



## Evaluation of tolerance to *Phytophthora cinnamomi* Rands in avocado (*Persea americana* Miller.) germplasm

### Evaluación de la tolerancia a *Phytophthora cinnamomi* Rands en germoplasma de aguacate (*Persea americana* Miller.)

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#### Abstract

In order to obtain twenty-one evaluated accessions from the Avocado Germplasm Bank of CORPOICA, Palmira Research Station with two pathogenic strains of the oomycete, *Phytophthora cinnamomi* Rands. The aim of this research was to identify avocado accessions, which used as rootstocks in a cultural control strategy for preventing root rot disease. Disease progression was evaluated using mycelium of the pathogen by cut-stem inoculation. The measurements of symptom progression length and width were carried out and analyzed. In order to obtain the area under the disease progression curve (AUDPC), these data were analyzed. A randomized complete block design (RCBD), with a factorial design of 3 x 21 in-subdivided parcels (2 strains of the pathogen, a control strain, and 21 avocado accessions) was performed. Eight readings were determined per plant throughout evaluation time. Statistical analysis showed significantly differences using the AUDPC for some avocado accessions. Tukey's test revealed five tolerance levels. Accession 'NATU-001' from Tumaco, Nariño, was identified as promising for its high tolerance and 'CANO-008' from Norcasia, Caldas, as a tolerant control accession had the second lowest value of AUDPC. Susceptible accessions used as control, e.g. 'Hass' variety and rootstock 'Topa-Topa', performed a very high susceptibility to the pathogen along with 'QUIQUI-030' accession from Quimbaya, Quindío, Colombia

**Keywords:** Root rot, germplasm bank, landrace cultivars, Hass, accessions.

#### Resumen

Se evaluaron 21 accesiones del banco de germoplasma de aguacate criollo de CORPOICA como aporte a la búsqueda de materiales de aguacate *Persea americana* Mill., potencialmente resistentes a la enfermedad de pudrición de raíces causada por *Phytophthora cinnamomi* Rands. Dos cepas patogénicas de este oomiceto fueron evaluadas con el objetivo de identificar accesiones del banco de germoplasma como tolerantes, y potencial uso como portainjertos para el manejo preventivo de esta enfermedad. Se evaluó la infección con micelio del patógeno mediante la técnica de herida al tallo. Se midió periódicamente el largo y ancho del avance de síntomas, con estos registros se estableció el Área Bajo la Curva del Progreso de la Enfermedad (ABCPE) en el tejido afectado de la planta, utilizando un diseño de bloques completos al azar (BCA) con un arreglo factorial de 3 x 21 en parcelas subdivididas (dos cepas del patógeno más una cepa testigo y 21 accesiones de aguacate). Durante el estudio se realizaron ocho lecturas, que permitieron conocer el avance de la enfermedad. El análisis estadístico mostró diferencias significativas del ABCPE para algunas accesiones de aguacate, la prueba de separación de medias de Tukey reveló cinco niveles de tolerancia. Se identificó la accesión NATU-001 proveniente de Tumaco, Nariño, promisorio por su alta tolerancia y la accesión CANO-008 de Norcasia, Caldas, testigo tolerante, presentó el segundo menor valor de AUDPC. Los testigos susceptibles, cultivar Hass y Topa-Topa, presentaron alta susceptibilidad al patógeno junto con la accesión QUIQUI-030 de Quimbaya, Quindío.

**Palabras clave:** Pudrición radical, banco de germoplasma, cultivares criollos, Hass, accesiones.

## Introduction

The avocado *Persea americana* Mill., belongs to the Lauraceae family, originally found in Guatemala, Central part of America and Mexico (Knigh, 2007; Sánchez, 1999). It is distributed from Mexico to Peru, throughout Central America, Colombia, Venezuela and Ecuador (Knigh, 2007).

