

Assessment of four genotypes of cacao in Nariño, Colombia

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Abstract

The cacao (*Theobroma cacao* L.) crop for the department of Nariño represents a productive alternative to the substitution of illicit crops, on which small and medium producers depend; nevertheless, high relative humidity, temperature, and rainfall, as well as inadequate phytosanitary management, cause a high incidence of diseases such as *Moniliophthora roreri* and *Phytophthora* sp., limiting productive yield. In this sense, it is necessary to identify cacao clones adapted to the conditions of the area and tolerant to the main diseases. This study aimed to assess the productive and sanitary potential in the initial stages of development of four cacao clones, TCS 01, TCS 06, TCS 13, and TCS 19, under environmental conditions of the Nariño Pacific. The SAS 9.4 software was used for the statistical analysis, employing the Glimmix procedure to analyze the variables, and the analysis was adjusted to the Poisson distribution. In addition, Tukey's tests were used when there were significant differences. The clone TCS 19 presented the best results in production (1.44 kg dried bean tree⁻¹), surpassing the commercial control ICS 95 (0.6 kg dried bean tree⁻¹). In terms of health, *M. roreri* was the disease with the highest incidence, especially in the genotypes TCS 01 (38.67%) and TCS 13 (25.85%). The yields of the materials evaluated exceeded the average national (460 kg ha⁻¹) and regional (560 kg ha⁻¹) production. According to these results, TCS 19 could potentially be considered a promising genetic resource for the development of cacao farming on the Pacific Coast of Nariño.

Keywords:

Afro-Colombian, agroforestry, crops, plant health, productivity.

Introduction

The world chocolate industry is growing, and international demand increases from new countries such as Angola, United Arab Emirates, Mexico, Costa Rica, and Spain; however, this market is led by few countries, resulting in price management according to particular convenience (Vásquez-Barajas *et al.*, 2018). According to the world production reported by ICCO (2022), the largest producers of cacao are Côte d'Ivoire (40%), Ghana (20%), and Indonesia (9%).

In the Americas, Ecuador's cacao production is equivalent to 4.5% of world production, while Colombia only represents 1%. In the Colombian territory, the production of dried cacao beans is around 400 kg ha⁻¹, a yield value that does not represent economic viability for producers (Rodríguez-Medina *et al.*, 2019).

The main causes of low productivity are the lack of agronomic management, small planting areas, age of plantations, lack of knowledge of planting materials appropriate for the agroecological conditions of each region, and high susceptibility to pests and diseases. This has caused producers to look for other alternatives to increase their income, among which is the establishment of illicit crops (World Cacao Foundation, 2014).

The department of Nariño (Colombia), according to data reported by the Ministry of Agriculture and Rural Development-MADR (2021), ranks sixth in cacao production nationwide, and 76% of cacao production is concentrated in the municipality of Tumaco, which is located in the southwest of Colombia on the Pacific Coast, which is characterized by having a humid tropical climate and has approximately 17 809 ha of cacao planted and the average yield does not exceed 0.466 kg ha⁻¹. This has caused producers in the region to lose interest in the crop (FEDECACAO, 2021).

In this sense, currently, in the region, research entities, such as the University of Nariño, the National Federation of Cacao Growers (FEDECACAO), and the Colombian Corporation of Agricultural Research (AGROSAVIA), have been working on changing the traditional management of the cacao production system, to increase yields without altering the organoleptic characteristics of the product that give it the quality of fine cacao with flavor and aroma typical of the area.

The agroecological conditions of the Nariño Pacific have positioned the cacao of this region as a world reference (Casa-Lúker, 2012); the cacao from Tumaco has fruity and floral aromas and flavors with notes of nuts; in 2016, it was awarded the distinction 'Best Sample of South America' for its quality and aroma in the 'Cocoa of Excellence' Contest of the Salon du Chocolat of Paris.

