





Plant genetics and biodiversity

Scientific and technological research article

Phenotypic Performance Evaluation of the Coffee Variety Marsellesa® over 1400 meters a.s.l. as an Alternative for Coffee Growing

Rendimiento fenotípico de la variedad de café Marsellesa como una alternativa para la caficultura sobre los 1400 metros s.n.m.

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Abstract: Most studies on coffee varieties have focused on resistance to several conditions, evaluating a maximum of two varieties at altitudes below 1,000 m a.s.l. To fill this gap, the present study aims to find phenotyping differences across Marsellesa, Red Caturra, and Catimor coffee crops evaluated over 1,400 m a.s.l. Experimentally, this work was divided into three plots (1,477., 1,548, and 1,797 m a.s.l.) with three treatments and three repetitions, totaling 27 experimental plots. We tested the resistance to rust and Cercospora, and the organoleptic quality was assessed by an expert coffee taster with a SCA Q-Grader Coffee Certificate. We found similar results in the three cultivars, with high production (around 1 t/ha of dry parchment coffee) in their first year. The Caturra variety showed a higher plant height. Marsellesa showed the best resistance to rust with a 0 % incidence; however, the three crops were susceptible to Cercospora. We concluded that Marsellesa coffee adapts to the humid montane forest zone over 1,400 m a.s.l. with good organoleptic properties and better rust resistance. Marsellesa has been used in the area for the last two years; therefore, this specialty coffee shows rust resistance and helps the small farmer meet the international market's expectations.

Keywords: Caturra, Catimor, coffee production, cultivars, disease resistance, organoleptic quality.

Resumen: La mayoría de los estudios sobre variedades de café se han enfocado en la resistencia a diferentes condiciones, específicamente en dos variedades o en altitudes menores a 1000 m.s.n.m. Para llenar este vacío, este estudio pretende encontrar las diferencias fenotípicas entre los cultivares de café Marsellesa, Caturra Rojo y Catimor evaluados sobre los 1400 m.s.n.m. Para el experimento, este trabajo se dividió en tres parcelas (1477 m s.n.m., 1548 m.s.n.m. y 1797 m s.n.m.) con tres tratamientos y tres repeticiones, para un total de 27 parcelas experimentales. Se probó la resistencia a la roya y a Cercospora y la calidad organoléptica, la cual estuvo a cargo de un experto catador de café con un Certificado de Café Q-Grader de la SCA. Se encontraron resultados similares en los tres cultivares, con alta producción (alrededor de 1 t/ha de café pergamino seco) en su primer año, siendo el Caturra el que mostró una mayor altura de planta. El Marsellesa presentó una mejor resistencia a la roya con una incidencia de cero por ciento. Sin embargo, ante Cercospora, los tres cultivos resultaron ser susceptibles. Se concluyó que el café Marsellesa se adapta a la zona de bosque montano húmedo con propiedades organolépticas adecuadas y una mejor resistencia a la roya; desde este estudio, esta variedad viene empleándose en la zona. Por lo tanto, este café especial muestra resistencia a plagas y ayuda al pequeño agricultor a cumplir con las expectativas del mercado internacional.

Palabras clave: Catimor, Caturra, cultivares, , calidad organoléptica, producción de café, resistencia a la enfermedad.



Introduction

Coffee, *Coffea arabica* L. (*Rubiaceae*), is the number one Peruvian export product (Zegarra, 2019). Peru is the seventh-largest coffee exporting country globally and the second-largest world exporter of organic coffee, after Mexico, with 425,400 hectares devoted to cultivation (Vargas & Willems, 2017). The coffee crop represents 6 % of the national agricultural area with the potential to expand by around two million hectares (Ministerio de Agricultura y Riego [MINAGRI], 2015).

The estimated global consumption of coffee for 2018-2019 was more than 163 million bags (Alkaltham et al., 2020), with four main species produced: Arabica, Robusta, Liberica, and Excelsa. The first two represent at least 98 % of coffee consumption worldwide, and the remaining two are lower sensory quality coffees of a marginal consumption (MINAGRI, 2019). In addition, there are health benefits associated with coffee consumption (Zivković, 2000), including antioxidant properties found especially in oven-dried coffee (Alkaltham et al., 2020; Andrade et al., 2012) and dietary fiber in Barbari bread (Pourfarzad et al., 2013).

Another recent study has investigated differences in behavioral responses due to coffee (e.g., Córdova-Berriós et al., 2018). However, production costs of *C. arabica* have increased mainly due to stricter demands on soil degradation and changing climatic conditions, crop management, primary processing, and pest and disease control, especially coffee leaf rust in susceptible varieties (Van der Vossen et al., 2015). There is a high production cost in specialty organic coffee because it requires the development of processing technology for the reuse of coffee waste (Arteaga-Cuba et al., 2021; Dilas-Jiménez et al., 2020).

The economy of the Cajamarca region is the tenth (out of twenty-four) most important in Peru, focusing on real GDP (excluding Lima and Callao) (Instituto Peruano de Economía [IPE], 2020), mainly due to mining, which is almost a quarter of the region's added value. The second most important activity is agriculture, with 14 % of the region's production whose main product is coffee (Ministerio de Comercio Exterior y Turismo [MINCETUR], 2017). For this reason, this study focuses on coffee at an altitude higher than 1,400 m a.s.l. in Cajamarca in different plots and with various treatments.