The avocado is an important crop worldwide with a global production of 4.717.102 metric tonnes (MT). The main producer is Mexico (1,467,837 MT) (31.11%), followed by Dominican Republic (387,546 MT) (8.21%), Colombia (303,340 MT) (6.43%), Peru (288,387 MT) (6.11%), Indonesia (276,311 MT) (5.85%), Kenya (191,505 MT) (4.05%), United States of America (175,226 MT) (3.71%), Chile (164,750 MT) (3.49%), Brazil (157,482 MT) (3.33%) and Rwanda (148,823 MT) (3.15%). (Agronet, 2015).

Other 42 countries contribute with 1.155.895 MT (24.50%). In Colombia, the avocado crop has an increased importance for the area it occupies and its annual growth in comparison with other agricultural products. According to the official data from the information and communication network of the agricultural sector of Colombia (Agronet, 2015), in the recent years an important increase in the planted area has occurred, reaching 32,066 ha in 2013 with a production equals to 303,352 tonnes and average yields of 9.5 tonnes per hectare.

Several species of *Phytophthora* attack the avocado in different regions of the world some of them are: *P. citricola*, *P. cactorum*, *P. parasitica*, *P. palmivora* and *P. heveae*. Some produce cankers or stalk rots. In Colombia, the main specie identified in the producing areas is *Phytophthora cinnamomi*. Recently, the complex of *P. cinnamomi*, *P. heveae*, *P. citricola*, *Verticillium* sp. and *Cylindrocarpon destructans* was detected in the Antioquia department, Colombia, causing root rot in the avocado plants (Ramírez, Castañeda, & Morales, 2014). *Phytophthora cinnamomi* Rands is an oomycete from the Pythiaceae family, affects any age plants, causes root wilting and stem cancer (Andrade, De León, Espíndola, Alvarado, López, & García, 2012).

*Phytophthora cinnamomi* Rands., is worldwide distributed, it is a pathogen naturally found in soil and can affect almost 3000 plant species, causing problems in agriculture and forestry (Hardham, 2005). *Phytophthora cinnamomi* Rands is the causal agent of the root rot in avocado and this is the most important worldwide disease caused by *Phytophthora* in avocado (Pagliaccia, Pond, McKee, & Douhan, 2013; Coffey, 1987). This disease removed commercial areas in Latin America and is the major factor, which limits the

avocado production in Australia, South Africa and California (Ploetz, Schnell, & Haynes, 2002). In addition, it has decimated important repositories of avocado germplasm as reported by USDA-ARS in Isabella, Puerto Rico and in the Pan American School of Agriculture in Zamorano, Honduras (Violi, Borrone, Ploetz, Schnell, & Olano, 2006).

Effective control measures to mitigate the avocado root rot caused by *P. cinnamomi* are limited and integrated strategies are usually necessary to manage the disease (Coffey, 1987) as prevention, chemical and biological control and the use of rootstocks resistant to the pathogen. In addition, the production of tolerant rootstocks is one of the most promising components in the disease management (Douhan, 2011; Violi *et al.*, 2006).

The most effective control actions is the use of chemical substances as metalaxyl and mefenoxam (Ridomil and Ridomil Gold respectively), fosetyl aluminium (Aliette) and other phosphorate products which reduce the disease for short periods of time (months), but do not eliminate *P. cinnamomi*. In addition, the frequent use of these products for long periods and in a repetitive way can produce resistance in the pathogen populations (Cohen & Coffey, 1986). The origin centres of *Persea americana* Mill., and *P. cinnamomi*, are located in different areas of the world (they do not co-evolved), meaning that no evolutionary selection has occurred for tolerance to root rot in avocado. Depending on the cultivar, the plants take among 5 and 15 years to mature. Only 1% of the flowers result in fruit and these can be the result of self-pollination (Davenport, Parnitzki, Fricke, & Hughes, 1994). In spite of these challenges, rootstocks tolerant to root rot were obtained in California. Unfortunately, these rootstocks are not suitable for tropical climates (Violi *et al.*, 2006). Rootstocks resistant to the pathogen as the varieties Duke 6, Duke 7, G6, D9, Toro Canyon, Thomas and Martin Grande (G755) (Cortés *et al.*, 2010), are not commercially used in Colombia, except Duke 7 cloned by the Profrutales Ltda nursery. Trees grafted in resistant rootstocks show good performance and productivity even in soils with presence of the pathogen.

