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Research article

Characterization of *Coffea arabica* L. parent plants and physicochemical properties of associated soils, Peru

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HIGHLIGHTS

- Identification and characterization of 100 coffee parent plants.
- The coffee varieties Típica and Caturra roja were present in all five provinces.
- The incidence of coffee rust (*Hemileia vastatrix* Berk & Br.) was 4.90%.
- The soils presented favorable physicochemical properties for coffee cultivation.

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ABSTRACT

It is important to carry out the morphological characterization of coffee parent plants and the physicochemical properties of the associated soils in the Amazon region, Peru, in order to achieve germplasm conservation. One hundred coffee mother plants were identified and located in five provinces of the region and evaluated according to morphological descriptors such as stipula shape, young leaf color, leaf shape, leaf apex shape, young shoot color, leaf color, fruit color, fruit shape, mature leaf color, and rust incidence percentage. In the plots where the parent plants were located, soil sampling was carried out to determine the physical and chemical properties. The varieties with the greatest presence in the five provinces were Típica and caturra roja, with the greatest number of specimens reported for the province of Bagua. The predominant stipule shape was triangular (91%), lanceolate leaf shape (60%) and red fruit color (90%). Bongará reported the lowest incidence of yellow rust, as well as the Mundo Novo Rojo variety. Soil pH ranged from acidic to neutral values, low electrical conductivity, high organic matter content, low phosphorus content, high potassium levels and medium cation exchange capacity. The predominant textural class was sandy loam. The physical and chemical characterization of the soils under study show favorable ranges to encourage the best development of coffee cultivation.

1. Introduction

Coffee is one of the most traded commodities in the global market and the most consumed beverage (Torres et al., 2020). In addition to being the livelihood of 25 million families worldwide (Espinoza et al., 2021), which places it in second place after oil (Proyecto Café & Clima, 2017).

In Peru, coffee is produced in 210 rural districts located in 47 provinces in 10 regions, with a cultivated area of 350 000 ha distributed in three zones, being the most appropriate region to obtain the best yields with high quality the one located in the jungle zone, under a tropical ecology (Andina, 2018; Junta Nacional del café, 2020). During the last few years, Peruvian coffee has had a great growth placing it in the first positions of specialty coffees (Dilas-Jiménez and Cernaqué, 2021).

Peruvian coffee reached more than 40 countries in the period January to July 2021, with the United States leading the list with 25.9% of shipments worth US$40.8 million, followed by Germany (US$12.3 million), Colombia (US$14.7 million), Canada (US$12.3 million) and Belgium (US$11 million) as destinations; these countries represent

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67.8% of the total export market (Comex Peru, 2021). A nivel de la región Amazonas también destaca el café como uno de sus principales cultivos dentro de la agricultura (Milla et al., 2019), con un incremento de producción anual de 7.6% en el 2021 (INEI, 2021). En el primer periodo del año 2021, Amazonas ocupó el cuarto lugar a nivel nacional en cuanto a exportaciones con un valor de 15.1 millones de dólares (Comex Perú, 2021).

In the Amazon region there are coffee varieties with potential characteristics to be considered as parent plants and to conserve their germplasm. The process of identification and characterization allows the selection of varieties that show characteristics such as productivity and tolerance to diseases and are the subject of research (Julca et al., 2019; Sánchez et al., 2019). In addition, it is important to know the soil characteristics in which they develop and allow adequate growth and express their maximum potential (Mora, 2019).

In recent years, 45 pathogenic strains of *Hemileia vastatrix* Berk & Br (coffee rust) have been reported, which react with resistance genes generated by coffee plants and increased up to 30% in aggressiveness over time (Torres et al., 2020). Thus, over the years, special interest has been placed on discovering different coffee ecotypes that express some tolerance to this pathogen (Chain-Guadarrama et al., 2019).

In this context, it is important to identify parent plants in order to achieve their conservation. Studies worldwide and in Nicaragua show that, from the agroindustrial point of view of coffee, the most important morphological characteristics are: plant height, stem diameter, presence of productive branching, length of bandolas and number of productive buds (Suazo, 2020).

At the national level in the provinces of Jaén and San Ignacio, an identification and morphological characterization of the different coffee varieties was carried out using 21 phenotypic descriptors, which allowed the identification of 12 coffee varieties: Bourbon, Catimor cogollo rojo, Catimor cogollo verde, Caturra amarilla, Caturra roja, Catuai rojo, Colombia, Costa Rica 95, Geisha, Mundo Novo, Pache y Típica (Coronel, 2019).

However, at the national level, to date there is no research oriented to the identification and characterization of coffee mother plants and their associated soils, so the main objective of the study was to carry out the morphological characterization of coffee mother plants and the physicochemical properties of the associated soils in the Amazon region of Peru in order to conserve the genetic material and to know the soils for their optimal development.

2. Materials and methods

2.1. Location of the study area

The research was carried out in five provinces of the Amazon region: Rodriguez de Mendoza, Bagua, Luya, Utcubamba and Bongará, where parent plants with characteristics of resistance to coffee rust were identified.

The province of Rodríguez de Mendoza is located at 6°23′44.41 ″S and 77°28′56.03 ″W at 1597 masl, with maximum temperatures of 22 °C and minimum temperatures of 12 °C, with an annual precipitation of 2059 mm/year and a relative humidity of 83% (CLIMATE-DATA.ORG, 2021). The province of Luya is located at coordinates 6° 8′13.06 ″S and 77°57′1.19 ″W at 2303 masl, with a maximum temperature of 18.1 °C and a minimum of 10.8 °C with 2031 mm/year of precipitation and 73% relative humidity (CLIMATE-DATA.ORG, 2021). The province of Bagua is located at 5°38′14.19 ″S and 78°31′52.75 ″W at 424 masl, with a maximum temperature of 36.8 °C and a minimum temperature of 14 °C (SENAMHI, 2021a), 75.58% relative humidity and 2319 mm/year of precipitation (CLIMATE-DATA.ORG, 2021). The province of Utcubamba is located at 5°45′33.24 ″S and 78°26′36.23 ″W at 465 masl, has a maximum temperature of 31 °C and a minimum temperature of 14.5 °C (SENAMHI, 2021b), a relative humidity of 81 % and 2319 mm/year of precipitation (CLIMATE-DATA.ORG, 2021) and the province of Bongará is located at coordinates 5°56′37. 04 ″S and 77°58′37.13 ″W at 1315 masl, with a maximum temperature of 25 °C and a minimum temperature of 14 °C (SENAMHI, 2021c), a relative humidity of 72.6 % and 154 mm/year of precipitation (CLIMATE-DATA.ORG, 2021).

Table 1. Methods used to determine the physical and chemical properties of soils.

