

COCOA PORCELANA SHOWS LESS VEGETATIVE VIGOUR THAN ‘VRAE 99’ AND ‘CCN 51’ AFTER REHABILITATION PRUNING, UNDER RAINFED AGRICULTURE

CACAO PORCELANA PRESENTA MENOS VIGOR VEGETATIVO QUE ‘VRAE 99’ Y ‘CCN 51’ DESPUÉS DE UNA PODA DE REHABILITACIÓN BAJO UNA AGRICULTURA DE SECANO

Toño Pariona-Ircañaupa¹, Alberto Julca-Otiniano^{2,3}, José Falconí^{2,4}, Viviana Castro-Cepero⁵ y Ricardo Borjas-Ventura^{2,6}

Abstract

Cocoa production is the livelihood of plenty of smallholders, particularly in developing countries such as Peru, where the production of *Theobroma cacao* has a social and economic impact. However, one of the most important problems in cocoa production is the low productivity caused by the aging of the cacao trees. In this context, we carried out an experiment to evaluate the response of CCN 51, VRAE 99, VRAE 15 and Porcelana genotypes to rehabilitation pruning. The pruning was done at one meter above the ground during the month of February in the district of Vizcatán del Ene (Satipo). On overall, the results pointed out that CCN 51 and VRAE 99 presented greater number, length and diameter of buds; they also showed greater number of nodes, length of internodes, length and width of leaves and fresh and dry matter than Porcelana ($p \leq 0.05$). Furthermore, CCN 51, VRAE 99 and VRAE 15 showed short acuminate apex, while all genotypes studied presented stiff texture leaves. Likewise, the color of the terminal bud was mainly red, dark red, red and light green to CCN 51, VRAE 99, VRAE 15 and Porcelana, respectively. Finally, we can conclude that CCN 51 and VRAE 99 were the most vigor genotypes and, and Porcelain the least vigorous, under harsh conditions.

Key words: shoots, genotypes, buds, growth.

Resumen

La producción de cacao es el medio de vida de muchos pequeños agricultores, particularmente en países en vías de desarrollo, como el Perú, donde la producción de *Theobroma cacao* tiene un impacto social y económico. Sin embargo, uno de los problemas más importantes que tiene la producción de este grano es su bajo rendimiento causado, entre otras cosas, por el envejecimiento de los árboles. En este contexto, se llevó a cabo un experimento para evaluar la respuesta de los genotipos CCN 51, VRAE 99, VRAE 15 y Porcelana a la poda de rehabilitación. La poda fue hecha a un metro de altura desde el suelo durante el mes de febrero en el distrito de Vizcatán del Ene (Satipo). En general, los resultados señalaron que CCN 51 y VRAE 99 presentaron mayor número, longitud y diámetro de los brotes; además, mostraron tener más cantidad de nudos y longitud de entrenudos, y largo y ancho de hojas, así como mayor peso seco y fresco comparado con Porcelana. CCN 51, VRAE 99 y VRAE 15 mostraron un ápice acuminado, mientras que las hojas de todos los genotipos estudiados tuvieron una textura rígida. Asimismo, el color de los brotes terminales fue principalmente rojo, rojo intenso, rojo y verde claro para CCN 51, VRAE 99, VRAE 15 y Porcelana. Finalmente, podemos concluir que CCN 51 y VRAE 99 fueron los genotipos más vigorosos, y Porcelana el menos vigoroso, bajo una agricultura de secano.

Palabras clave: brotes, genotipos, yemas, crecimiento.

Introduction

The cacao bean is one of the most traded agricultural commodities, particularly in developing countries such as Côte d'Ivoire, Nigeria, Ghana, Ecuador, and Peru (STATISTA, 2022), where it plays a significant economic and social role, especially for smallholders. For example, in Peru, cacao is cultivated on 143 000 hectares by over 89 000 smallholder farmers, and its production has contributed to the eradication of cocoa plantations in various regions. Additionally, cacao agroforestry systems provide

habitats for birds, insects, arthropods, microorganisms (Haggar *et al.*, 2019; Marsden *et al.*, 2019; Akesse-Ransford *et al.*, 2021), and plants (Raneri *et al.*, 2021), while also mitigating the impacts of climate change (Niether *et al.*, 2020; Notaro *et al.*, 2020).