The aim of this research was to evaluate the tolerance of 21 accessions from the Avocado Germplasm Bank of CORPOICA, Palmira Research Station, with two pathogenic strains of the oomycete *Phytophthora cinnamomi*. This study have allowed to identify avocado landrace accessions potentially tolerant to the pathogen in order to continue with the process of finding promising rootstocks, which could be used as a cultural control strategy for preventing root rot disease in Colombia.

## Material and methods

### Avocado plant material

In order to obtain twenty-one selected accessions, the Avocado Germplasm Bank (B.G.) of CORPOICA, Palmira Research Station, was evaluated. The Research Station is located in the municipality of Palmira, Valle del Cauca, Colombia located at the following geographic coordinates: 03°30'43.6"N and 76°18'53.5"W, at 1.001 m. a. s. l., Eighteen accessions were selected according to their collection site, considering they were not geographically closed. The clone CANO-008 from Norcasia, Caldas, was performed as tolerant control and the Hass cultivar (Ramirez *et al.*, 2014) and the rootstock Topa-Topa (Gabor, Guillemet, & Coffey, 1990; Kellam & Coffey, 1985) as susceptible controls. The latest was used as rootstock due to its tolerance to some fungal diseases. However, is susceptible to *Phytophthora cinnamomi*. Nineteen of the selected accessions come from 12 Colombia departments: Bolívar (1), Caldas (2), Cauca (1), Cesar (1), Huila (1), Magdalena (1), Meta (1), Nariño (2), Quindío (2), Santander (2), Tolima (1), Valle del Cauca (4), in addition to the susceptible controls (Table 1).

**Table 1.** Avocado accessions selected for the study and collection site

Avocado accession	Collection site	Geographic coordinates of the collection site
Boca-021 <sup>1</sup>	Carmen de Bolívar-Bolívar	09°44'43.4"N, 75°16'28.2"O
Caro-019 <sup>1</sup>	Rosas-Cauca	02°14'10.0"N, 76°44'32.6"O
Cavi-041 <sup>1</sup>	La Victoria-Caldas	05°20'36.1"N, 74°54'20.2"O
Cepu-008 <sup>1</sup>	Pueblo Bello-Cesar	10°24'57.8"N, 73°38'54.8"O
Husu-004 <sup>1</sup>	La Suaza-Huila	01°55'16.5"N, 75°49'14.7"O
Masa-031 <sup>1</sup>	Santa Marta-Magdalena	11°12'90.7"N, 74°02'68.8"O
Mevi-001 <sup>1</sup>	Villavicencio-Meta	04°01'17.3"N, 73°14'28.8"O
Natu-001 <sup>1</sup>	Tumaco-Nariño	01°32'54.4"N, 78°41'49.8"O
Natu-002 <sup>1</sup>	Tumaco-Nariño	01°34'24.4"N, 78°42'02.0"O
Quiqui-030 <sup>1</sup>	Quimbaya-Quindío	04°37'37.1"N, 75°44'59.0"O
Quite-027 <sup>1</sup>	La Tebaida-Quindío	04°27'50.3"N, 75°48'22.0"O
Saca-014 <sup>1</sup>	Carmen del Chucuri-Santander	06°39'03.2"N, 73°35'51.7"O
Saca-017 <sup>1</sup>	Carmen del Chucuri-Santander	06°44'23.8"N, 73°35'40.6"O
Toma-003 <sup>1</sup>	Mariquita-Tolima	04°40'14.2"N, 74°59'07.5"O
Vabu-014 <sup>1</sup>	Buga-Valle del Cauca	03°52'40.6"N, 77°00'44.7"O
Vapa-062 <sup>1</sup>	Palmira-Valle	03°30'37.9"N, 76°19'33.9"O
Varo-002 <sup>1</sup>	Rozo-Valle del Cauca	03°36'39.0"N, 76°25'29.0"O
Varo-006 <sup>1</sup>	Rozo-Valle	03°36'39.0"N, 76°25'29.0"O
Cano-008 <sup>2</sup>	Norcasia-Caldas	05°36'38.9"N, 74°52'35.9"O
Topa-Topa <sup>3</sup>	Germplasm from CORPOICA	03°36'43.6"N, 76°18'53.5"O
Hass <sup>4</sup>	Germplasm from CORPOICA	03°36'43.6"N, 76°18'53.5"O