Soil Properties	Parameters	Determination method
Physicals	Textural class % sand, silt and clay	Bouyoucos Hydrometer
Chemicals	Hydrogen potential (pH)	Potentiometer method
	Electrical conductivity (EC) (dS/m)	Reading of the aqueous extract in a 1:1 soil water ratio.
	Phosphorus (P) (ppm)	Modified Olsen's method. NaHCO3 extract 0.5 M, Ph 8.5
	Potassium (K) (ppm)	Ammonium acetate extraction method.
	Organic Matter (% OM)	Walkley and Black method
	Cation Exchange Capacity (CEC) (meq/100g)	Saturation with ammonium acetate (CH3–COOOCH4) N; pH 7.0
	$Al^{+3} + H^{+1}$ (meq/100 g)	Atomic Absorption Spectrophotometry
	Mg (meq/100 g)	Atomic Absorption Spectrophotometry
	Na (meq/100 g)	Atomic Absorption Spectrophotometry
	Ca (meq/100 g)	Atomic Absorption Spectrophotometry

The provinces where the parent plants were located present shade coffee production using plantations such as guaba (*Inga feuilleei* DC.), banana (*Musa paradisiaca* L.), avocado (*Persea americana* Mill), Eucalyptus torreliana (*Eucalyptus torelliana* F. Muell.), Pashaco (*Schizolobium* spp) (Chinguel, 2017).

2.2. Identification and location of parent plants

The identification of 100 parent plants distributed throughout the five coffee-producing provinces of the Amazon region was carried out; these were coded and recorded on evaluation cards. For the identification, it was taken into account that the plants were less than 10 years old and with good productivity and coffee rust severity degree from 1 to 2 as tolerance indicators (Sánchez, 2017; Arévalo et al., 2021). Two plants per variety of five years and older were identified (Típica, Pache, Caturra, Catuaí, Borbón and Mundo Novo), locating the coordinates and height above sea level with the help of a GPS.

2.3. Evaluation of morphological descriptors

The characterization of coffee plants was based on eight morphological descriptors: stipula shape, young leaf color, leaf shape, leaf apex shape, young shoot color, leaf color, fruit color, fruit shape, established by the International Plant Genetic Resources Institute (IPGRI, 1996) and mature leaf color (Cárdenas, 2007).

2.4. Evaluation of coffee rust incidence

The information collected was through field observation in each of the districts under evaluation. The evaluation of rust incidence was carried out in each of the selected coffee matrix plants. For this, the first step was to collect 10 leaves for each matrix plant from the lower, middle and upper part (3-4-3 leaves, respectively). Then, the incidence was determined using the formula: number of leaves with rust/total leaves sampled per 100 (SENASA, 2013).

2.5. Determination of physical and chemical properties of the soil

Soil sampling was carried out in the 5 provinces where the parent plants were identified, the collection was done as a quadrant with 5 sub

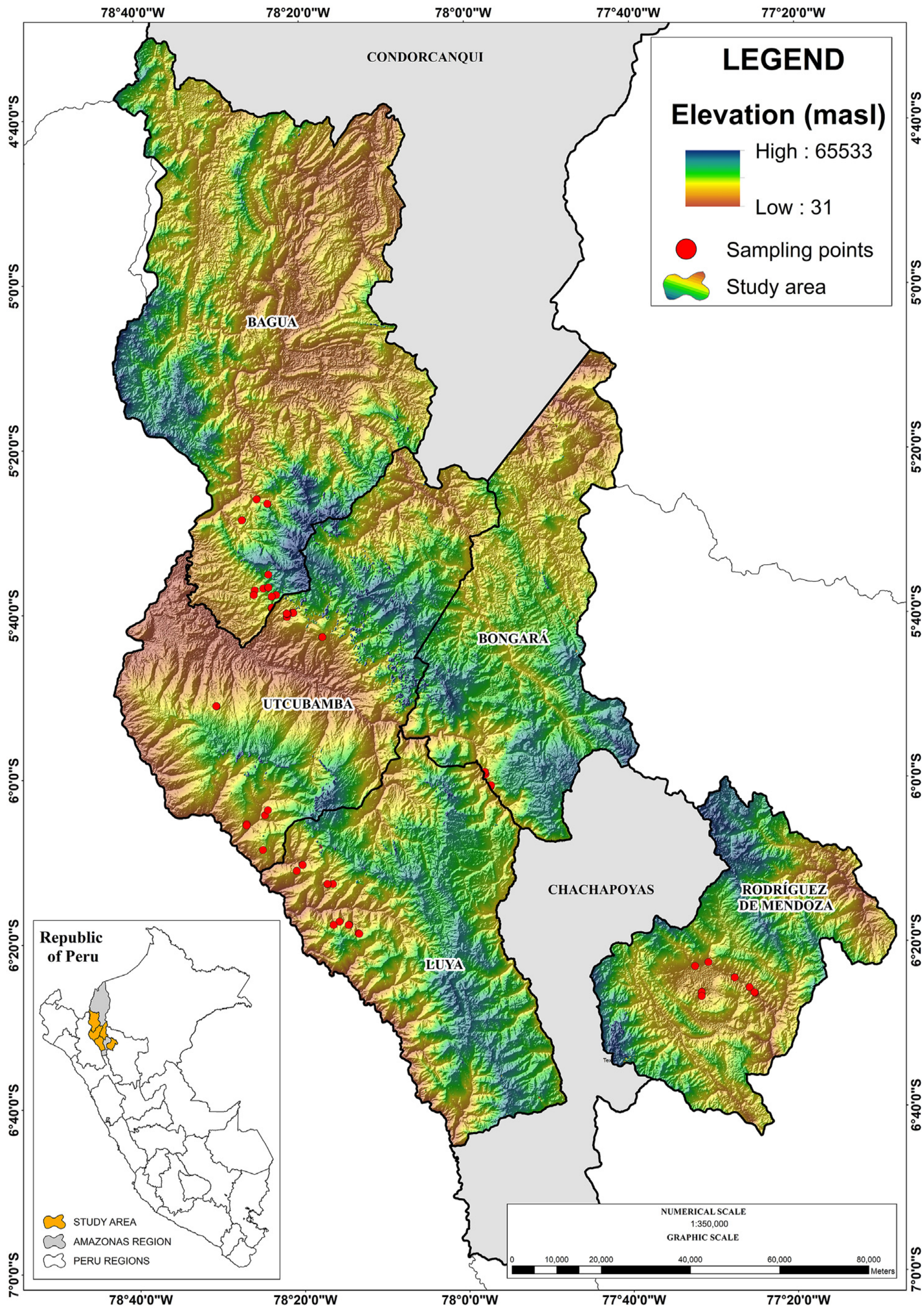

Figure 1. Identification of 100 coffee parent plants in 5 provinces of Amazonas.

samples per point, the samples were collected under the canopy of the coffee plants, the methodology proposed by Mendoza and Espinoza (2017) was followed. The samples were analyzed at the Soil and Water Research Laboratory (LABISAG) of the Toribio Rodríguez de Mendoza Nacional University of Amazonas, recording the following parameters (Table 1).