Consequently, under adequate technical management, this productive system has become a profitable production alternative, different from coconut (*Cocos nucifera* L.), oil palm (*Elaeis guineensis* Jacq.), and even illicit crops, so it is considered the crop of peace. In 2014 and 2017, AGROSAVIA delivered to producers four new cacao clones TCS 01, TCS 06, TCS 13, and TCS 19, identified from participatory selection on producer farms (Agudelo *et al.*, 2017) and whose agronomic behavior had been evaluated in the departments of Santander and Boyacá.

The cultivar TCS 19 presented an average annual yield of 1.8 kg tree⁻¹ and the TCS 01 of 3.3 kg tree⁻¹, the latter also stood out for presenting relatively large beans (seed index of 3 g) (Agrosavia, 2019a). Due to the potential shown by these materials in the area where they were selected (Patricia *et al.*, 2022) and wishing to know if the behavior is similar in other regions of the country, the present research aimed to assess the agronomic, productive, and sanitary behavior of four cacao clones (TCS 01, TCS 06, TCS 13, and TCS 19) under the conditions of the municipality of Tumaco-Nariño in the initial stages of crop development.



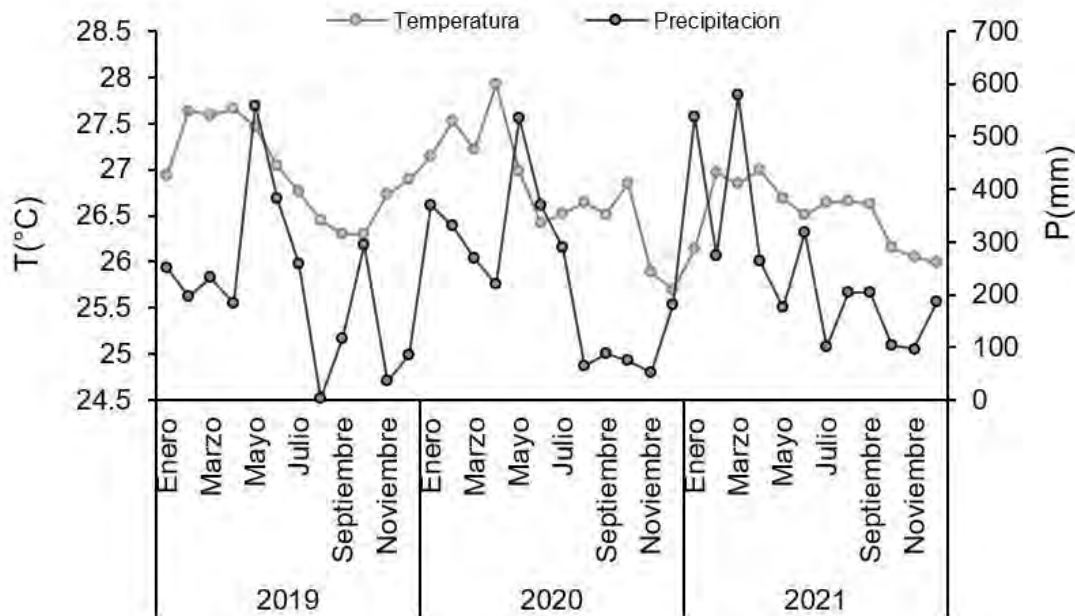
Materials and methods

Location

The study was conducted at the El Mira Research Center of the Colombian Corporation of Agricultural Research-AGROSAVIA, located in the municipality of Tumaco (Nariño, Colombia), geographical coordinates: -77° 41' 22" north latitude and 1° 32' 58", west longitude and altitude of 16 m, Holdridge life zone: Tropical Rainforest (Bacca-Acosta *et al.*, 2021).

According to data from the IDEAM climate station located in the El Mira RC., it was observed that during the first semesters of each year, there is greater rainfall (183.6 mm to 578 mm) and high temperature (26.4 °C to 27.9 °C), the minimum monthly relative humidity was 64.66%, maximum relative humidity of 98.65% and average solar brightness for the years 2012 to 2019 of 695.61 h year⁻¹ (Figure 1).

Figure 1. Annual climatic conditions of temperature and precipitation from 2019 to 2021 in the municipality of Tumaco-Nariño, Colombia.