Type of selection: <sup>1</sup>Germplasm from CORPOICA, <sup>2</sup>Tolerant accession,

<sup>3</sup>Susceptible rootstock (Gabor *et al.*, 1990; Kellam & Coffey, 1985) and

<sup>4</sup>Susceptible cultivar (Ramirez *et al.*, 2014).

Selected materials were identified and cloned from the plant material in the Avocado Germplasm Bank of CORPOICA, Palmira Research Station.

The respective agronomic management for five months was established with the aim to promote bud growth. The pruned plants were available to induce the vegetative growth, obtain new buds with the required conditions for grafting and obtain enough clonal material for the evaluation. In addition, buds from the 21 selected accessions, were collected. For the collection, it was determined the buds in optimal conditions for grafting following these methodological steps:

Selection of young branches in an active growth and medium flexibility.

Selection of bud woods of 15 cm long with a cork point in the stem centre, approximately 1 mm wide, to allow the fluid flow.

The bud woods were disinfected in a solution of Mancozeb or Benomyl (Mancozeb 80% wp, Benomyl 50 wp) at a concentration equal to 1.5 g. l<sup>-1</sup> for five minutes.

The bud woods were placed in kraft paper and masking tape, which clearly identified with the bank accession code in order to ensure their genetic identity.

The plant material was immersed in water to assure their wetting and avoid excessive transpiration. In addition, were packed in a polystyrene cool box for transport.

Twenty-one avocado accessions were grafted on native or common rootstocks from Alvarado, department of Tolima; 12 grafts per accession to ensure the nine plants required for the infection assay and were properly identified to assure the germplasm traceability. The plants were kept three months in the nursery and the agronomic management was established as follows:

The seed used as rootstock came from a basic orchard of native or common trees propagated in a registered nursery, using the previously established management protocols. The grafting was performed at 25 cm of height in the rootstock terminal spike. Consequently, was covered with a plastic bag to conserve the humidity and a paper bag to keep it in darkness and stimulate the bud rapid growth. Each week, disease and plague control was carried out in terms of metalaxyl, fosetyl aluminium, carbendazim, potassium sulphite and chlorpyrifos rotation (Ridomil, Aliette, Carbendazim 50, Potassium sulphite E225 and Lorsban).

The grafted plants were put in a nursery under a plastic cover to control leaf moisture and water supplying, lifted off the ground 70 cm, on concreted beds and supported by a plastic pot to avoid contact among them and ensure adequate drainage. The portable weather station Watch Dog serie 2009, installed to monitor the



temperature and relative humidity conditions and guarantee the required conditions for the plants and expression of the pathogen.

The optimal temperature for the infection with *P. cinnamomi* ranges from 21 to 30°C and there is little or no infection at 33°C or among 9 and 12°C (Andrade *et al.*, 2012). These temperatures coincide with the growth curve observed in this study for the oomycete. The growth response of the avocado plantlets at soil temperatures is similar to the growth of plants affected by the fungus with exception of avocados with optimal growth temperature of 33°C. Likewise, moisture is a primary environmental factor that affects the occurrence of the root rot caused by *P. cinnamomi* and determines its development or growth, sporulation and infection process. High moisture levels in soil increase the infection due to higher formation of sporangia and appropriated conditions for the release of zoospores, mobility and movement at the infection site.