In Peru, among other diseases that attack coffee plants, there is still a severe problem affecting production, “coffee rust” (*Hemileia vastatrix*). In 2013, incidence levels of 30–60 % in agricultural areas affected 290,000 ha (MINAGRI, 2014). The rust crisis in Central and South America has reduced coffee crop production in many countries: in Colombia, by up to 31 % in the 2008 campaign compared to 2007 for several commercial coffee plantations, and in El Salvador, production fell by 54 % between 2012 and 2013 (Avelino et al., 2015; Cristancho et al., 2012). This rust crisis has caused social and environmental problems (Amico et al., 2020). Therefore, research conducted on coffee rust has investigated the effects of a combination of nitrogen fertilization and specific temperature ranges (Toniutti et al., 2017). In this work, we compare the resistance of different coffee varieties to rust.

The development of cultivars resistant to “coffee rust” has been possible by the Timor Hybrid (HDT), the interspecific hybridization between *Coffea canephora* and *C. arabica* (Avelino et al., 2015). In research conducted in Colombia by a scientist at CENICAFE, the introduction of resistant strains, together with better monitoring of the climate to help predict rust outbreaks, has meant less than 10 % of plants now need to be treated with fungicides, compared to 60 % four years earlier (Cressey, 2013). In Central America, through the PROMECAFE project, different resistant cultivars were selected locally from hybrid genotypes called Catimor (Caturra x HDT). In Costa Rica, all the local Catimor selections (Catrenic, IH café 90, and Costa Rica 95) were made with criteria of productivity and resistance to rust race II (Julca-Otiniano et al., 2018). Unfortunately, its quality deficiencies have meant that its expansion has not been as expected.

In Colombia, multiple lines of Colombia and Castillo cultivars derived from crosses between Caturra and Timor Hybrid 1343 have exhibited resistance against coffee rust (Jaramillo et al., 2011). According to Romero et al. (2010), little is known about the inheritance and genetic determinism of partial resistance to *H. vastatrix* in coffee. Romero’s research found that estimates for segregating genes showed at least five independent genetic regions. These regions were associated with partial resistance to rust.

Through segregation studies, Prakash et al. (2004) confirmed the hypothesis of a single dominant gene for resistance factor SH3, a rust resistance gene. On the other hand, foliar disease incidence could be lowered if shade could be reduced throughout the plantation system, reducing the incidence of rust (Ehrenbergerová et al. (2018). Julca et al. (2010) found that fertilization further decreased the incidence of rust by 21.2 % (Julca et al., 2010), possibly due to its influence on intraspecific variation (Buchanan et al., 2019) and a protective effect on symptomatic tissues, mainly from the addition of potassium and calcium (Belan et al., 2015).

However, some references indicate that the physical and organoleptic quality of hybrids such as Catimor does not differ from more traditional cultivars such as Caturra (Marie et al., 2020; Muschler, 2001). The comparison among cv. Colombia with Typica, Caturra, and Borbón, or between Castillo, Typica, Caturra, Borbón, and Colombia showed no statistically significant differences in drink quality (Alvarado & Puerta, 2002), as well as cv. Colombia, Costa Rica and Catimor was tested in Peru with similarity results (Julca et al., 2018).

These differences did not consider that the altitude of the coffee plantation land influenced quality (Bertrand et al., 2006). In addition, the quality may be better if the processing method is dry and cultivation occurs in a shaded system (Worku et al., 2018). In other words, these HDT varieties with characteristics of rust resistance have a high potential not only in production but also for the specialty coffee market. Therefore, bearing in mind that the Specialty Coffee Association of America (SCAA) classifies coffee with 80 points in cup quality as Specialty (specialty coffees), the HDT varieties become an alternative to the rust crisis.

Other studies in Costa Rica at 600 m a.s.l. in 19 agroforestry systems studied the morphology of coffee and production (Schnabel et al., 2018). Further, a study in the San Martín region, Peru, showed that the Caturra variety coffees increase their organoleptic quality when harvested over 1,000 m a.s.l. (Gamonal et al., 2017). Therefore, this research considered the morphology and

production of coffee according to altitudinal strata to explain the present results. Recently, altitudes up to 1,250 m a.s.l. have been studied to compare the Red Caturra and Marsellesa varieties, opening the possibility of increasing the number of hybrid varieties produced by seeds through the future identification of markers of male sterility (Georget et al., 2019), especially in ecosystems favorable for pathogens (Van der Vossen et al., 2015). For this reason, Marsellesa and Red Caturra were used for the present study in Peru, where the altitude is variable due to geography.

In Peru, farms with Caturra and Typica varieties are highly susceptible to rust dominance (Vallejos-Torres et al., 2020) with limited area due to resistant cultivars such as Catimor and others. The present study sits within the framework of an Adaptive Research Project 2016, funded by the National Program for Agrarian Innovation (PNIA, for its acronym in Spanish) and the Cooperativa Agraria Cafetalera APROVAT (2016), in the district of Tabaconas, province of San Ignacio, Cajamarca Region between 1,400 and 1,800 m a.s.l. The present study assesses how the Marsellesa cultivar show its adaptability through its vegetative behavior, productive capacity, yield, and organoleptic quality. In addition, the incidence of pests and foliar diseases such as *Hemileia vastatrix* and *Cercospora coffeicola* was also tested, compared with cultivars such as Red Caturra and Catimor, which also exist in the area.