2.6. Design and data análisis

The design used in the evaluation of the physicochemical parameters of the soils was the Completely Randomized Design with different number of experimental units (soil sampling points), the five provinces represented the treatments, Rodriguez de Mendoza with six experimental units, Bagua with 11, Luya with eight, Utcubamba with eight and Bongará with 6 experimental units, making a total of 39 experimental units. The degrees of freedom of the error were 34.

For the evaluation of the morphological characteristics, a frequency analysis was carried out. For the physicochemical characteristics of the soil associated with the coffee plants, the assumptions of normality and homogeneity of variances were first verified, then an analysis of variance and Tukey's multiple comparisons test at 95% confidence was performed for the characteristics that met these assumptions. The characteristics that did not meet the assumption of normality were analyzed with the Kruskal Wallis nonparametric test. In addition, a graph was made to determine the relationship between the Cation Exchange Capacity and the percentage of Clay. The statistical software InfoStat/professional v. 2018 was used.

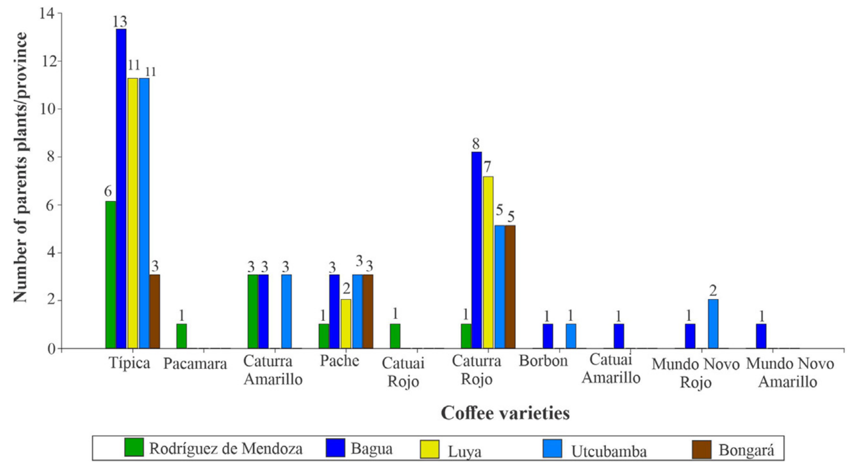

Figure 2. Distribution of parent plants by province.

3. Results and discussion

3.1. Identification and location of parent plants

Having the identification and location of coffee mother plants is a previous and important activity to determine the soil characteristics associated with these plants, and to identify the best physical and chemical properties for coffee nutrition and also to reduce fertilization needs (Sancho et al., 2019). A total of 100 coffee mother plants were identified in five provinces of the Amazon region (Figure 1).

The most abundant varieties present in the five provinces were Típica with 44 specimens and Caturra rojo with 26. The province with the highest number of mother plants was Bagua with 31 specimens (Figure 2).

In the province of Rodríguez de Mendoza, a reduced number of coffee mother plants was found, this could be associated with the fact that this province has abundant rainfall and more shade trees in its cultivation areas (Huamá n, 2021). This causes a higher incidence of diseases such as coffee rust that leads to the renewal of these plants for new resistant varieties by farmers (Gamarra et al., 2015).

3.2. Morphological characteristics

Figure 3a shows that for stipule shape, the triangular shape predominated with a percentage of 91%, average of 100 parent plants evaluated. Julca-Otiniano et al. (2018) characterized three coffee cultivars (Catimor, Colombia and Costa Rica 95) with 50 replicates in the Junín region, Peru, obtaining a triangular stipule shape. On the other hand, Julca et al. (2019) reported 33% triangular stipule shape for the agronomic characterization of coffee accessions in the province of San Ramón, Peru.

Regarding the color of the young leaves, the predominant color was bronze with 55%, followed by green with 43% (Figure 3b), the predominant leaf shape was lanceolate with a percentage of 60% (Figure 3c) and for the variable apex shape, the highest percentage corresponded to the apiculate shape (Figure 3d). These results were superior to those reported by Calle (2009), who evaluated 20 coffee varieties from the Tropical Agricultural Research and Higher Education Center (CATIE), finding 23% predominance of green color and 18% bronze, in conditions of Panama and Costa Rica, and similar to the results of Suazo (2020) with respect to green color, who found 46.7% for the Catrenic variety in Nicaragua.

Similar results were reported by Cosme-De La Cruz et al. (2021) who evaluated five coffee varieties (Colombia, Catimor, Limani, Catuai and Caturra) in conditions of Tingo Maria Peru, where they reported that 100% of these varieties studied presented lanceolate leaf shape and apiculate apex shape.

The evaluation of young shoot color showed a higher percentage of green color (54%) (Figure 3e), Suazo (2020) found results higher than those of this research with 91.70% of shoot green color.

Green mature leaf color predominated in the evaluation of coffee variety identification with a total of 89% (Figure 3f), these results were higher than those reported by Coronel (2019) who found 33.33% green color in mature leaf for 12 varieties identified and evaluated in the province of Jaen, Peru.

In the evaluation of fruit color, red color predominated with 90% (Figure 3g), superior results were reported by Catari (2017) who obtained 80% for this fruit color, in the morphoagronomic characterization of ten coffee cultivars in conditions of La Paz, Bolivia.

In the evaluated variable of fruit shape, the rounded shape was identified as the highest percentage with 55% (Figure 3h), different research reports different results such as Alarcón (2016), who found the oblong fruit shape for three varieties of coffee Catimor, Colombia and Costa Rica 95 in the Junín region, Peru and Sandoval and Prieto (2007) reported the ellipsoidal-spherical fruit shape for the Colombia variety in Colombian conditions. These differences in fruit shape may be due to the changing edaphoclimatic conditions of each location, coffee cultivation is affected by these changing patterns especially if they are manifested in important phenological stages of coffee such as flowering and fruit development (Parada et al., 2020).

3.3. Coffee rust incidence (%IR)

The places that showed the lowest percentages of rust incidence were the province of Bongará followed by Utcubamba and Luya with 25.45%, 32.40% and 38.50% respectively. The provinces that reported the highest incidence of coffee rust were Rodriguez de Mendoza and Bagua with 70% and 40.65% respectively. All coffee mother plants in the 5 provinces did not exceed 5% of affection and were therefore classified in grade 1 of severity. This is associated with the fact that the soils of the provinces under evaluation are in slightly acidic pH ranges close to neutrality, which are considered suitable for coffee development and decrease the susceptibility of the crop to coffee rust (Gamarra et al., 2015).