In order to keep a high relative humidity, under the concrete beds were put cement tanks with a capacity of 190 H<sub>2</sub>O l, a total of eight tanks to cover 1.52 m<sup>3</sup>. Additional irrigation was carried out every two days at field capacity to ensure optimal humidity conditions, which can lead to avoid splashing among plants.

### Isolates of *Phytophthora cinnamomi*

Two strains of the pathogen *P. cinnamomi* reported as the most pathogenic isolates out of 22 strains evaluated in Hass avocado using mycelium of the pathogen by cut-stem inoculation. The isolates were collected in different regions of Colombia where the death of avocado trees were presumably caused by *P. cinnamomi*. The identification of *P. cinnamomi* was conducted by macroscopic colony growth (rosette form and petaloid type) and microscopic vegetative and reproductive structures (coraloid hyphae and globose chlamydospores).

The selected isolates were Ag A-041 collected by The Universidad Nacional de Colombia, Palmira campus, in Tribunas Córcega, Risaralda department, and Ag A-003 collected by CORPOICA-Palmira Research Station, in Rionegro, Antioquia department, respectively, according to their pathogenicity. Purification and increase of the selected strains of *P. cinnamomi* were carried out in the Phytopathology Laboratory in CORPOICA, Palmira Research Station.

### Experimental design

A randomized complete block design (RCBD), with a factorial design in subdivided parcels was performed. The major parcels were the *P.*

*cinnamomi* strains, the subparcels were the *P. americana* accessions and the sub-subparcels were the evaluations. Two strains (Ag A-041, Ag A-003 and the control inoculated with agar-water), 21 avocado accessions in a factorial design of 3 x 21 (63 treatments in total) and three repetitions per treatment for 189 total plants were evaluated. The evaluation of the response variable was performed every two days from the fifth day of inoculation and for 16 days.

### Inoculation

The methodology used was mycelium of the pathogen by cut-stem inoculation of each plant. The cutting was performed 5 cm above the grafting point, the wound was done up-down with a disinfected scalpel without disturbing the woody part of the plant and partially removing the plant bark at 2 mm deep approximately. Inside the wound was placed an agar disc diameter 6 mm with mycelia of *P. cinnamomi*. In addition, the wound was covered with parafilm to prevent the fall of the agar with mycelia, to control the moisture and ensure the pathogen colonisation. The control plants were inoculated with an agar disc diameter 6 mm with water.

### Data analysis

Measures of the length and width of symptom progression were recorded every two days from the fifth day after inoculation and for 16 days. These values were multiplied to calculate the lesion area and establish the area under the disease progression curve (AUDPC). The results were analysed with SAS (Statistical Analysis System) software version 9.3. An analysis of variance (ANOVA) and a Tukey's test for means comparison were performed. The information obtained from the evaluations and the statistical analysis were performed to select the promissory avocado accessions with higher tolerance to *P. cinnamomi*.

### Results and discussion

The records of temperature and relative humidity allowed establishing that the conditions required for the expression of the pathogen and the disease were within the optimal range, according to Andrade *et al.*, (2012). Temperature fluctuated among 21.3 and 31.9 °C and the relative humidity was higher than 51% with a maximum value of 93.8%. Eight reads of the length and width of the lesion progression were obtained and used to establish the area under the disease progression curve (AUDPC) for 1512 AUDPC data.

The variance analysis of AUDPC showed significant differences ( $P \leq 0.001$ ) for the avocado accessions,

the *P. cinnamomi* strains, the evaluations and the interactions strain x accession, strain x evaluation, accession x evaluation and strain x accession x evaluation (Table 2). The estimated statistics for each source were based on their associated error.

**Table 2.** Variance analysis of the AUDPC obtained for the inoculation of 21 avocado accessions with two *P. cinnamomi* strains.