Materials and Methods

The following experimental methods were employed to conduct this study:

Place and location of blocks. To ensure that test plots were located randomly throughout the study area, we used a randomized complete block design (RCBD) with two-criteria fertilization assessment (1) growing state and (2) productive state. Finally, we detailed the characteristics, vegetative development, incidence of pests and foliar diseases, productive capacity, yield, and organoleptic quality. The experiment was carried out between November 2017 to November 2019 in three experimental blocks in Tabaconas (see Figure 1), San Ignacio, Cajamarca region, Peru (see the small yellow square in Figure 1), belonging to coffee producers of APROVAT.

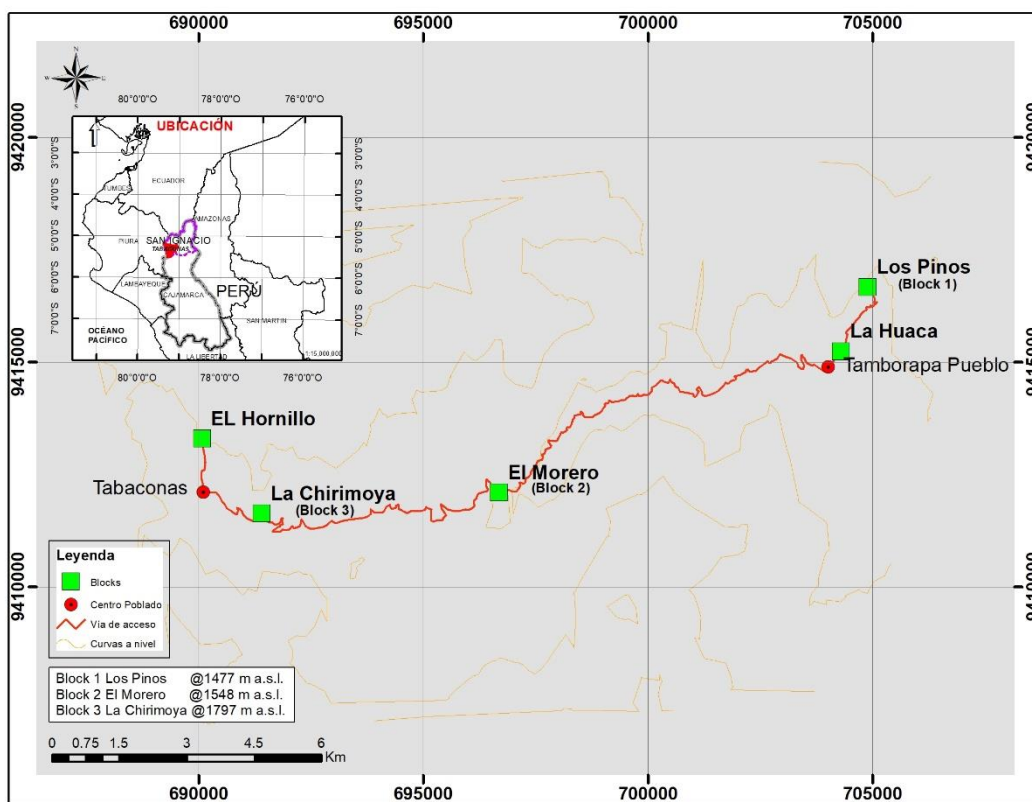


Figure 1. Study location map. Agricultural blocks highlighted: Block 1 at 1,477 m a.s.l., Block 2 at 1,548 m a.s.l., and Block 3 at 1,797 m a.s.l.

Source: The location map of the three blocks was based on geo-reference data collected using GPS navigator equipment; later, data were processed in AutoCAD, Arc Gis 10.4.1, and Google Earth software.

In the present research, an RCBD of 3 x 3 x 3 (3 blocks x 3 treatments x 3 repetitions) was established with nine experimental units in each block, totaling 27 experimental plots. The treatments were coffee cultivars T1 Marsellesa, T2 Red Caturra, and T3 Catimor, characterized according to the catalog of varieties or cultivars for *C. arabica* (International Plant Genetic Resources Institute [IPGRI], 2019). The planting system was 2 x 1 (1 meter between plants x 2 meters between rows of plants), making a sowing projection of 5,000 plants/hectare. Each experimental unit contained approximately 100 plants. The seedlings were produced in a nursery in Tamborapa Pueblo town near the “Los Pinos” plot and transplanted to the final field after five months.

The Marsellesa (Sarchimor) seeds are certified by the National Seed Office of Costa Rica (March 03, 2017 and imported by FJ Orlich Hnos Ltd. The Catimor and Red Caturra came from selected seeds from farms in the same research area.