The difference found at the provincial level could be associated with the shade used in each location since it has been shown that this could have antagonistic effects on coffee rust (López-Bravo et al., 2012). In addition, climatic variables such as temperature, which is a determining factor for the germination and penetration phases of the fungus, precipitation, which contributes to dispersal conditions and the washing of uredospores, and relative humidity also play a role (Lasso et al., 2020).

The varieties that reported the lowest incidence of coffee rust were Mundo Novo Rojo (6.67%), Borbón (15%) and Catuai Amarillo (20%). The varieties with the highest incidence of coffee rust were Mundo Novo

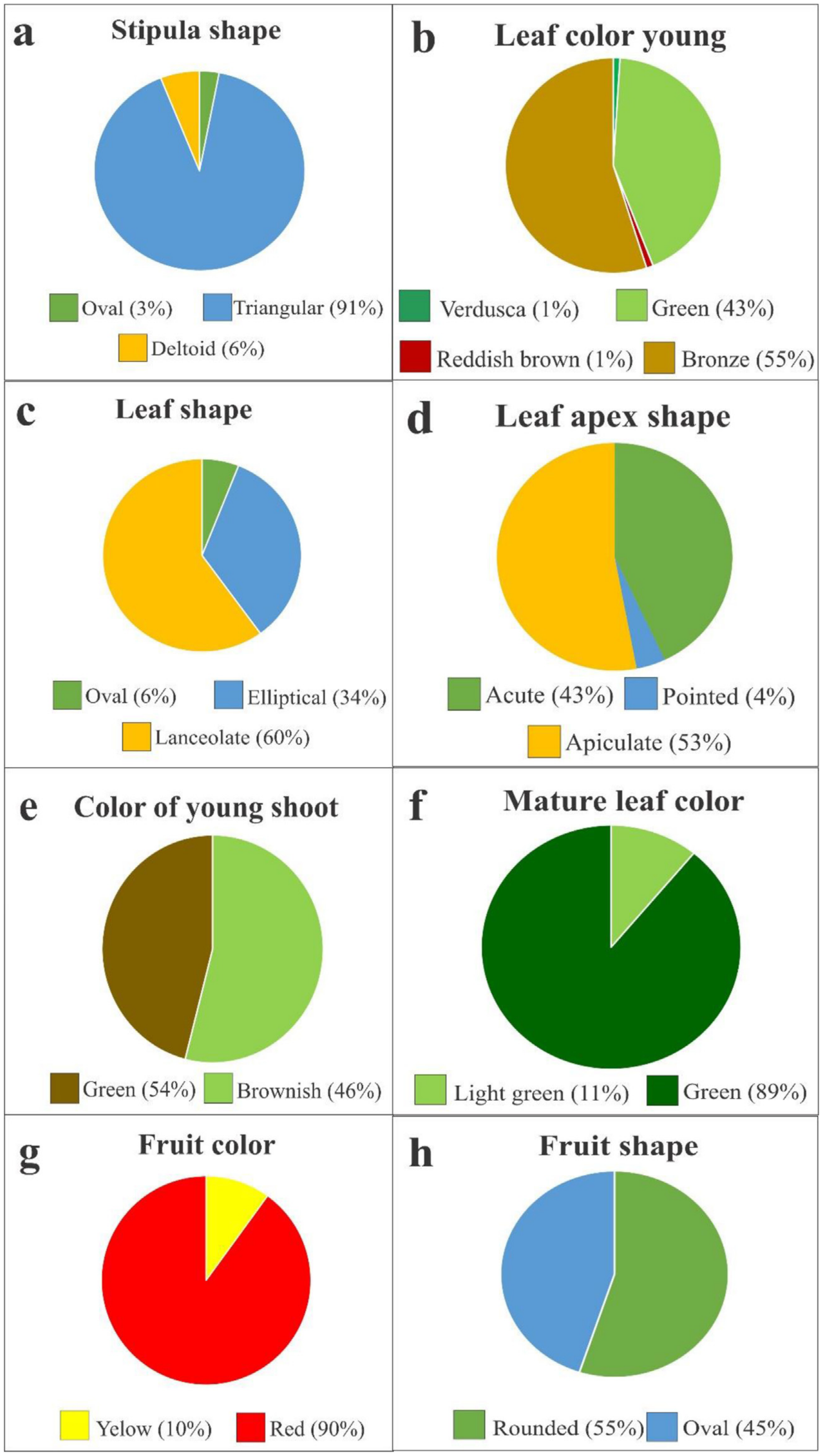

Figure 3. Morphological characteristics of coffee mother plants.

Amarillo and Pacamara (60%). The difference found at the variety level is regulated by susceptibility genes of *Hemileia vastatrix* in each variety, and the incidence can decrease or increase depending on the nutritional level of the plant (Quiroga-Cardona, 2021). This genetic resistance was transferred to *Coffea arabica* varieties through the Timor hybrid (*C. arabica* and *C. canephora*) (Bustamante et al., 2004). This hybrid has originated most of the rust resistant varieties in Latin America (Moreno and Castillo, 1984; Aguilar, 1995).

3.4. Soil characterization of coffee parent plants

The physicochemical parameters that showed a normal distribution of their data were pH, Potassium, Cation Exchange Capacity, Calcium, Magnesium, Sum of cations, Sum of bases and Base saturation ($p > 0.05$). Regarding homogeneity of variances, most of the properties complied with this assumption ($p > 0.05$), the four properties that did not comply

Table 2. Shapiro-Wilk normality test.

	pH	CE	P	K	MO	CIC	Ca^{+2}
W-stat	0.962	0.900	0.667	0.955	0.917	0.965	0.957
p-value	0.215	0.002	0.000	0.120	0.007	0.270	0.140
	Mg^{+2}	**K^{+2}**	**Na^{+1}**	**$Al^{+3} + H^{+1}$**	**SC**	**SB**	**SAB**
W-stat	0.958	0.935	0.861	0.591	0.959	0.959	0.945
p-value	0.157	0.026	0.000	0.000	0.166	0.165	0.057

Table 3. Homogeneity of variances test.

	pH	CE	P	K	MO	CIC	Ca^{+2}
Levene's statistic	1.329	2.265	2.187	0.938	1.222	3.855	3.764
Sig.	0.279	0.083	0.091	0.454	0.32	0.011	0.012
	Mg^{+2}	**K^{+2}**	**Na^{+1}**	**$Al^{+3} + H^{+1}$**	**SC**	**SB**	**SAB**
Levene's statistic	1.798	0.436	1.483	4.418	3.178	3.273	1.823
Sig.	0.152	0.781	0.229	0.006	0.25	0.023	0.147

were Cation Exchange Capacity, Calcium, $Al^{+3} + H^{+1}$ and the sum of bases (Tables 2 and 3).