Source	DF	MS	P valor b
Block	2	1.69	0.0002 **
Strain	2	2389.43	<.0001 **
Block x strain. E(a)	4	0.64	
Genotipo	20	13.18	<.0001 **
Strain x accession	40	12.47	<.0001 **
Block x accession (cepa). E(b)	120	5.32	
Evaluation	7	174.19	<.0001 **
Strain x evaluation	14	77.68	<.0001 **
Accession x Evaluation	140	0.53	<.0001 **
Strain x accession x evaluation	280	0.46	<.0001 **
Error (c)	882	0.20	
Total	1,511		

C.V: 21.2%.

DF: degrees of freedom. MS: mean square. P valor b: probability of finding higher values of F \*\* Significant differences

The variance analysis and the media separation using the Tukey's test identified the strain Ag A-041 from Tribunas Corcega, Risaralda, as the most pathogenic because it had the highest AUDPC average value for the different avocado accessions evaluated. The strain Ag A-003 from Rionegro, Antioquia, showed statistical differences from the control strain Ag A-000 that was asymptomatic and had lower AUDPC average value than the Ag A-041 strain. Then the Ag A-003 strain did not register a high pathogenicity for the avocado accessions evaluated (Table 3).

**Table 3.** Pathogenicity levels of two *Phytophthora cinnamomi* strains in avocado and a control (agar plus water).

Tukey's groups	Mean	Strain
A	4,086	Ag A-041
B	0,741	Ag A-003
C	0,000	Ag A-000

The significantly statistical differences observed among avocado accessions, involved the genotypes respond differentially to the pathogen, represented by dissimilar AUDPC average values. The tolerance levels were assigned based on the mean values determined by the Tukey's test for the AUDPC and correspond to highly susceptible, susceptible, low tolerance, moderate tolerance and tolerant.

According to the Tukey's test, 5% of the accessions performed the highest tolerance level. Accession

NATU-001 from Nariño department, municipality of Tumaco, showed the lowest AUDPC values. Twenty nine (29%) of the accessions exhibited moderate tolerance, 57% low tolerance, 5% were susceptible and 5% highly susceptible; the avocado accession QUIQUI-030 from Quimbaya-Quindio, Colombia was the most affected and performed the highest AUDPC value (Table 4). The Hass cultivar reported as susceptible presented the second highest average AUDPC value followed by the accession CARO-019 from Rosas, Cauca, and the rootstock Topa-Topa known in United States as susceptible. These results demonstrate the cut-stem inoculation in avocado is a valid methodology to evaluate and characterize the genetic response of avocado to *P. cinnamomi*.

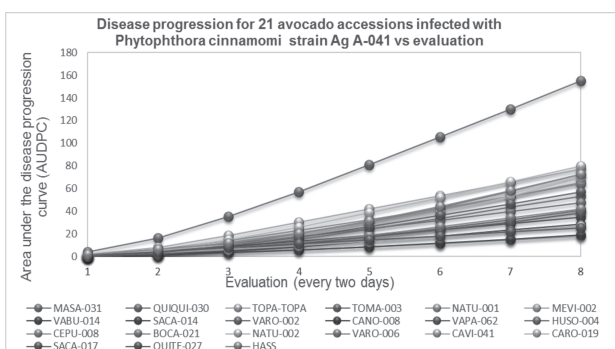
The statistically difference observed for strain x accession interaction was highly significant and means that the avocado accessions had differential responses to the inoculated strains. The strain Ag A-041 results from the most pathogenic strains, which exhibited the highest infection pressure over the evaluated accessions (Table 4).

**Table 4.** Tolerance levels of 21 avocado accessions from the Germplasm Bank of CORPOICA, Palmira Research Station against *Phytophthora cinnamomi* strain Ag A-041.