Rehabilitation pruning is an effective agronomic practice aimed at replacing old, unproductive tissue (Yacomelo-Hernández *et al.*, 2021) and those parts severely damaged by adverse conditions. It also enhances the vigour and yield of cocoa trees (Pajsi *et al.*, 2019; Vega *et al.*, 2021). However, its impact on

cocoa trees varies depending on the cultivars used (Nadaleti *et al.*, 2018) as well as environmental conditions and management practices (Meneses-Buitrago *et al.*, 2019). Temperature and rainfall have exhibited significant fluctuations in recent years due to climate change and the El Niño-Southern Oscillation, resulting in harsh conditions in many tropical regions (Fawzy *et al.*, 2020; Gateau-Rey *et al.*, 2018), including those where cocoa trees are grown.

In the case of Peruvian conditions, renovation or rehabilitation pruning is often not carried out due to social factors (Somarriba *et al.*, 2021). Other factors, such as potential yield increases or the control of pests and diseases, are also not considered when implementing this practice, leading to low productivity (approximately 0.755 t·ha⁻¹). This low yield may be attributed, on one hand, to the aging of the cacao trees. In fact, Somarriba *et al.* (2021) reported a 20% decline in yield in cocoa trees that are 30 years old. On the other hand, it may also be linked to the weather conditions in the orchards.

The response of cocoa plants to rehabilitation pruning is not well understood, which limits the ability to manage different cocoa genotypes effectively. In Peru, there is considerable genetic variability in cacao, although only a few genotypes are widely cultivated, including CCN 51, ICS 1, ICS 6, ICS 95, UF 613, IMC 67, and TSH 565 (M & O CONSULTING S.A.C., 2008). However, other genotypes, such as VRAE 99 (Forastero), VRAE 15 (Forastero), and Porcelana (Trinitario), also warrant attention (MINAGRI, 2016; Prado, 2019). Given the importance of renewing cocoa vegetative tissues, we conducted an experiment to quantify the response of four cocoa genotypes to rehabilitation pruning under harsh weather conditions in Satipo, Peru.

Materials and methods

Study site and plant material

This experiment was conducted in the district of Vizcatán del Ene, in the province of Satipo (Junín, Peru) (12° 12' 38.711" S, 74° 5' 28.94" W, 753 masl), from August 2020 to February 2021. The plant material used consisted of four cocoa genotypes (*Theobroma cacao* L.): CCN 51, VRAE 99, VRAE 15, and Porcelana, all of which were five years old. The genotypes mentioned were abandoned. For all genotypes, the rootstock used was "Criollo". In Peru, the growers use the term "Criollo" to refer to wild cocoa trees. The cocoa trees were planted with a spacing of 9.0 meters within rows and 9.0 meters between rows. Shade trees (*Parkia oppositifolia*) were planted at a spacing of 14 x 14 meters.

Treatments

The treatments consisted of the following genotypes: CCN 51 (T1), VRAE 99 (T2), VRAE 15 (T3), and Porcelana (T4). The CCN 51 genotype is the most widely cultivated in Peru, whereas Porcelana is

highly valued for its quality in the chocolate industry. The remaining genotypes are Peruvian cultivars of the Forastero variety. Each treatment was replicated five times, resulting in a total of 20 experimental units. Evaluations were conducted monthly over a period of six months.

Agronomic management

The cacao plantations were managed according to standard practices for the region. Weed control was carried out through both chemical and manual methods. Pest management involved the use of chemical control, such as chlorpyrifos. Due to restrictions imposed by the COVID-19 pandemic, certain inputs, including fertilizers, were limited, resulting in the soil not being fertilized. Additionally, the experiment did not include supplemental irrigation.