Table 1. Description of the three blocks where the study was conducted around Cajamarca, Peru. Marsellea cultivar's environmental response to the tests for incidence of pests and foliar disease

	Variables	Unit	Block		
			1	2	3
Farm description	Block name		<i>Los Pinos</i>	<i>El Morero</i>	<i>La Chirimoya</i>
	Locality		Tamborapa Pueblo	Yuscapampa	Agua Blanca
	GPS location (coordinates)	(<i>S, W</i>)	05°16'29", 79°09'05"	05°18'58", 79°13'31"	05°19'14", 79°16'22"
	Elevation	(<i>m</i>)	1,477	1,548	1,797
	Area	(<i>ha</i>)	5	3	3
Meteorological data	Average temperature (min-max]	°C	NA	NA	18.5
	Cumulative rainfall	(mm/year)	NA	NA	(14-23) 1120
	Relative humidity	%	NA	NA	78
	Average coffee age	(<i>years</i>)	2 (2016-2018)	2 (2016-2018)	2 (2016-2018)
Coffee plot description	Coffee density	(<i>plants/ha</i>)	5,000	5,000	5,000
	Average shade cover (min-max]	(%)	None	None	None
Coffee crop management	Weed control	<i>times/year</i>	Manual (3 per year)	Manual (3 per year)	Manual (3 per year)
	Diseases	<i>Product</i>	No treatment	No treatment	No treatment
	Pests	<i>Product</i>	No treatment	No treatment	No treatment
	Fertilization program	<i>Formula N-P-K</i>	144N-88P2O5-23K2O	226N-88P2O5-10K2O	233N-73P2O5-62K2O
	Sources of fertilization	Product type	Organic	Organic	Organic

Note. NA = There is no weather station near the locality

Source: Elaborated by the authors

Fertilization was carried out based on two criteria:

Criteria 1. Fertilization in the vegetative growth stage followed the same doses and formula for the three blocks assessed; from zero to 14 months of age, they received a dosis of 30 g/plant of guano from islands. At two months, six months, and 14 months, 30, 90, and 140 g/plant of island guano were used. These applications were accompanied by 19 g/plant of Sulpomag, 0.2-0.3 g/plant of zinc sulfate, 0.2 g/plant of Sulpomag manganese, and 2-3 g/plant of Ulexite.

Criteria 2. Fertilization in the productive stage was carried out after 14 months, always using organic source fertilizers according to the fertilization program for each block and the soil analysis. The formulations in kg/ha were 144N-88P2O5-23K2O for the Los Pinos plot; 226N-

88P2O5-10K2O for the El Morero plot; and 233N-73P2O5-62K2O for the La Chirimoya parcel.

For the evaluations, ten plants were chosen for each experimental unit, accounting for 30 individuals for each treatment for each experimental plot; these plants were in the center, in two rows of five plants per row. For statistical data treatment in each experimental plot, an average value of the individuals was evaluated. The measurements were carried out 24 months after the installation of the coffee trees in the final field, so the behavior of the cultivars was assessed as follows:

Characteristics and vegetative development. Eleven qualitative variables were evaluated through phenotypic characteristics: plant shape, branching habit, insertion angle, stipule shape, leaf shape, apex shape, leaf color, shoot color, petiole color, fruit color, and fruit shape. Further, four quantitative variables corresponding to the coffee descriptors considered by the IPGRI (2019) were considered: plant height (cm), the number of branches per plant, the number of nodes per branch, and branch length (cm). Figures including standard error bars in bar plots were made using matplotlib in Python at <https://colab.research.google.com/>, and code is accessible under <https://github.com/cmugruza/MarsellesaCoffeePaper>.

Incidence of pests and foliar diseases. The incidence of diseases such as yellow rust (*Hemileia vastatrix*), Cercospora (*Cercospora coffeicola*) and the coffee miner pest (*Leucoptera coffella*) were evaluated in a single measure at the end of the 24 months. For the incidence, the total number of leaves per branch is divided by the number of diseased leaves. This result was multiplied by 100, with the procedure performed on branches in the lower, middle, and upper third in one branch for each third (according to Brannen & Jewett, 1969), excluding coffee from the analysis; Julca et al. (2010) used only for coffee. For the analysis of variance (ANOVA), the equation $X = (\arcsen\sqrt{x})$ transformed these measures previously.

The statistical treatment of the data, ANOVA, and statistical significance were performed using Duncan's multiple range test (hereinafter, Duncan's test), at a confidence level of 95 %, using Statgraphics 16.1 and Ms. Excel.

Productive capacity. Only one harvest was gathered at 24 months of the coffee age. This harvest was used to estimate the production per hectare. This estimate was based on the number of cherries per plant (ripe cherry) determined by the number of producing branches and the number of cherries per branch. This estimation followed the estimation method by UTZ (2016); the production of cherry coffee (green coffee) is obtained in kg/ha, which is then multiplied by 0.20 to get the amount of kg of dry parchment coffee in kg/ha (Montilla et al., 2008). Finally, this value was converted into quintals/ha using 55.2 kg as equivalence for one (1) quintal of dry parchment coffee (*café pergamino* in Peru), different from gold coffee where the values can be converted into quintals/ha using 46.0 kg as the equivalent of one (1) quintal.

Yield. With the harvest gathered in November 2019 from a sample for each treatment and experimental plot, the yield (in percentage) was determined in the laboratory of the Cooperativa Agraria Cafetalera la Prosperidad de Chirinos (Chirinos-San Ignacio-Peru). Subsequently, the adjusted yield factor method and classification of defects were used under the Arabica Green

Coffee Classification System of the Specialty Coffee Association (Instituto Interamericano de Cooperación para la Agricultura [ICCA], 2010).

