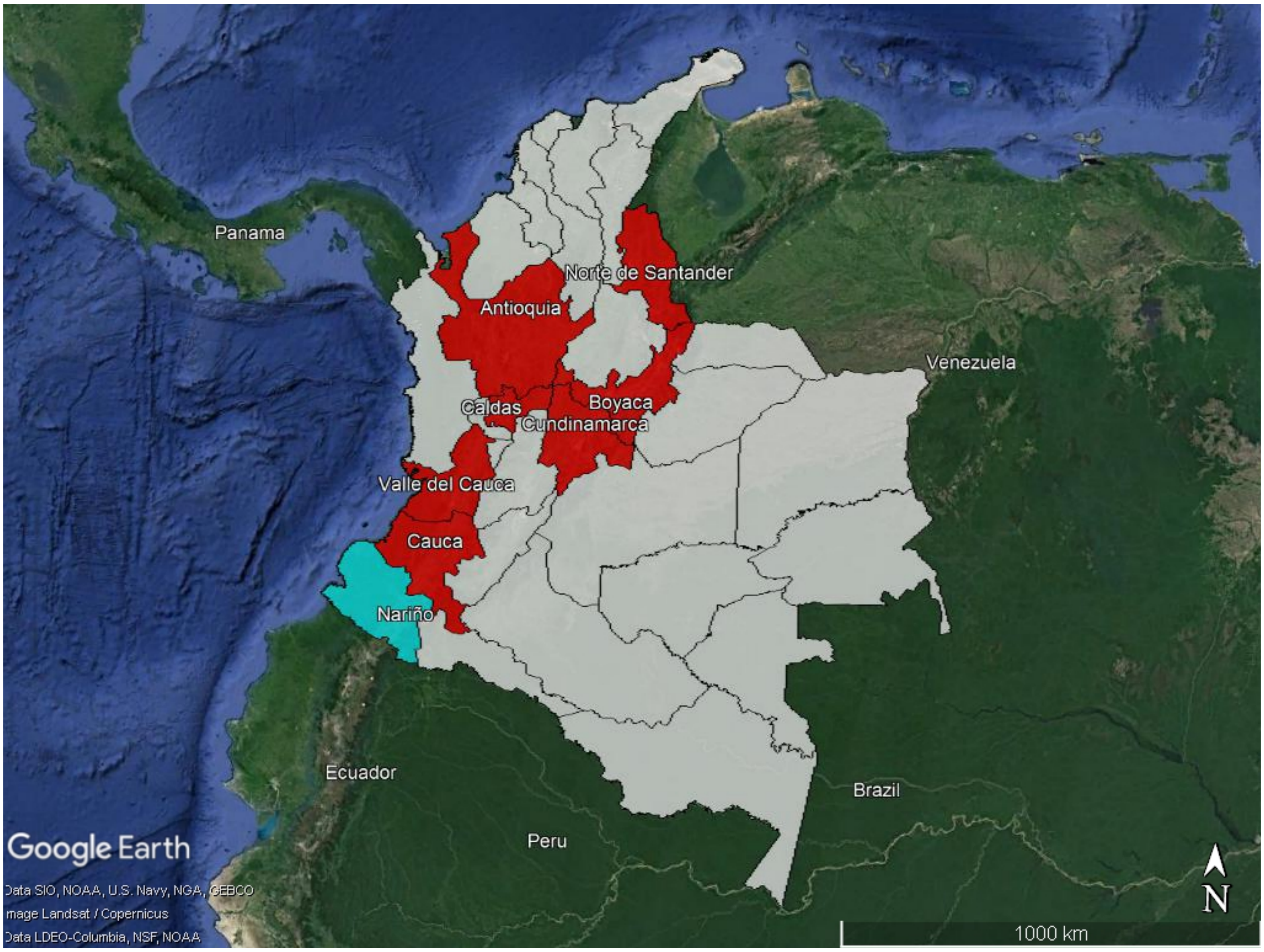

FIGURE 2. Clubroot prevalence in the main productive areas of cruciferous crops in Colombia. The map presents the departments were a survey for clubroot disease was conducted in 127 fields; the color cyan shows the only department where clubroot symptoms were not observed nor reported; in red the departments where clubroot symptoms were observed and/or reported.

Relationship between the soil, environmental characteristics, and clubroot infestation

A correlation between clubroot infestation, soil characteristics, and environmental variables was established (Tab. 2). From the evaluated variables, calcium, phosphorus, boron, copper, soil pH and the effective cation exchange capacity (ECEC) were positively correlated with the disease infestation (Tab. 2). Those results show that as levels in these variables increase, the odds of observing the disease in a field increases as well. However, aluminium content in soil and the average of rainy days per year showed a negative correlation with clubroot infestation. This implies that the odds of finding the disease in a field are reduced as the aluminium content in soil and the number of rainy days per year increase.