Of all the parameters evaluated, pH was the one that reported significant statistical differences between provinces, with the province of Luya reporting acid values compared to those of the province of Bongará, which is in the neutral range (Table 4). The electrical conductivity values presented in the different provinces indicate that they are non-saline soils because they are in a range of 0.15–2.05 dS/m (Table 4) (Arriola et al., 2012).

The province that reported the lowest phosphorus concentrations was Utcubamba and the province that reported the highest phosphorus content was Rodríguez de Mendoza, showing significant differences between them. All provinces are in a high potassium range with values between 180 to 300 ppm (Table 4) (Garcí a-Serrano et al., 2009).

The organic matter values for the provinces are very high, exceeding 5%, and present similar values between provinces; these values influence the low aluminum content (Álvarez-S á nchez et al., 2010) as shown in Table 4. Cruz-Mací as et al., 2020 mention that organic matter values above 4% cause a decrease in aluminum saturation. These high levels of organic matter are influenced by factors such as agroforestry systems with permanent or temporary shade plants, pruning residues and continuous weeding (Márquez et al., 2020).

Cation exchange capacity values are at medium levels as they are between 16.50 to 20.20 meq/100g (Álvarez-S á nchez et al., 2010) and base saturation of the five provinces is at high levels (Table 4), due to pH values close to neutrality (Cepeda, 2020).

Vilchez et al. (2019) mencionan que los suelos apropiados para el cultivo de cafés especiales de alta calidad organoléptica, presentan una clase textural de tipo franco, pH de 5.16, materia orgánica alta de 4.40% y una capacidad de intercambio catiónico de 16.46 meq/100g, para condiciones de San Ignacio en Cajamarca, Perú. Los resultados de esta investigación indican que las cinco provincias presentan buenas características agronómicas, con potential para el desarrollo y obtención de plantas matrices ya que presentan suelos óptimos que van desde un pH de 5.77 a 6.88, materia orgánica ente 5.35 % hasta 5.72 %, con una textura de suelo franco arenosa y franco arcillo arenosa y con capacidad de intercambio catiónico de 16.50 meq/100 g y 19.31 meq/100g.

3.5. Characterization of the textural class of parent plants according to provinces

The predominant textural class was Sandy loam, which is present in all five provinces, with the highest representation in the province of Luya, followed by sandy clay loam, present in four provinces. In the provinces of Bongará and Luya, the predominant textural class was sandy loam; in the province of Rodríguez de Mendoza, two textural classes were sandy clay loam and sandy loam; in Bagua and Utcubamba, the predominant textural class was sandy clay loam (Figure 4).

The existing relationship between the percentage of clay and the percentage of cation exchange are directly proportional in four provinces, since the higher the percentage of clay the cation exchange capacity increases, due to the fact that clay particles have the largest surface area per unit volume of soil and, therefore, can contain the largest amount of cations (López et al., 2019). In contrast, this increasing trend was not observed for the Luya province (Figure 5).

These physical-chemical characteristics are favorable and determinant to ensure yield and low incidence reports of coffee rust and thus maintain important relationships between plants, microorganisms and fungi as reflected in the high content of organic matter (Baba et al., 2020).

Table 4. Physical and chemical characterization of soils associated with coffee parent plants.

Properties	Provinces				
	Bongará ($\bar{x}$ and SD)	Rodríguez de Mendoza ($\bar{x}$ and SD)	Bagua ($\bar{x}$ and SD)	Utcubamba ($\bar{x}$ and SD)	Luya ($\bar{x}$ and SD)
pH (F = 2.76, p = 0.043)	6.88 ± 0.92 a	5.89 ± 0.97 ab	5.83 ± 0.91 ab	5.77 ± 0.65 ab	5.53 ± 0.45 b
CE (H = 5.50, p = 0.2378)	0.31 ± 0.10 a	0.25 ± 0.14 a	0.2 ± 0.11 a	0.24 ± 0.16 a	0.17 ± 0.04 a
P (H = 10.0, P = 0.04)	5.60 ± 5.55 b	6.29 ± 6.00 b	3.24 ± 3.80 ab	1.81 ± 1.49 a	2.12 ± 1.15 ab
K (F = 0.95, P = 0.44)	292.26 ± 125.89 a	230.90 ± 130.46 a	184.92 ± 90.38 a	213.93 ± 125.18 a	231.14 ± 92.15 a
MO (H = 2.91, P = 0.56)	5.35 ± 0.61 a	5.72 ± 1.02 a	5.57 0.82 a	5.61 ± 1.06 a	5.47 ± 0.46 a
CIC (F = 0.55, P = 0.69)	19.31 ± 5.22 a	18.08 ± 7.37 a	18.32 ± 6.59 a	20.20 ± 3.08 a	16.50 ± 3.42 a
Ca^{+2} (F = 1.25, P = 0.30)	15.90 ± 5.22 a	13.50 ± 8.02 a	12.22 ± 6.24 a	12.85 ± 3.71 a	9.52 ± 2.94 a
Mg^{+2} (F = 5.55, P = 0.0015)	1.27 ± 0.64 a	1.17 ± 0.44 b	1.90 ± 1.90 ab	2.79 ± 0.95 a	2.69 ± 0.84 a
K^{+2} (H = 3.55, P = 0.46)	0.70 ± 0.30 a	0.47 ± 0.32 a	0.44 ± 0.23 a	0.54 ± 0.27 a	0.55 ± 0.23 a
Na^{+1} (H = 2.19, P = 0.69)	0.18 ± 0.07 a	0.12 ± 0.04 a	0.14 ± 0.07 a	0.17 ± 0.11 a	0.17 ± 0.09 a
$Al^{+3} + H^{+1}$ (H = 2.26, P = 0.49)	0.00 ± 0.00 a	0.12 ± 0.22 a	0.11 ± 0.21 a	0.06 ± 0.10 a	0.08 ± 0.10 a
SC (F = 0.74, P = 0.5684)	18.05 ± 5.26 a	15.37 ± 8.25 a	14.82 ± 6.684 a	16.50 ± 4.38 a	13.01 ± 3.31 a
SB (F = 0.74, f = 0.57)	18.05 ± 5.26 a	15.25 ± 8.36 a	14.70 ± 6.98 a	16.35 ± 4.40 a	12.92 ± 3.33 a
SAB (F = 1.91, P = 0.139)	92.33 ± 12.68 a	80.83 ± 12.64 a	77.00 ± 14.68 a	81.00 ± 10.18 a	77.50 ± 4.90 a

Different letters horizontally indicate significant statistical differences between provinces Tukey test and Kruskal Wallis ($p \leq 0.05$). Ph = Hydrogen Potential, EC = Electrical Conductivity, P= Phosphorus, K= Potassium, MO = Organic Matter, N=Nitrogen, CIC = Electrical Conductivity, Ca^{+2} = Calcium, Mg = Magnesium, K^2 = exchangeable potassium, Na^+ = Exchangeable sodium, $Al^{+3} + H^{+1}$ = Aluminum plus hydrogen, SC = Sum of Cations, SB = Sum of Bases, SAB = Saturation of Bases. $\bar{x}$ and SD = Average and Standard Deviation.