Genotypes evaluated

Four regional cacao genotypes, TCS 01, TCS 06, TCS 13, and TCS 19, and the commercial cultivar Imperial College Selection 95 (ICS 95), which is the most cultivated in the region, were evaluated; they were grafted in the field on the rootstock IMC 67. The most relevant characteristics of each genotype are presented below (Table 1).



Table 1. General characteristics of the five genotypes established in the field.

Characteristic	TCS 01	TCS 06	TCS 13	TCS 19	ICS 95*
Pod shape	Ovate	Elliptical	Oblong	Elliptical	Elliptical
Immature fruit color	Red	Red	Red	Red	Red
Sexual compatibility	Self-compatible	Self-incompatible	Self-compatible	Self-compatible	Self-compatible

* = commercial control (Agudelo *et al.*, 2017; Agrosavia, 2019a, 2019b; Jaimes *et al.*, 2021).

For the assessment of the materials, an experimental plot was established in June 2018 in an area of 0.7 ha under conditions of agroforestry arrangement; the cacao planting distance was 3.5x3.5 m in a triangle, for a density of 704 plants ha⁻¹. The forest species Colombian mahogany (*Cariniana pyriformis* Miers) was used as a permanent shade, planted in double furrows, with a distance of 4 m between plants and 16 m between furrows for a density of 324 trees ha⁻¹.

Cultural tasks of plot management, training pruning (especially the first year) and phytosanitary pruning, control of weeds with scythe every three months, and removal of weeds around the plant prior to fertilization according to soil analysis were carried out (Toala *et al.*, 2019). The soil was characterized by a loam-clay texture, pH of 5.89, and organic matter content of 1.99 g 100 g⁻¹.

Experimental design

The trial was established in a randomized complete block design with four repetitions, where four genotypes, TCS 01, TCS 06, TCS 13, and TCS 19, plus the commercial control (ICS 95) were evaluated. The experimental unit consisted of 20 plants, and the six central trees were used as a useful plot.

Variables recorded

Seven productive and phytosanitary variables were measured, which were recorded every 15 days from 2019 to 2021. Within the production components, the number of ripe and healthy pods produced by genotype, number of seeds per pod, and weight of dried bean produced per tree (kg tree⁻¹) were quantified.

The following indices were calculated: bean index (BI), which is defined as the average weight of 100 dried and fermented beans chosen at random, for this four samples of 100 cacao beans were weighed, the average of the weights was calculated and divided by 100 beans to find the average weight per dried cacao bean (Solís Bonilla *et al.*, 2018) and the pod index (PI): for the calculation of the PI, NTC1252, 2021 was taken into account, in which this index is defined as the number of fruits required to obtain one kilogram of dried cacao beans, in this trial 20 pods of each clone were used per repetition.

In addition, the incidence of frosty pod rot (*Moniliophthora roreri*) and black pod (*Phytophthora* sp.) was determined by counting affected pods and applying the incidence percentage formula (equation 1). Incidence (%) = (total pods with symptoms) / (total pods harvested) * 100 (equation 1), this variable was also evaluated every 15 days for a period of 36 months.

Statistical analysis

Analysis of variance was performed at a significance level of 0.05 to determine the effect of genotype on production variables and health status. The Glimmix procedure was used to analyze the variable of percentage of pods affected by *M. roreri* and *Phytophthora* sp., for the data on the number of pods, the analysis was adjusted to the Poisson distribution.