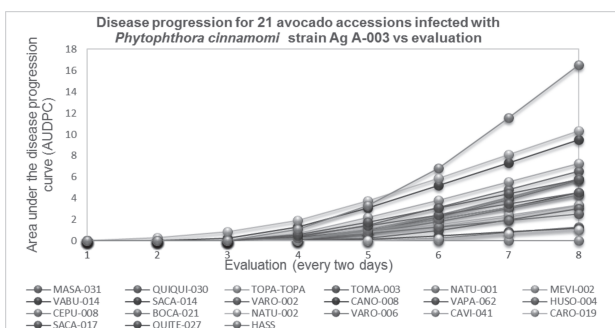
Tolerance level	Avocado accession	Audpc mean	Tukey grouping
Highly susceptible	QUIQUI-030	2.802	A
Susceptible	HASS	2.200	AB
	CARO-019	2.057	ABC
	TOPA-TOPA	1.971	ABC
	BOCA-021	1.884	ABC
	CEPU-008	1.786	ABC
	NATU-002	1.716	ABC
	SACA-017	1.684	ABC
Low tolerance	MASA-031	1.603	ABC
	TOMA-003	1.593	ABC
	HUSO-004	1.535	ABC
	VARO-002	1.498	ABC
	VARO-006	1.428	ABC
	SACA-014	1.420	ABC
	QUITE-027	1.398	BC
	CAVI-041	1.394	BC
Moderate tolerance	VAPA-062	1.371	BC
	MEVI-002	1.316	BC
	VABU-014	1.312	BC
	CANO-008	1.057	BC
Tolerant	NATU-001	0.760	C

The significantly statistical difference for the AUDPC evaluations, indicates the disease progression was continuous and increasing over time. Similarly, the differences in the interactions strain x evaluation, accession x evaluation and strain x accession x evaluation confirm progression of the disease as function of time.

Each avocado accession and each *P. cinnamomi* strain performed a disease progression that varies according to the time. The avocado accession NATU-001 had the lowest AUDPC value and QUIQUI-030 showed the highest (Figure 1). The AUDPC values of the strain Ag A-003 were 90% lower than the strain Ag A-041 and the Hass cultivar, susceptible control, showed the greatest disease progression for the last strain (Figure 2). The control Ag A-000 without pathogen did not exhibit AUDPC for any of the avocado accessions confirming that the inoculation protocol used met the required parameters to ensure good results and reducing the experimental error.



**Figure 1.** Tolerance levels of 21 avocado accessions against *P. cinnamomi* strain Ag A-041 according to the AUDPC.



**Figure 2.** Tolerance levels of 21 avocado accessions against *P. cinnamomi* strain Ag A-003 according to the AUDPC.

The plant material with the higher tolerance level was NATU-001, collected in Tumaco, Nariño-Colombia. This place is located in the Colombian Pacific Coast, at 25 m. a. s. l., with 29 °C average temperature and oscillations among 16 and 33°C, relative humidity of 83.86%, annual precipitation of 2792mm.

These weather conditions are typical of the Tropical Rain Forest (TRF, the flat topography favours the terrain super saturation and flooding which are optimal conditions for the pathogen presence and development.

The nature of avocado cross-pollination, increases the genetic variability and could lead to the segregation of individuals with different tolerance levels. This could explain the NATU-002 and NATU-001 accessions behaviour, which displayed different tolerance responses in this research. The accession CANO-008 performed the second lowest AUDPC value. This accession was collected in Norcasia, Caldas, the municipality has climatic conditions of TRF, is located at 551 m. a. s. l., its average temperature is 25°C, annual rainfall of 3675mm and relative humidity 76.76%. Norcasia weather is hot and present hard rainfall in short time, optimal conditions for the presence of *P. cinnamomi*, the avocado crops and for the interaction pathogen-host. Those climatic conditions are perfect for a high production of sporangia, release and movement of zoospores due to high precipitations favour the transfer of the pathogen propagules between the roots of infected trees and the roots of healthy ones using the water as their means of transport (Andrade *et al.*, 2012). Based on this, the accessions NATU-001 and CANO-008 were collected in places with high temperature and relative humidity, ideal conditions for selecting rootstocks of avocado landraces with any tolerance degree to the root rot problem.