Organoleptic quality. The harvest was reaped in November 2019 from samples (dry parchment coffee of 12 % humidity, ripe coffee beans, and processed coffee beans by wet processing) obtained from each treatment and experimental plot. The organoleptic quality (score in rate) was determined through a sensory analysis (of the coffee made in the laboratory of the Cooperativa Agraria Cafetalera la Prosperidad de Chirinos) by an expert coffee taster with a Q-Grader Coffee Certificate using the SCA assessment sheet. Nine samples were analyzed, i.e., five cups from each sample and each type (treatment) from each block. This protocol is according to the SCAA (ICCA, 2010).

Results and discussion

Characteristics and vegetative development

The phenotypic characteristics of the three cultivars studied are similar. As shown in Table 1, Marsellesa and Red Caturra showed more significant phenotypic similarity, with the only difference found in the shape of the apex. On the other hand, Catimor showed differences in leaf color (dark green) and shoot color (dark bronze). For this shoot color, Julca et al. (2018), in their evaluation conducted in Valle del Perené, Junín, Peru, found that Catimor showed a light bronze-colored apex. In this regard, Blas-Sevillano et al. (2011) pointed out that the color of young leaves is governed by two genes (Br = bronze and br = green) with incomplete dominance, finding three phenotypes (BrBr = dark bronze, Brbr = light bronze, and brbr = green).

Table 2. Phenotypic characteristics of the coffee cultivars evaluated from the Tabaconas district, San Ignacio, Cajamarca, Peru. Marsellesa, Red Caturra and Catimor cultivars' response to the environment.

Variable	Marsellesa	Red Caturra	Catimor
Plant shape	Conic	Conic	Conic
Branching habit	A lot branches	A lot branches	A lot branches
Insertion angle	Upright (semi-upright)	Upright	Upright
Stipule shape	Oval	Triangular	Triangular
Leaf shape	Elliptic	Elliptic	Elliptic
Apex shape	Apiculate	Apiculate	Apiculate
Leaf color	Green	Green	Dark green
Shoot color	Green	Green	Dark bronze
Petiole color	Green	Green	Green
Fruit color	Red	Red	Red
Fruit shape	Oblong	Oblong	Oblong