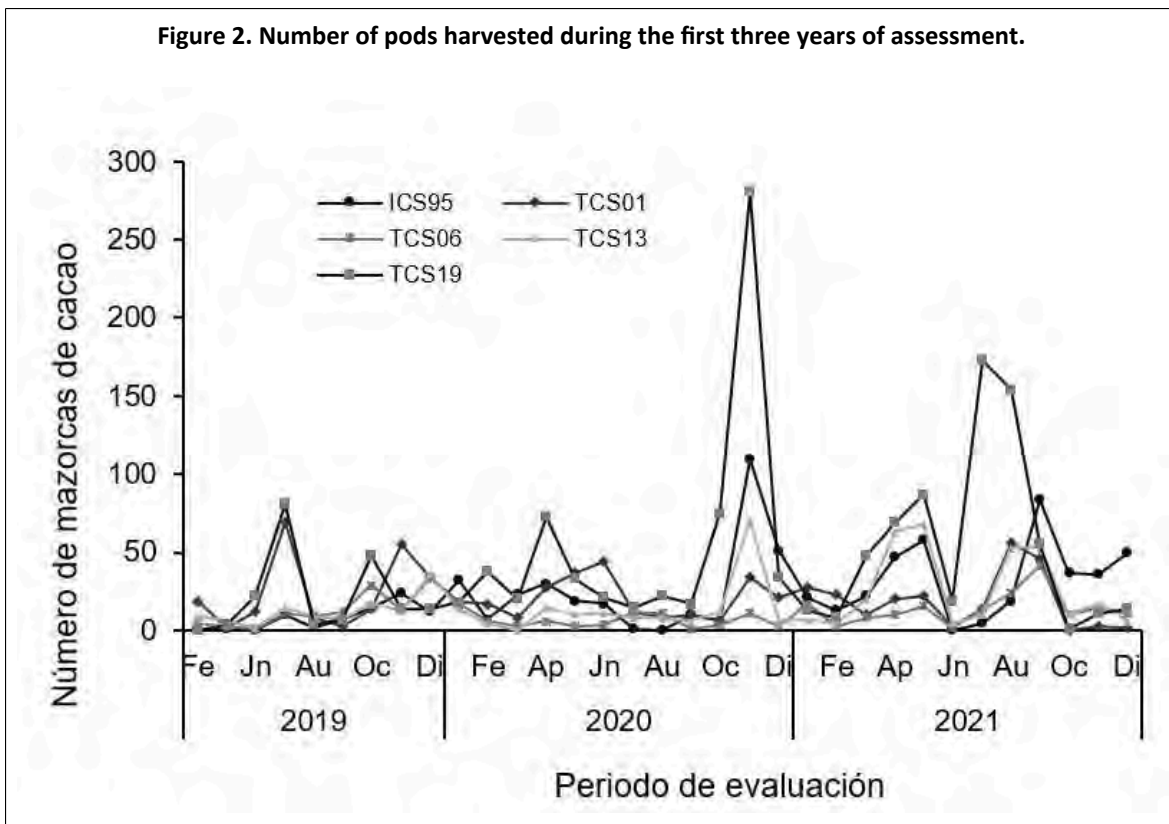
For the yield variables, the effect of the interaction between genotype and harvest year was evaluated using the Glimmix procedure and the correction of compound symmetry. In all cases,

Tukey's multiple comparison test was used. The information was analyzed using the SAS 9.4 software.

Results and discussion

Evaluation of the number of healthy pods harvested

Next, the initial behavior of the variable of the number of healthy cacao pods produced each year is presented. Two harvest peaks were observed, unlike the first year, the highest values occur in the second semester. In addition, the increasing trend of the productive level is evident, this is to be expected because it is a young plantation, and its production will increase until reaching physiological maturity approximately between five and seven years (Wuellins, 2019) (Figure 2).



Assessment of agronomic indices

In the first year, the materials TCS 19 and TCS 01 obtained the highest values of pod production, presenting values of 48 and 81 healthy pods year⁻¹, respectively. In the second year, the genotype TCS 19 was again the most relevant, in the second semester, it produced up to 281 healthy pods on average, followed by ICS 95 (110 pods), TCS 13 (70 pods) and TCS 01 (44 pods).

In the third year, TCS 19 stood out once again and produced 173 healthy pods on average, followed by ICS 95 (84 pods), TCS 13 (68 pods), and TCS 01 (53 pods). In relation to this, similar data were reported by Agudelo *et al.* (2023), who assessed different genotypes in four localities of the natural subregions Montaña Santandereana and Magdalena Medio in northeastern Colombia, concluding that TCS 19 and TCS13 presented higher yields compared to the commercial control ICS95.