## Conclusion

There are accessions from the Avocado Germplasm Bank of CORPOICA, Palmira Research Station with different tolerance levels to the pathogen *Phytophthora cinnamomi* Rands causal agent of root rot. The tolerance of the avocado accessions (NATU-001 y CANO-008) could be related with outstanding characteristics with genetic origin.

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## References

- Agronet. (2015). Sistema de Estadísticas Agropecuarias SEA. <http://www.agronet.gov.co/www/htm3b/ReportesAjax/VerReporte.aspx>.
- Andrade, H.P., De León, C., Espíndola, B.M.C., Alvarado, R.D., López, J.A., & García, E.R. (2012). Selección de porta-injertos de aguacate para tolerancia-resistencia a *Phytophthora cinnamomi* Rands usando temperaturas controladas. *Spanish Journal of Rural Development*, 3(4), 23-30. doi:10.5261/2012.GEN4.03.

- Coffey, M.D. (1987). Phytophthora root rot of avocado: an integrated approach to control in California. *Plant Disease*, 71, 1046-1052.
- Cohen, Y., & Coffey, M.D. (1986). Systemic fungicides and the control of oomycetes. *Annu Rev Phytopathol*, 24(1), 311-338. doi:10.1146/annurev.py.24.090186.001523.
- Davenport, T.L., Parnitzki, P., Fricke, S., & Hughes, S. (1994). Evidence and significance of self-pollination of avocados in Florida. *J Amer Soc Hort Sci*, 119(6), 1200-1207.
- Douhan, G.W. (2011). Screening and Evaluation of New Rootstocks with Resistance to *Phytophthora cinnamomi*. Final Production Research Report Commission. California Avocado. Breeding and Genetics. pp 26.
- Gabor, B.K., Guillement, F.B., & Coffey, M.D. (1990). Comparison of Field Resistance to *Phytophthora cinnamomi* in Twelve Avocado Rootstock. *Hort Science*, 25(12), 1655-1656.
- Hardham, A.R. (2005). *Phytophthora cinnamomi*. *Molecular Plant Pathology*, 6(6), 589-604. doi:10.1111/j.1364-3703.2005.00308.x.
- Kellam, M.K., & Coffey, M.D. (1985). Quantitative comparison of the resistance to *Phytophthora* root rot in three avocado rootstocks. *Phytopathology*, 75(2), 230-234. doi:10.1094/Phyto-75-230.
- Pagliaccia, D., Pond, E., McKee, B., & Douhan, G.W. (2013). Population genetic structure of *Phytophthora cinnamomi* associated with avocado in California and the discovery of a potentially recent introduction of a new clonal lineage. *Phytopathology*, 103(1), 91-97. doi:10.1094/PHYTO-01-12-0016-R.
- Ploetz, R., Schnell, R.J., & Haynes, J. (2002). Variable response of open-pollinated seedling progeny of avocado to *Phytophthora* root rot. *Phytoparasitica*, 30(3), 262-268. doi:10.1007/BF03039994.
- Ramírez, J.G., Castañeda, D.A., & Morales, J.G. (2014). Estudios etiológicos de la marchitez del aguacate en Antioquia-Colombia. *Ceres*, 1, 050-061. doi:10.1590/S0034-737X2014000100007.
- Sánchez, J. (1999). Recursos genéticos de Aguacate *Persea americana* Mill. y especies afines en México. *Revista Chapingo Serie Horticultura* 5, 7-18.
- Violi, H.A., Borrone, J.W., Ploetz, R., Schnell, R.J., & Olano, C.T. (2006). Development of *Phytophthora* root rot-resistant avocado rootstocks for the Caribbean. *Proc Fla State Hort Soc*, 119, 41-44.