Relationship between crop management and clubroot infestation

Analysis showed that the probability of finding a clubroot-infested field is higher whenever cruciferous crops are included in the rotation scheme, and these chances are reduced when CR cultivars are included in the rotation scheme (Tab. 3).

Soil and climatic characteristics and their relationship with the clubroot infestation

Only the soil pH, the ECEC, the aluminium, phosphorous, calcium, boron and copper contents in soil and the number of rainy days per year correlated with clubroot infestation. The pH of the sampled soils was between 4.45 and 7.75. In Cundinamarca, soil pH was between 4.66 and 7.07, in

TABLE 2. Point biserial correlation of clubroot infestation and soil properties or environmental characteristics in the main productive areas of cruciferous crops in Colombia.

Variable	Point biserial correlation coefficient	*P*-value
Soil chemical properties		
pH	0.272	0.0037*
ECEC[a]	0.259	0.0058*
Organic carbon (%)	-0.056	0.556
Nitrogen (%)	-0.057	0.550
Calcium (meq/100 g)	0.268	0.004*
Potassium (meq/100 g)	0.084	0.375
Magnesium (meq/100 g)	0.168	0.074
Sodium (meq/100 g)	0.140	0.139
Aluminum (meq/100 g)	-0.259	0.030*
Phosphorus (mg kg^{-1})	0.413	<0.0001**
Copper (mg kg^{-1})	0.268	0.0042*
Iron (mg kg^{-1})	-0.141	0.137
Manganese (mg kg^{-1})	0.129	0.176
Zinc (mg kg^{-1})	0.112	0.241
Boron (mg kg^{-1})	0.289	0.002*
Environmental characteristics		
Altitude (m a.s.l.)	-0.165	0.092
Rainfall[b] (mm)	-0.188	0.060
Number of rainy days per year[b]	-0.297	0.002*
Average temperature[b] (°C)	0.070	0.620
Maximum temperature[b] (°C)	0.133	0.370
Minimum temperature [b](°C)	0.102	0.491

[a] Effective Cation Exchange Capacity.

[b] Annual average of the historical normalized data from 1981-2010.

The asterisks (*) show the variables which are correlated with clubroot infestation ($P<0.05$).

TABLE 3. Point biserial correlation of clubroot presence and crop management variables in the productive areas of cruciferous crops in Colombia.

Variable	Point biserial correlation coefficient	*P*-value
Use of seedlings instead of direct sowing	-0.069	0.535
Inclusion of cruciferous crops in rotation scheme	0.763	<0.0001*
Cruciferous cultivars included in rotation scheme	-0.489	0.0006*
Property of the mechanisation equipment	-0.007	0.949
Application of liming materials	-0.211	0.053
Application of organic matter	0.042	0.701
Application of fresh organic matter	-0.031	0.823
Incorporation of harvest residues	0.110	0.311

The asterisks (*) show the variables that are correlated with clubroot infestation ($P<0.05$).

Boyacá it was between 5.11 and 7.7, between 4.75 and 6.93 in Caldas, between 6.12 and 7.75 in Norte de Santander, between 4.68 and 7.72 in Valle del Cauca, between 4.45 and 6.47 in Cauca, between 4.85 and 7.33 in Nariño, and between 4.85 and 7.33 in Antioquia. The ECEC was highly variable, ranging from 1.03 to 85 meq 100 g^{-1}, and Cundinamarca and Boyacá had the highest averages (33 and 30 meq 100 g^{-1}, respectively). Calcium, aluminium, phosphorus, copper, and boron contents in soil had average values of 17.22 meq 100 g^{-1}, 0.76 meq 100 g^{-1}, 21.99 mg kg^{-1}, 2.23 mg kg^{-1}, and 0.59 mg kg^{-1}, respectively. The national average of number of rainy days per year was 149, and departmental averages were 135 d in Boyacá, 180 d in Caldas, 171 d in Norte de Santander, 213 d in Cauca, 161 d in Valle del Cauca, 195 d in Nariño, and 217 d in Antioquia.

Discussion

This research reports on the first clubroot survey conducted in Colombia, and to our knowledge in Latin America. The research allowed the estimation of the disease prevalence in the main productive areas of cruciferous crops in Colombia. It also assessed the correlation between clubroot infestation and soil and climatic characteristics, and crop management strategies.

This survey confirmed that clubroot is present in all departments where cruciferous crops are grown in Colombia with the exception of Nariño. These results expand previous reports from Torres (1969) and Jaramillo and Díaz (2006), who confirmed the disease presence in Cundinamarca, Antioquia and Caldas, therefore, confirming for the first time clubroot infestation of fields in Norte de Santander, Cauca, Valle del Cauca and Boyacá. Though in Nariño disease symptoms were not observed, the department cannot be declared ‘clubroot free’ yet; further confirmation is required by the application of molecular techniques for *P. brassicae* detection in soil such as endpoint PCR and/or qPCR (Cao *et al.*, 2007; Rennie *et al.*, 2011). Given the widespread presence of the pathogen in the country, it is likely that some inoculum of *P. brassicae* is already present in the fields of Nariño, but the inoculum densities are below the required threshold to cause visible disease symptoms under the predominant environmental conditions. Hwang *et al.* (2011) reported that for consistent symptoms of development under highly conductive conditions, a minimum inoculum density of 1×10^3 resting spores per gram of soil is required. The department either has lower inoculum densities or the environmental conditions are not conducive for symptom development.