The results showed the superiority in terms of production of the genotype TCS 19 in the three years of evaluation, it is inferred that it is an early flowering material (18 months) compared to the

other materials evaluated, this characteristic allows it to evade high levels of infection and favors its productivity. For its part, TCS 06 presented the lowest production values, which is probably due to its self-incompatibility condition (Jaimes *et al.*, 2021).

Considering these results and what was mentioned by AGROSAVIA (2019b), it is suggested that in future assessments, the material TCS 06 should be planted in a controlled manner together with genotypes such as TCS 01 and TCS 19 to favor fertilization and thereby improve the production of pods.

In the analysis of variance, significant differences ($p < 0.05$) were detected between clones regarding the number of seeds pod^{-1} (NS), bean index (BI), and pod index (PI) (Table 2). In relation to NS pod^{-1} , the genotypes TCS 06 and TCS 13 were the most outstanding since they presented the highest values, 44 and 43 seeds pod^{-1} , respectively.

Table 2. Results of agronomic indices in the four genotypes evaluated and commercial control.

Clone	NS		BI		PI	
	Mean	Group	Mean	Group	Mean	Group
TCS 01	34.56	B	2.68	A	11.41	B
TCS 13	43.11	A	1.94	AB	13.8	AB
TCS 06	43.68	A	1.86	AB	13.68	AB
TCS 19	34.35	B	1.66	B	18.69	AB
ICS 95	34.03	B	1.25	B	21.7	A

NS= number of seeds; BI= bean index; PI= pod index. Means with different letters in the same column are statistically different (p -value < 0.05).

The results of TCS 06 regarding this variable exceed the general average of 43.5 beans obtained in the morphological characterization research of 104 cacao genotypes evaluated in the municipality of Tumaco, Nariño (Ballesteros, 2011). In another research conducted in Ecuador, in four promising genotypes, the materials TCS 06 and TCS 13, in the number of seeds, were only surpassed by the clone INIAPT 185, in which an average number of 50 seeds pod^{-1} was reported (Sotomayor-Cantos *et al.*, 2017).

As for the BI, it ranged between 1.25 g and 2.68 g, with the genotype TCS 01 having the highest value and ICS 95 having the lowest. With respect to TCS 13, TCS 06, TCS 19, and ICS 95, they did not present significance in this variable (Table 2). However, the values obtained by these materials, except for ICS 95, exceeded the general average weight of 1.45 g/bean reached in the study by Ballesteros *et al.* (2021) in the same locality.

Similarly, in relation to this, Sotomayor-Cantos *et al.* (2017) reported that the best material evaluated obtained a value of 1.53 g almond^{-1} for the cultivar INIAPT 484, a value that is lower than the interval of 1.66 and 2.68 g almond^{-1} in which the values of the TCS genotypes are found. When comparing the data of this research with the results obtained by AGROSAVIA, TCS 01 is also characterized by presenting a relatively high bean index (3 g bean^{-1}) (Agrosavia, 2019a, 2019b; Agudelo *et al.*, 2017; Jaimes *et al.*, 2021).

Nevertheless, it should be considered that given the amount of mucilage and the size of the bean they present, particular management is required for postharvest processes such as fermentation and drying time. Therefore, it is not recommended to mix it with other materials during this stage. Regarding the PI, the most relevant genotypes were TCS 01 (11.41 pods), TCS 13 (13.8 pods), and TCS 06 (13.68 pods) since they presented the lowest values, they were also statistically similar, while ICS 95 (21.7 pods) and TCS 19 (18.69 pods) presented the highest data.