Source: Elaborated by the authors

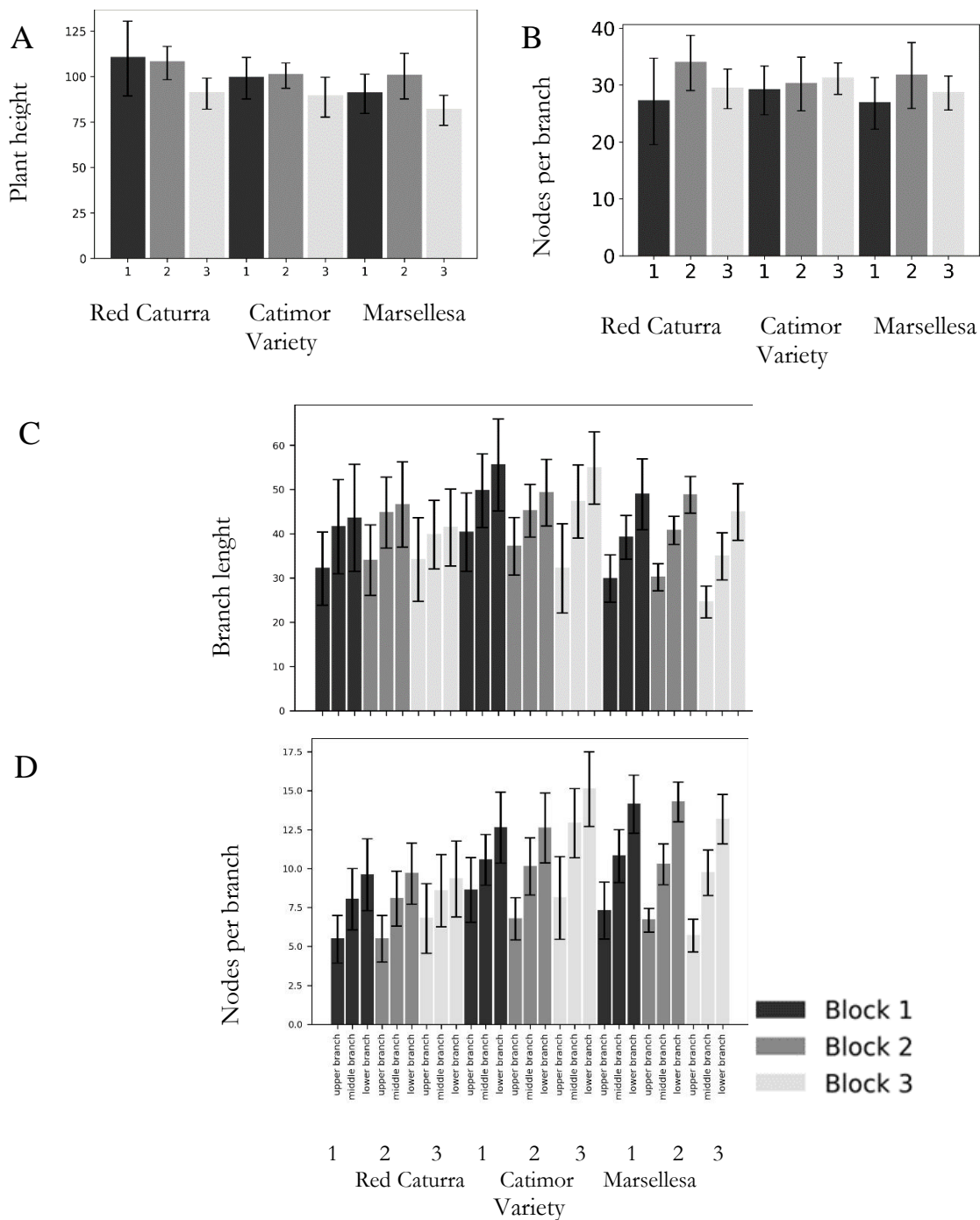


Figure 2. Vegetative behavior of coffee varieties according to plant height (A: top left), number of branches (B: top right), branch length (C: center), and number of nodes per branch (D: down). Black: Block 1, Gray: Block 2, Light gray: Block 3.

Regarding the quantitative variables, these have to do with the growth and vegetative development of the plant directly correlated with the initial production of coffee plantations (Carvalho et al., 2011).

In this test, significant differences were found in plant height in the three cultivars (ANOVA, $p = 0.0008$, and Duncan's test), 80.14 cm for Marsellesa, 91 cm for Red Caturra, and 86.29 cm for Catimor (see Figure 2).

These differences may be related to a response to fertilization. In evaluating three coffee cultivars for the effects of fertilization during juvenile growth (Caturra, Catuai, and Catimor), Caturra exhibited the most significant height and greater branch length and number of internodes. Zhang et al. (2017) found comparable results and specified that the ratio of N:P₂O₅:K₂O was 1:0.8: 0.5 was optimum for the youthful growth of coffee plants. Additionally, the present study found that the average growth was higher in the El Morero plot located in the middle zone at 1,548 m a.s.l.

The average branch length per plant between the three cultivars showed no significant difference (ANOVA, $p = 0.6683$, and Duncan's test), with averages of 29.03 cm for Marsellesa, 30.11 cm for Red Caturra, and 30.13 cm for Catimor. Likewise, the three cultivars showed no significant difference in the average number of branches per plant (ANOVA, $p = 0.3437$, and Duncan's test), with averages of 19 branches for Marsellesa and 21 branches for Red Caturra and Catimor. Zhang et al. (2017) reported equivalent results in varieties Caturra, Catuai, and Catimor, in line with findings by Manchego et al. (1999) for a three-year coffee plantation.

Regarding the number of nodes per branch in the upper, middle, and lower branches (ANOVA, $p = 0.6241$, 0.5774, and 0.8854, respectively, and Duncan's test), the evaluated cultivars showed no significant difference. The average number of nodes in the upper, middle, and lower branches were as follows: Marsellesa (7, 10, and 13, respectively); Red Caturra (7, 10, and 12, respectively); and Catimor (6, 9 and 11, respectively).

No significant difference was found regarding length for the upper, middle, and lower branches (ANOVA, $p = 0.2704$, 0.3651, and 0.7097, respectively, and Duncan's test) between the evaluated cultivars. The average length of the upper, middle, and lower branches was as follows: Marsellesa (30.22, 40.67, and 47.04 cm, respectively); Red Caturra (34.12, 43.43, and 49.25 cm, respectively); and Catimor (33.37, 43.51, and 48.22 cm, respectively). The average branch lengths here are longer than those found by Zhang et al. (2017), who do not specify if the coffee had grown in shade or full sun. These higher averages may be due to the evaluated farms being installed as monocultures in full sun, as the shade gradient affects the intraspecific variation of the resulting plant in the physiological, morphological, and chemical traits (Buchanan et al., 2019).

Productive capacity

Before determining dry parchment coffee production in quintals/ha, the number of producing branches was determined without significant difference. The findings showed an average of 19 productive branches for Marsellesa and 21 for Red Caturra and Catimor. In addition, the number

of cherries per branch was measured, finding an average of 31 cherries for Marsellesa, 26 cherries for Red Caturra, and 36 cherries for Catimor. It should be noted that this is the first production in the evaluated coffee plantations (two years old), foreseeing increases in the following years according to the productive cycle of coffee and reaching its maximum productivity around six years of age (Arcila et al., 2007). In the present results, the production of 55.2-kg quintals was determined by an average production of 18.10 quintals/ha for Marsellesa, 17.66 quintals/ha for Red Caturra, and 23.19 quintals/ha for Catimor. These results showed no statistical significance (ANOVA, $p = 0.0901$, and 'Duncan's test). The forecast production results agree with the production per hectare found by Julca et al. (2018) in a four-year-old plantation with a determined production of 29.29 quintals/ha (1.65 t/ha). The results may be influenced by the full-sun cultivation system, which according to results found in Costa Rica by Hagggar et al. (2011), had higher yields per ha than shade-grown coffee. However, in terms of costs, the shade produced by trees in a coffee agroforestry system positively impacts the soil's chemical, biological and biochemical components, increasing organic matter and microbial communities (Dilas-Jiménez & Mugruza-Vassallo, 2020; Rigal et al., 2019). These factors can, therefore, partially compensate for the cost of fertilization. Indeed, although marked by the COVID-19 pandemic, Marsellesa coffee has increased its use in San Ignacio province, Cajamarca, Peru, in the last two years.