Our results show that about half of the fields where cruciferous crops are grown in Colombia are infested with clubroot (national prevalence 53.6%). However, this estimation is likely skewed, and the percentage of infested fields is even higher. Such skewing might have been caused by Antioquia, since in this department clubroot symptoms were not found in fields grown with white cabbage since all of them were grown with the cultivar 'Tekila'. Therefore, it is likely that *P. brassicae* inoculum is already present in those fields, but they were reported as non-infested since disease symptoms were not observed by the researchers nor by the farmers in that department. The fields where clubroot was reported and/or observed were grown with red cabbage, broccoli, or cauliflower, given that resistant cultivars with highly commercial acceptance are not available.

A positive relationship was observed between the disease´s presence and some edaphic conditions such as pH, ECEC, and aluminium, phosphorus, calcium, boron, and copper contents in soil. Calcium content in soil and pH are crucial for clubroot development (Webster & Dixon, 1991b). Previous research shows a weak correlation between clubroot and soil pH, where alkaline soils (with pH higher than 7.2) can reduce disease levels even under highly conductive scenarios (Wallenhammar, 1996; Gossen *et al.*, 2013). These results at first glance would indicate a disagreement of previous reports with ours, since our results show that as the pH increases so does the likelihood of finding an infested field.

Conducive pH levels for clubroot development are between 5.0 and 6.5 (Webster & Dixon, 1991a; Narisawa *et al.*, 2005; Niwa *et al.*, 2007, 2008; Ruaro *et al.*, 2010; Gossen *et al.*, 2013; Rashid *et al.*, 2013). From the collected soil samples 83.6% were acidic, from those, 76% were in the range between 5.0 and 6.5 the most favourable pH for the disease development. This might indicate that the observed pH values in this research are below or very close to the optimum required for disease development. For that reason, as the pH levels are increased the conditions for the disease development are improved, explaining the observed correlation.

As calcium and boron content in soil increased, the chance of finding clubroot in a field increased. These results differ from previous research reporting that an increment in calcium and boron concentrations cause a reduction in the number of infections and expression of the disease symptoms (Webster & Dixon, 1991a, 1991b). The effect of these nutrients over the disease symptoms is negatively correlated with the inoculum levels; and thus, under high inoculum pressure, disease reduction is diminished (Webster & Dixon, 1991a, 1991b; Gossen *et al.*, 2014). In most of the infested fields, disease was very severe (data not shown); as disease severity is positively corelated with high inoculum densities (Murakami *et al.*, 2002) we can presume that inoculum levels in the infested fields is high, hindering the calcium and boron effect on it.

Bhering *et al.* (2017) reported that low pH values and high aluminium contents in soil are favourable for clubroot development; however, our results show the opposite pattern. The negative correlation between clubroot infestation and aluminium contents in soil might be explained mainly by the negative effect of aluminium over the reduction of root branching in the host roots (Marschner, 1995); it can lower the infection probability and along with it the chance of finding the disease in a field. However, that hypothesis needs to be proved by further research.

The largest correlation coefficient with disease occurrence was for the inclusion of cruciferous crops in the rotation scheme; that agrees with reports from Gossen *et al.* (2014) and Dixon (2009), who state that clubroot incidence and severity increases as cruciferous crops are intensified.

Finally, a negative correlation was found in the number of rainy days per year and clubroot infestation. Bhering *et al.* (2017) indicates a lower chance of observing clubroot disease in areas with low precipitation and well drained soils, but fluctuations in the amount of precipitation (rainy seasons, with precipitation levels over the average, followed by drought seasons) can cause epidemics. It is also important to dig deeper into this observation, since it might be a spurious result; the departments with more rainy days per year were Antioquia and Nariño that also are the ones with the lowest number of infested fields, the first one because mostly CR cabbage is grown and the second because it might be clubroot free or the inoculum densities are low.

This research confirmed the presence of clubroot in the main productive departments of cruciferous crops in Colombia with the exception of Nariño. Based in the current methodology, Nariño appears to be clubroot-free; however, further confirmation is required. This is the first research that attempts to establish clubroot disease status in Colombia, and it becomes a starting point for the design and implementation of integrated management practices for the disease.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

ABR, CGD, and FLPH contributed to development of the research concept. ABR and CGD secured funding support and supervised and administered the project. ABR and FLPH designed and directed sample collection and processing, ABR performed statistical analyses and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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