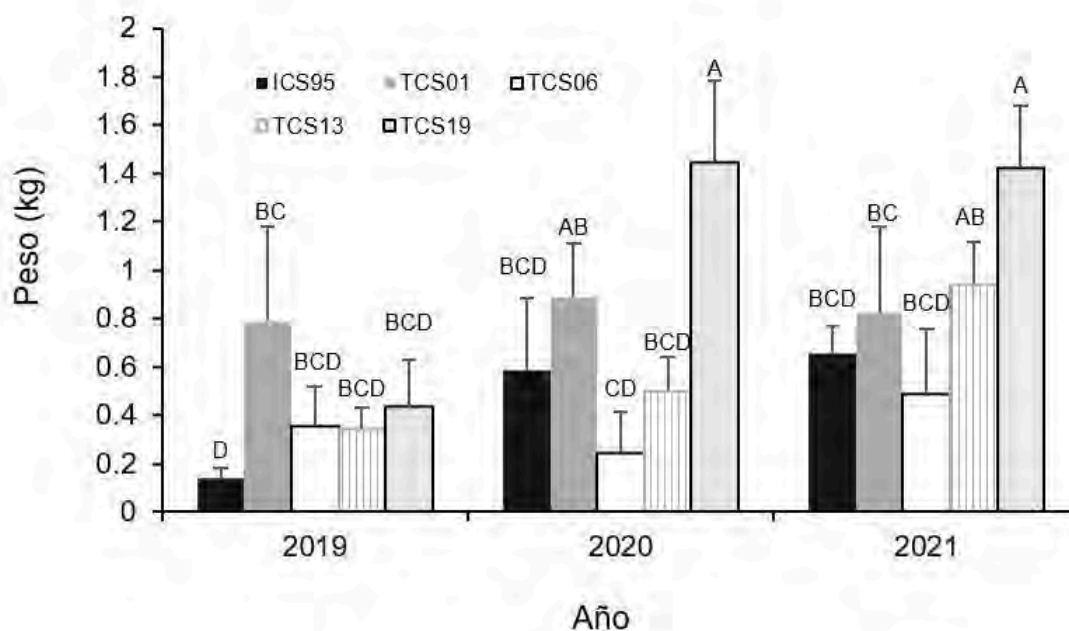
Therefore, according to these results, it can be established that genotypes TCS 01, TCS 13, and TCS 06 require approximately between 12 and 14 pods to obtain one kg of dried cacao beans, while for TCS 19 and ICS 95, approximately 19 to 22 pods would be needed. Regarding ICS 95,

similar results were described by Quintana *et al.* (2018), who determined that, on average, the genotype ICS 95 has a PI of 20 and a BI of 1.4 g.

Annual production assessment (kg dried bean tree⁻¹)

During the three years of assessment, the genotypes showed significant differences (p -value < 0.05) in the variable of production kg dried bean tree⁻¹ (Figure 3). During the first year of monitoring, the four Agrosavia materials presented average values between 0.34 kg tree⁻¹ and 0.79 kg tree⁻¹, surpassing the commercial control ICS 95 (0.14 kg).

Figure 3. Production kg dried bean tree⁻¹ of the five genotypes assessed during the first three years of production. Means with different letters are statistically different (p -value < 0.05)



Disease incidence

In the second year, the genotypes TCS 01 (0.887 kg) and TCS 19 (1.44 kg) presented higher average values with respect to the rest of the materials evaluated, and in the third year, the latter genotype was again superior with an average production of 1.44 kg tree⁻¹ (Figure 3).

The clone TCS 13 (0.94 kg), although it did not present significant differences compared to the other materials evaluated, its productive behavior should be highlighted since the average production value is relatively good in relation to the data reported for the region, 309.9 kg ha⁻¹ (Agronet, 2021).

On the other hand, to increase its production, it is recommended to plant it together with the clone TCS19 since, despite being self-compatible, it has a low fertilization rate (35%); therefore, it is relevant to consider planting arrangements that contribute cross-pollination and fertilization of flowers to increase the production of pods and with it the profitability of the productive system (Agudelo *et al.*, 2017).

In terms of production, the material TCS 19 (1.44 kg) was statistically superior in the third year of production compared to the materials TCS 13 (0.94 kg), TCS 01 (0.82 kg), TCS 06 (0.49 kg), the latter three do not differ statistically from the commercial control ICS 95 (0.66 kg) (Figure 3).

The results of this analysis indicate that the genotypes of Agrosavia could be established on the Pacific Coast of Nariño because their production could be equal to or slightly higher than the commercial control of the study region.

In agreement with the above and considering the planting density, 816 trees ha⁻¹ (3.5 m between trees x 3.5 m between furrows), it can be estimated that for the third year, the approximate average yield in kg dried bean ha⁻¹ of the materials TCS 19, TCS 13, and TCS 01 could be around 1,175, 767.1 and 669.12, respectively, values that are higher than those reported by Agronet (2021) in mature plantations for the municipality of Tumaco (309.9 kg ha⁻¹).