Yield

The yield of coffee is a necessary characteristic to determine the exportable volume of coffee. In the present study, the yield for the three cultivars did not exhibit a significant difference (ANOVA, $p = 0.3433$, and 'Duncan's test), finding an average yield of 77.17 % for Marsellesa, 79.03 % for Red Caturra, and 75.43 % for Catimor. However, these results were more significant than those found by Julca et al. (2018) in Valle del Perené, Junín, for Catimor (73.62 %) and Colombia (72.72 %) cultivars. It should be noted that yield largely depends on the care taken in postharvest processing and the level of pests and diseases.

Organoleptic quality

According to the SCAA Protocol, organoleptic quality depends on ten criteria, with a maximum score of 100 points in rate. In the present study (ANOVA, $p = 0.2897$, and Duncan's test), equal scores were found in Marsellesa with 84 points and Red Caturra with 84.14 points in the total score as an average value. The Catimor cultivar showed a significant difference, which reached a score of 82.55 points. The present results revealed higher values than those found by Julca et al. (2018) in Valle del Perené, Junín, Peru, where the cultivar Colombia (82.05) reached the highest score, followed by Costa Rica 95 (80.89) and Catimor (79.93). Red Caturra was better in the organoleptic quality results than Caturra (82.10 points) in the San Martín Region, Peru (Gamonal et al., 2017).

It should be noted that Catimor was only equal to the other two cultivars in the uniformity and sweetness criteria. For the other criteria, it scored lower (see Figure 3). Because the organoleptic quality in the three varieties showed no significant difference, it was impossible to address any changes in coffee acidity due to altitude for the three different plots studied. However, Worku

et al. (2018) found a 0.22 point increase for every 100 m a.s.l. This effect could be related to the spatial variability of soil (Rodríguez-Garayet al., 2016).

The results of the present study have shown that any of the three cultivars could be considered for the specialty coffee market (80 to 84.99 points). This finding agrees with the results of altitude above sea level (highland coffee) from the blocks evaluated (over 1,200 meters) and varieties used, mainly Red Caturra and Marsellesa (Bertrand et al., 2012; Gamonal et al., 2017). Moreover, Bertrand et al. (2006) confirmed that the homeostasis for which the biochemical composition of the coffee bean was less affected by elevation than that of the traditional varieties and the organoleptic evaluation in samples from higher altitudes did not show significant differences between Arabica hybrids and traditional cultivars. However, only for the conditions evaluated in the present study, Marsellesa and Red Caturra at altitudes greater than 1,400 m a.s.l. showed specialty coffees of excellence since they are close to the minimum necessary range of 85 points. This result is economically beneficial for small producers since the local market of Jaén, Peru has prices for specialty coffees between 30-50 % over the conventional coffee price.

Particularly relevant in the present study, technologies for postharvest processing such as unique treatments during fermentation, were not used due to the small quantities processed by wet processing (Ribeiro et al., 2017). In addition to fermentation times according to altitude (Bodner et al., 2019), storage packaging and drying, among other remarkable technologies such as the application of Polyphenol Oxidase, increased the sensory attributes of the coffee (Mathur et al., 2015). Compared to a traditional cultivar, such as Red Caturra, Marsellesa produces up to 10 % more, with good organoleptic qualities (Georget et al., 2019). Thus, the results of this part of the present research are supported by recent studies and producers from Jaén, Peru.

Incidence of pests and foliar diseases

The present study evaluated the resistance of the Marsellesa cultivar to the incidence of foliar disease. Due to its reported characteristics (IPGRI, 2019), the results in the present research showed non-significant differences in the incidence of coffee rust (ANOVA, $p = 0.4444$, and Duncan's test), for the upper, middle, or lower branches. In detail, the finding averages of incidence were as follows: for Marsellesa, 0 % in its three levels of branches; for Red Caturra, 0.59 %, 4.22 %, and 0.33 %, respectively; and for Catimor, 0 % in the middle and lower branches and only 0.61 % in the upper branches.

Despite not finding a significant difference in the results, Marsellesa and, to a lesser extent, Catimor were resistant to rust attack. Red Caturra was the most susceptible. These results agree with those reported by Ehrenbergerová et al. (2018) and Julca et al. (2010, 2018) in coffee plantations from various regions of Peru; on the other hand, Julca et al. (2019) found a positive correlation between the incidence and severity of coffee rust. It should be noted that the incidence of foliar diseases has been low in this study, especially rust, which may be due to the environmental conditions in 2019 (as seen in Amico et al., 2020, such as temperature and humidity). A study to evaluate the parasitism of *H. vastatrix* with *Lecanicillium lecanii* found an inversely proportional relationship between temperature and the incidence of the disease. Dry climates with high average temperatures and foliar humidity associated with high relative

humidity (> 80 %) imply a better potential for biocontrol application at low temperatures (Capucho et al., 2013; Martins et al., 2015).