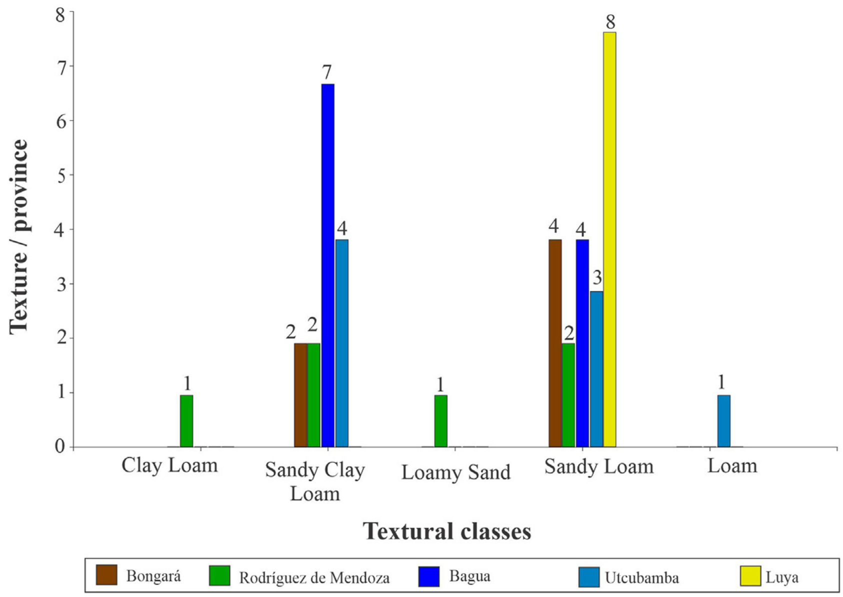

Figure 4. Textural class of soils associated with parent plants.

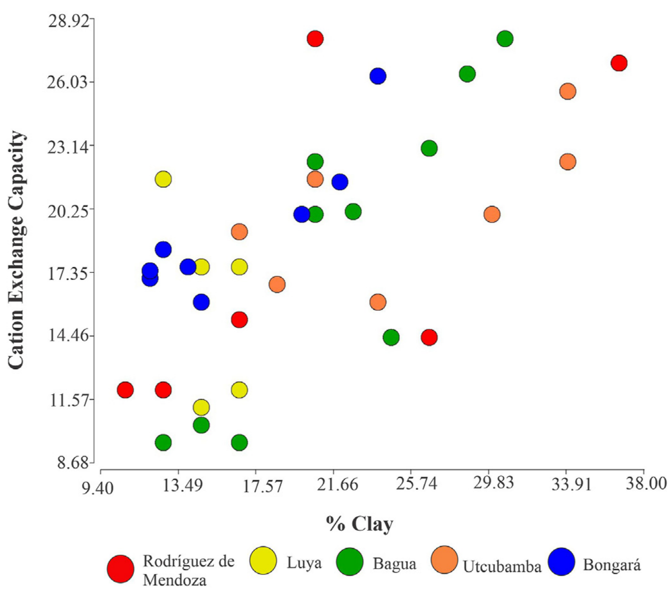

Figure 5. Cation exchange capacity and % of clay associated with parent plants.

The characterization of soils associated with parent plants contributes to the conservation of the genetic material identified and selected (Oscco et al., 2020), these coffee parent plants are currently part of ongoing research and are in the germplasm bank of the National Institute for Agrarian Innovation (INIA), in order to make improvements in coffee technology through genetic improvement programs in coffee and sustainable propagation, thus contributing to the economic development of small, medium and large coffee growers in the various provinces of the Amazon region.

4. Conclusions

A total of 100 mother plants were identified and characterized according to morphological descriptors; the highest number of coffee mother plants was found in the province of Bagua. With respect to the physicochemical characterization of the soils, there were no significant statistical differences for the characteristics evaluated; therefore, the five provinces under study show optimal ranges for the development and maximum potential of coffee cultivation. However, it is important in the future to evaluate the correlation between the soil and the sensory quality of the coffee varieties.

Declarations

Author contribution statement

Wigoberto Alvarado C: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Gelver Silva Valqui: Conceived and designed the experiments.

Lamberto Valqui-Valqui; Leandro Valqui: Performed the experiments.

Carmen N. Vigo; Leidy G. Bobadilla: Analyzed and interpreted the data; Wrote the paper.

Héctor V. Vásquez: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Aguilar, G., 1995. Variedad Costa Rica 95. Instituto del Café de Costa Rica (ICAFE), San José, Costa Rica, p. 33.

Álvarez-Sánchez, M.E., Velásquez-Mendoza, J., Maldonado-Torres, R., Almaguer-Vargas, G. y Solano-Agama, A.L., 2010. Diagnóstico de la fertilidad y requerimiento de cal de suelos cultivados con agave azul (*Agave tequilana* Weber). Terra Latinoamericana 28, 287–293.

Andina, 2018. Día del café peruano: conoce las zonas productoras en el Perú. Available in: https://andina.pe/agencia/noticia-dia-del-cafe-peruano-conoce-las-zonas-productoras-el-peru-723069.aspx#:~:text=Superficie%20cultivada%20asciende%20a%20230%2C000%20hect%C3%A1reas&text=de%2010%20departamentos.-,La%20superficie%20cultivada%20con%20caf%C3%A9%20ocupa%20230%2C000%20hect%C3%A1reas%20distribuidas%20en,selva%2C%20bajo%20una%20ecolog%C3%ADa%20tropical.

Arévalo, L.A., Vallejos, G., Gonzáles, R., 2021. Manual práctico: Desarrollo de tecnologías sostenible del café con hongos micorrízicos arbusculares. Available in: https://repositorio.iiap.org.pe/bitstream/20.500.12921/623/1/arevalo_manual_2021.pdf.