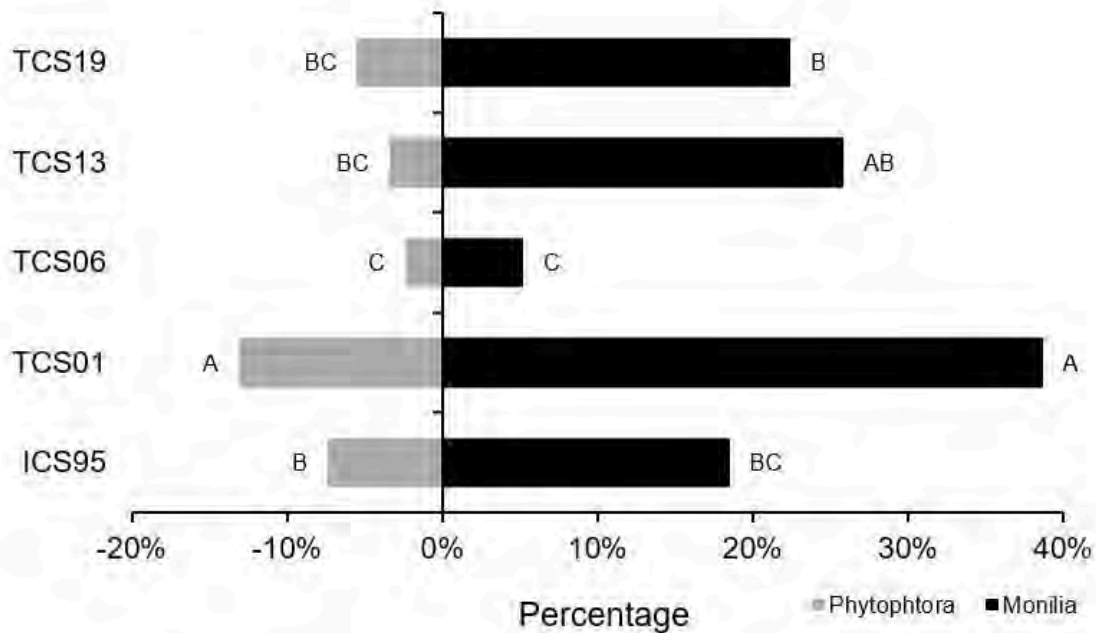
Similarly, Ballesteros *et al.* (2021) pointed out that in this area, the average yield is 560.30 kg ha⁻¹ and that these productivity values are probably due to old plantations and the absence of intensive management techniques, while the MADR (2021) reported average yields of 230 kg ha⁻¹ for Nariño in 2020.

The inadequate management in phytosanitary terms of the cacao crop is one of the factors that has promoted the expansion of the agricultural frontier and a significant loss of the tropical rainforest since the low yield and the high incidence of pests and diseases have caused producers to seek new areas of work (Abdulai *et al.*, 2020).

In this sense, the percentage of incidence of the main diseases present during the third year of production is presented below. Statistically significant differences ($p < 0.05$) were observed between the materials. *M. royeri* was the disease that occurred most frequently, and the incidence ranged from 5.2% to 38.67%, while for *Phytophthora* sp., the range of impact was between 2.39% and 13.12%.

The genotype TCS 01 presented the highest incidence values for *M. royeri* (38.67%) and *Phytophthora* sp. (13.12%), and TCS 06 exhibited the lowest values of impact by the two pathogens: *M. royeri* (5.22%) and *Phytophthora* sp. (2.39%) (Figure 4).

Figure 4. Incidence of *M. royeri* (%) and *Phytophthora* sp. (%) in the five genotypes evaluated during the third year of production. Means with different letters in the column are statistically different (p -value ≤ 0.05).