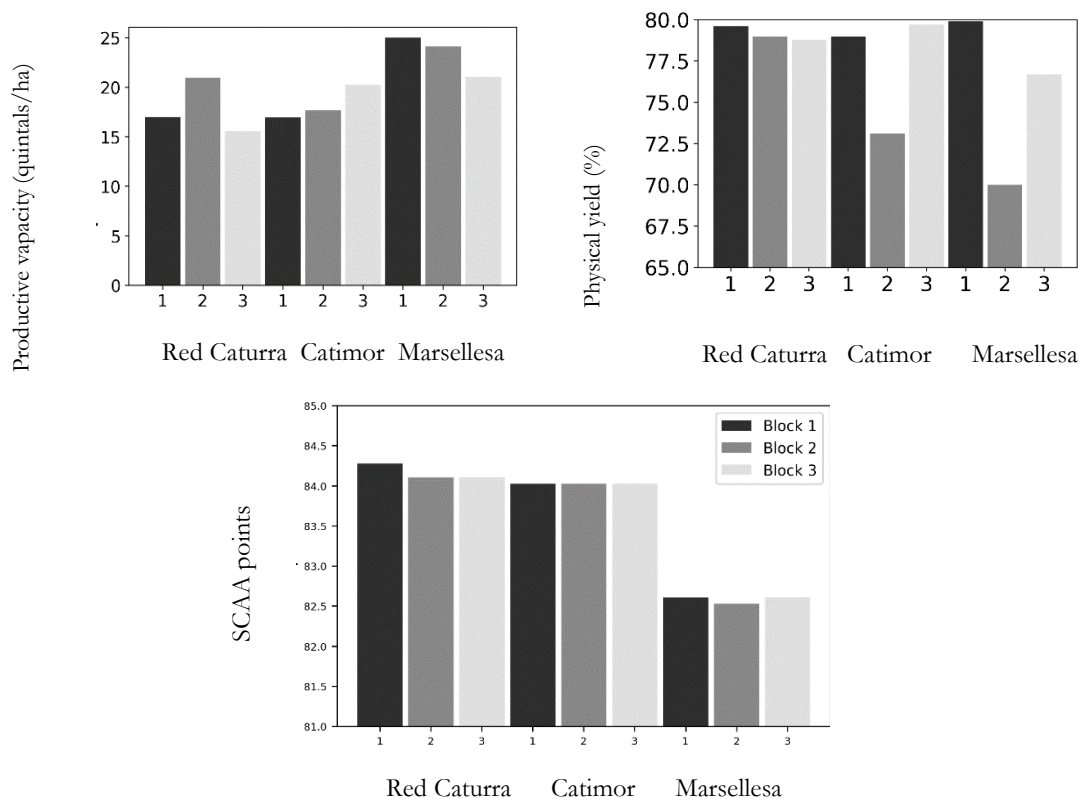


Figure 3. Productive capacity (quintals/ha), yield (%), and organoleptic quality (SCAA points) are based on five cups per sample. Black: Block 1, Gray: Block 2, Light gray: Block 3. Source: Elaborated by the authors

Regarding the incidence of *Cercospora* (*C. coffeicola*), the cultivars under study showed no significant difference (ANOVA, $p = 0.5878$, 0.6848 , and 0.7808 , respectively, and Duncan's test) for the upper, middle, and lower branches, finding averages of incidence for Marsellesa of 0, 2.26, and 4.64 %, respectively, for Red Caturra, 0.11, 0.37, and 7.79 % respectively, and Catimor, 0.33, 1.78, and 2.53 %, respectively. The present results show that the incidence of *Cercospora* was consistently higher in the lower branches. Julca et al. (2018) reported different results, with a higher incidence in the upper branches for the Catimor and Colombia cultivars. However, this may be because of the shady planting system for this trial. These results show, on average, incidence levels below 5 % indicated as the threshold according to Julca et al. (2018). Likewise, in the present study, the three cultivars had an incidence of *Cercospora*, in its three strata of branches, except for Marsellesa, which did not evidence an incidence in the upper stratum. Thus, together with Catimor, these cultivars obtained lower incidence percentages. These results are related to the findings reported by Botelho et al. (2017) in an evaluation on 124 accessions of eight commercial cultivars of *C. arabica*. They found that the Sarchimor genotype (Marsellesa

genotype) showed the highest resistance to *Cercospora*, followed by the Timor hybrids (Catimor genotypes).

Conclusion

The Marsellesa, Red Caturra, and Catimor coffee cultivars evaluated in this study showed similar phenotypic characteristics, with Caturra's highest plant height and Marsellesa's resistance to coffee rust (*Hemileia vastatrix*) with 0 % incidence. However, the three cultivars were susceptible to *Cercospora* (*Cercospora coffeicola*).

The three cultivars showed high productivity (around 1 t/ha of dry parchment coffee) for their first year of production, with yields higher than 75 % of exportable coffee. Furthermore, they were of high organoleptic quality, as demonstrated by a Q-Grader Coffee-certified expert coffee taster scoring 84 points for Marsellesa and Caturra, making them potential candidates for excellent specialty coffees (85 points or more). Catimor, with adequate postharvest treatment, may exceed the 82 points reached in this evaluation.

Conflicts of interest

The authors declare no conflict of interest.

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