Arriola, J., Batlle, J., y Mendoza, J.C., 2012. Estado de salud actual del suelo en la ladera norte del Cerro Gordo del Parque Estatal Flor del Bosque, Amozoc, Puebla, México. Tecnología, Ciencia, Educación 27, 17–23.

Baba, V.Y., Toma, M., Benedito dos Santos, T., de Carvalho, K., Moura, D., Ivamoto-Suzuki, S.T., Maluf, M.P., Padilla, L., Paccola-Meirelles, L.D., Pereira, L.F., Dominguez, D.S., 2020. Transcriptional patterns of Coffea arabica L. nitrate reductase, glutamine and asparagine synthetase genes are modulated under nitrogen suppression and coffee leaf rust. PeerJ 8, e8320.

Bustamante, J., Roa, S., Casanova, A., Roso, L., 2004. Líneas de café resistentes a la roya en una localidad del estado Táchira Venezuela. Agron. Trop. 54 (1), 75–91.

Calle, F., 2009. Calidad en taza y caracterización del color de las hojas jóvenes de 22 variedades de café. Thesis, Universidad Zamorano, Honduras. https://bdigital.zamorano.edu/handle/11036/361.

Cárdenas, S.I., 2007. Caracterización morfológica y agronómica de la colección núcleo de café (Coffea arabica L.) del CATIE. Thesis. Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica. https://repositorio.bibliotecaorton.catie.ac.cr/handle/11554/4589.

Catari, P., 2017. Caracterización morfoagronómico de diez cultivares de café (*Coffea arabica* L.) en la estación experimental de Sapecho del departamento de la Paz. Thesis. Universidad Mayor de San Andrés Facultad de Agronomía. https://repositorio.umsa.bo/handle/123456789/10714.

Cepeda, J., 2020. Tendencias químicas de suelos dominicanos. Parte I: pH y cationes extraíbles. Revista Agropecuaria y Forestal 9, 25–42.

Chain-Guadarrama, A., Martínez-Salinas, A., Aristizábal, N., Ricketts, T., 2019. Ecosystem services by birds and bees to coffee in a changing climate: a review of coffee berry borer control and pollination. Agriculture, Ecosystems and Enviromennt 280, 53–67.

Chinguel, D., 2017. Efecto de la sombra y variedad de café en la incidencia de la broca *Hypothenemus hampei* (Ferrari), en el distrito de Omia, Rodríguez de Mendoza-Amazonas, 2017. Thesis. Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas. Amazonas, Perú. http://repositorio.untrm.edu.pe/.

CLIMATE-DATA.ORG, 2021. Clima: Amazonas. Available in: https://www.senamhi.gob.pe/?p=estaciones.

Comex Perú, 2021. Exportación de café aún no se recupera. Available in: https://www.comexperu.org.pe/articulo/exportacion-de-cafe-aun-no-se-recupera#:~:text=De%20otro%20lado%2C%20las%20cifras,del%206%25%20respecto%20de%202020.

Coronel, D., 2019. Identificación de variedades de café especial en las parcelas agroforestales certificadas en Jaén y San Ignacio. Universidad Nacional de Jaén, Cajamarca, Perú. Thesis. http://m.repositorio.unj.edu.pe/handle/UNJ/119.

Cosme-De La Cruz, R., Buendía-Molina, M., Adama-Rojas, E., Pocomucha-Poma, V., 2021. Caracterización morfológica de cinco variedades de café (*Coffea arabica L.*) y su resistencia a la roya (*Hemileia vastatrix*), en el Valle del Alto Huallaga, Tingo María, 1. Revista Peruana de Innovación Agraria, pp. 151–162.

Cruz-Macías, W.O., Rodríguez-Larramendi, L.A., Salas-Marina, M.A., Hernández-García, V., Campos-Saldaña, R.A., Chávez-Hernández, M.H., y Gordillo-Curiel, A., 2020. Efecto de la materia orgánica y la capacidad de intercambio catiónico en la acidez de suelos cultivados en dos regiones de Chiapas, México. Terra Latinoamericana 38, 475–480.

Dilas-Jiménez, J.O., Cernaqué, O.C., 2021. Enfoque SIAL como estrategia para la producción y comercialización del café especial tostado en el norte del Perú. Rev. investig. cient. tecnol. alpha centauri. 2, 2–16.

Espinoza, A.L., Vásquez, G.H., Tapia, C.S., Duicela, L.A., 2021. Crecimiento, desarrollo y concentración de macronutrientes en genotipos de café (*Coffea robusta* P.) con diferentes dosis de abono orgánico. Ciencia Latina Revista Científica Multidisciplinar. 5, 1–17.

Gamarra, D., Torres, G., Casas, J., Riveros, H., 2015. Caracterización y manejo integrado de la roya amarilla del café en selva central del Perú. Convicciones 2, 6–17.

García-Serrano, P., Lucena, J.J., Ruano, S., Nogales, M., 2009. Guía práctica de la fertilización racional de los cultivos en España. 1 era edición, Ministerio de Medio Ambiente y Medio Rural y Marino. Available in: https://www.mapa.gob.es/es/agricultura/publicaciones/01_FERTILIZACI%C3%93N(BAJA)_tcm30-57890.pdf.

Huamán, A., 2021. Influencia de la sombra y fertilización en la resistencia de clones élites *Coffea arabica L.* ante la incidencia y severidad de Hemileia vastatrix Berk. & Br. Revista Científica UNTRM: Ciencias Naturales e Ingeniería, 4, pp. 36–43.

INEI [Instituto Nacional de Estadística e Informática], 2021. Producción de café se incrementó 17, 0% en julio de 2021. Available in: https://www.inei.gob.pe/media/MenuRecursivo/noticias/nota-de-prensa-no-146-2021-inei.pdf.

IPGRI (International Plant Genetic Resources Institute), 1996. Descriptores del café (*Coffea spp. y Psilanthus spp.*). Roma. Available in https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Descriptores_del_caf%C3%A9_Coffea_spp._y_Psilanthus_spp._487.pdf.

Julca, A., Alvarado, L., Borjas, R., Castro, V., Apaza, A., Maldonado, C., Vértiz, R., Bello, S., Jiménez, J., 2019. Caracterización agronómica de las accesiones del banco de germoplasma de café en San Ramón Chanchamayo, Perú. Available in: https://www.researchgate.net/profile/Viviana-Castro-Cepero/publication/332718709_CARACTERIZACION_AGRONOMICA_DE_LAS_ACCESIONES_DEL_BANCO_DE_GERMOPLASMA/links/5cc5c425a6fdcc1d49b7557a/CARACTERIZACION-AGRONOMICA-DE-LAS-ACCESIONES-DEL-BANCO-DE-GERMOPLASMA.pdf.