TCS 13 was the second material with the highest degree of impact by frosty pod rot (25.85%) and, together with TCS 19, presented a similar behavior in relation to *Phytophthora* sp. (3.41%)

and 5.48%, respectively). Regarding the commercial control ICS 95, the results show that the degree of impact by *M. rozeri* and *Phytophthora* sp. was similar to TCS 19 and TCS 13.

The incidence of *M. rozeri* in the third year of the trial ranged from an average minimum of 5.22% quantified in the cultivar TCS 06 and a maximum value of 38.67% in the cultivar TCS 01; this behavior of the TCS genotypes is relevant when referencing them with 11 hybrid families of cacao, obtained through crosses between parents PA 169, UF 273, SCA 6 POUND 7, RIM 117 and ICS 1, since these in the fourth year of the evaluation, presented a range of incidence of *M. rozeri* that ranged between 10.06% and 71.76% (Solís-Bonilla *et al.*, 2018).

These results allow us to point out the relevance of constant management of *Phytophthora* sp. and especially of *M. rozeri*, since the environmental conditions of the municipality of Tumaco, due to the high rainfall and relative humidity, favor the proliferation of these pathogens.

In this regard Solís-Bonilla *et al.* (2018) mention that, in the tropics, the cacao crop is affected by the fungi *M. rozeri* and *M. pernicioso*, causing losses of up to 90% of production, in some cases leading cacao farmers to abandon their crops. Másmela-Mendoza (2019) mentions that the agroclimatic conditions of high temperatures, humidity, and precipitation can positively influence the development of these pathogens, giving particular relevance to cultural work within the production system.

Phytopsanitary management is essential to avoid significant losses since inadequate inoculum removal increases the incidence of the disease (Sánchez-Mora *et al.*, 2015); in Venezuela, Brazil, West Africa, and Asia, due to inadequate management, losses between 50% and 90% of production have been reported (Meinhardt *et al.*, 2008; Ploetz, 2016; Trevizan and Marques, 2002). The control of this disease through phytopsanitary pruning can reduce the amount of inoculum that generates basidiocarps (Hernández-Villegas, 2016).

Given the importance of this production system in the department of Nariño, which is characterized by its diversity of thermal floors, it could be interesting to know the behavior of these materials (TCS 01, TCS 13, and TCS 19) in drier areas such as the Nariñense mountain range, which has a tropical dry ecosystem where the incidence of diseases may be lower and can favor productive yield.

In this sense McMahon *et al.* (2018) assessed 28 regional cacao clones in three provinces of Sulawesi in Indonesia and found that some cacao materials were susceptible to *Phytophthora* sp. in certain evaluation sites, while in others they were tolerant, noting that each locality must have its own technological management since the materials express their phenotypic characteristics according to the environment and agronomic management.

Conclusions

During the assessment period, it could be established that the material TCS 19 had better productive behavior compared to the rest of the AGROSAVIA materials and the commercial control ICS95. These results considerably exceeded the average national and regional production; 460 kg ha⁻¹ and 430 kg ha⁻¹, respectively, so it could be considered a promising genetic resource for development in the cacao farming of the Pacific Coast of Nariño.

The best NS pod⁻¹ indices were obtained by the genotypes TCS 06 and TCS 13 with 44 and 43 seeds, respectively, with respect to the BI, the best materials were TCS 01 with 2.68 and TCS 13 with 1.94, and in relation to PI, the most relevant material was TCS 01 with a value of 11.41.

The incidence of the diseases *Phytophthora* sp. and *M. rozeri* is related to the environmental conditions of the municipality of Tumaco, therefore, it is necessary to carry out an integrated management in the crop that reduces the proliferation of these pathogens and allows increasing the yield of the crop.

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Assessment of four genotypes of cacao in Nariño, Colombia

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 July 2023
Date accepted: 01 September 2023
Publication date: 16 October 2023
Publication date: October 2023
Volume: 14
Issue: 7
Electronic Location Identifier: e3331
DOI: 10.29312/remexca.v14i7.3331

Categories

Subject: Articles

Keywords:

Keywords:

Afro-Colombian
agroforestry
crops
plant health
productivity

Counts

Figures: 4

Tables: 4

Equations: 0

References: 30

Pages: 0