Julca-Otiniano, A., Alarcón-Águila, G., Alvarado-Huamán, L., Borjes-Ventura, R., Castro-Restrepo, V., 2018. Comportamiento de tres cultivares de café (Catimor, Colombia y Costa Rica (95) en el valle de El Perené, Junín, Perú. Chil. J. Agric. Anim. Sci. 34, 205–215.

Junta Nacional del Café, 2020. El café de Perú. Available in: https://juntadelcafe.org.pe/el-cafe-de-peru/.

Lasso, E., Corrales, D.C., Avelino, J., Virgilio, E.M., Corrales, J.C., 2020. Discovering weather periods and crop properties favorable for coffee rust incidence from feature selection approaches. Comput. Electron. Agric. 176, 105640.

López, W., Reynoso, R., López, J., Villar, B., Camas, R., García, J.O., 2019. Caracterización físico-química de suelos cultivados con maíz en Villaflores. Chiapas. Rev. Mex. Cienc. Agríc. 10, 897–910.

López-Bravo, D.F., Virgilio-Filho, E.M., Avelino, J., 2012. Shade is conducive to coffee rust as compared to full sun exposure under standardized fruit load conditions. Crop Protect. 28, 21–29.

Márquez, F.R., Quispe, P., Molleapaza, N., Cabrera, S., Peña, J., 2020. Relación entre las características del suelo y altitud con la calidad sensorial de café cultivado bajo sistemas agroforestales en Cusco. Perú. Sci. agropecu. 11, 529–536.

Mendoza, R.B., Espinoza, A., 2017. Guía Técnica para muestreo de suelos. Available in: https://repositorio.una.edu.ni/3613/1/P33M539.pdf.

Milla, M.E., Oliva, S.M., Espinoza, S.T., Collazos, R., Gamarra, O.A., Barrena, M.A., Maicelo, J.L., 2019. Características morfológicas de variedades de café cultivadas en condiciones de sombra. Acta Agron. 68, 271–277.

Mora, Y.V., 2019. Factores significativos para asegurar calidad del café, una revisión bibliográfica. Universidad Nacional Abierta y a Distancia, Colombia. Thesis. https://repository.unad.edu.co/bitstream/handle/10596/28231/yvmoraa.pdf?sequence=1&isAllowed=y.

Moreno, G., Castillo, J., 1984. La variedad Colombia una variedad de café con resistencia a la roya (*Hemileia vastatrix* Berk. y Br.). Federación Nacional de cafeteros de Colombia. Cenicafé. Chinchiná, Colombia. Boletín Técnico N° 9, 25.

Oscco, I., Roldan, E.P., Quispe, E., Camacho, A., Marmolejo, D., Marmolejo, K.J., 2020. Selección, identificación y zonificación de café (*Coffea arabica* L.) por su adaptabilidad, rendimiento, calidad sensorial y resistencia a plagas y enfermedades. Agroindus. Sci. 10, 249–257.

Parada, P.C., Gómez, M.J., Ortiz, G.C., Cerdán, C.R., Cervantes, J., 2020. Fenómenos meteorológicos y su efecto sobre la producción de café en la Zona Central de Veracruz. UVserva 9, 47–58.

Proyecto Café & Clima, 2017. Estudio de mercado del café peruano. Available in: https://camcafeperu.com.pe/admin/recursos/publicaciones/Estudio-de-mercado-del-cafe-peruano.pdf.

Quiroga- Cardona, J., 2021. La resistencia incompleta del café a la roya: una revisión. Revista Cenicafé 72 (2), e72208.

Sánchez, S., Montalve, G., Oliva, M., Arévalo, S., 2019. Influencia del estado fenológico y nutrición de plagas de café (*Coffea arabica* L.) en la producción de brotes, Rodríguez de Mendoza. Amazonas. Rev. de investig. agroproducción sustentable. 3, 74–82.

Sánchez, T., 2017. Efecto de inóculos de hongos micorrízicos arbusculares en plantas clonales de café (*Coffea arabica* L.) variedad caturra en condiciones de invernadero, Rodríguez de Mendoza, región Amazonas. Thesis. Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Peru. http://repositorio.untrm.edu.pe/bitstream/handle/UNTRM/1300/TESIS-TITO%20SANCHEZ%20SANTILLAN.pdf?sequence=1&isAllowed=y.

Sancho, E., Espinoza, D., Aguirre, D., 2019. El efecto de la fertilización mineral, orgánica y mineral-orgánica sobre las características agroproductivas en plantas de café y de la calidad de taza. Revista Universidad en Diálogo. 9, 175–185.

Sandoval, Z.L., Prieto, F.A., 2007. Caracterización de café cereza empleando técnicas de visión artificial. Rev. Fac. Nal. Agr. Medellín. 60, 4105–4127.

Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), 2021a. Datos Hidrometeorológicos a Nivel Nacional. Estación Convencional Meteorológica El Palto. Available in: https://www.senamhi.gob.pe/?p=estaciones.

Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), 2021b. Datos Hidrometeorológicos a Nivel Nacional. Estación Convencional Meteorológica Aramango. Available in: https://www.senamhi.gob.pe/?p=estaciones.

Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), 2021c. Datos Hidrometeorológicos a Nivel Nacional. Estación Convencional Meteorológica Jazán. Available in: https://www.senamhi.gob.pe/?p=estaciones.

Servicio Nacional de Sanidad Agraria (SENASA), 2013. Norma para la ejecución y remisión de actividades del programa manejo integrado de plagas de cafeto. Available in: https://www.senasa.gob.pe/senasa/descargasarchivos/jer/SUB_DIR_CONTEP/1222.pdf.

Suazo, T.D., 2020. Caracterización morfológica y molecular de café (*Coffea arabica* L.) variedad Catrenic proveniente de las fincas CENECOOP-Fedecaruna y El Rosal de Nicaragua, Laboratorio de Biotecnología, UNAN-Managua, 2018-2020. Thesis. Universidad Nacional Autónoma de Nicaragua. https://repositorio.unan.edu.ni/14575/1/14575.pdf.

Torres, N.E., Melchor-Jhosseph, M.M., Ochoa, J.S., Ramirez-Mendoza, R.A., Parra-Saldívar, R., Iqbal, H.M., 2020. Impact of climate change and early development of coffee rust – an overview of control strategies to preserve organic cultivars in Mexico. STE 738, 140225.

Vilchez, N.C., Yalta, J.R., Carril, V.B., 2019. Análisis comparativo de suelos de cinco distritos de la cuenca Chinchipe y su influencia en la fertilidad del cultivo de café (*Coffea arábica* l.). Pakamuros 7, 91–100.