Rehabilitation pruning

Regarding the rehabilitation pruning, it was carried out in August, when precipitation was at its lowest for the year (12 mm), and conversely, midday temperatures were at their highest (around 40 °C). The rehabilitation, or renovation, pruning was performed 1 meter above the ground (Quiroz & Amores, 2012), using a chainsaw and pruning saw to remove the treetops. Additionally, suckers were removed on a fortnightly basis

Variables

The evaluated variables were classified into environmental, quantitative, and qualitative categories. Regarding the environmental variables, temperature (°C) was measured at 6, 12, and 18 hours, and precipitation (mm) was recorded at the study site. The methodology for quantifying rainfall followed the approach suggested by Titchmarsh (2015). The quantitative variables included: a) Number of buds: This evaluation began 15 days after pruning (DAP) and continued until 45 DAP. At that point, only the appropriate buds were retained, and the remaining ones were removed. However, the appearance of new buds was recorded fortnightly over six months. b) Length (cm) of selected buds: This variable was measured starting 30 DAP and was recorded fortnightly for six months. c) Diameter (mm) of buds. d) Number of plagiotropic branches. e) Number of leaves. f) Number of nodes on buds. g) Length (cm) of internodes of buds. h) Length (cm) of the leaf blade. i) Width (cm) of the leaf blade. j) Length (cm) from the base to the widest point of the leaf blade. k) Length (mm) and diameter (mm) of the petioles. l) Length-width ratio. m) Fresh and dry mass: For the dry mass, plant material was dried in the open field for five days at 30 °C.

Regarding the qualitative traits, the following variables were described: color of terminal buds (INIFAP, 2014), shape of the leaf base (Perea *et al.*, 2013), shape of the leaf apex (Perea *et al.*, 2013), shape of the leaves, and leaf texture (Franco-Portillo *et al.*, 2019). All of these evaluations were conducted at the end of the experiment.

Statistical analysis

The statistical design was completely randomized. ANOVA was performed on the obtained data, and mean comparisons were conducted using the Tukey test at a 95% confidence level. For the qualitative traits, descriptive statistics were used.

Results and discussions

According to ICCO (2021), *T. cacao* requires an average annual precipitation ranging from 1 150 to 2 500 mm and temperatures between 18 and 32 °C. Regarding precipitation in our study area, the data showed a steady increase from August to February, ranging from 12 to 555 mm, with the highest peak occurring in January. August, September, and October had the lowest precipitation, with 12, 30, and 73 mm, respectively. From November to January, rainfall increased from 113 to 555 mm, after which it decreased to 368.5 mm in February (Table 1).

Regarding temperature (Table 1), measurements were taken at 6 h, 12 h, and 18 h, with the highest temperatures recorded at midday (34.8 - 41.5 °C) throughout the experiment. The months with the highest midday temperatures were from August to October. In contrast, the mean monthly temperature showed little variation (26.2 - 29.4 °C). However, a slight difference can be observed between temperatures from August to October (28.6 - 29.4 °C) and from November to January (26.2 - 28.2 °C).

Table 1. Temperature and precipitation during the assessment of cacao in Satipo, Peru.

Time (h)	Temperature (°C)						
	2020			2021			
	August	September	October	November	December	January	February
6	20.08	21.02	22.1	23.85	23	23.4	24.2
12	41.5	40.2	41.7	34.33	32.8	30.1	34.8
18	26.7	24.7	24.0	21.9	25.0	25.2	25.6
Mean	29.4	28.6	29.3	26.7	26.9	26.2	28.2
Precipitation (mm)							
	12	30	73	113	213	555	368.5

This study demonstrated the occurrence of harsh conditions, characterized by low precipitation and high temperatures, for a period of three months (from August to October). A similar situation has been reported by Kaba *et al.* (2021) in Ghana, Nigeria, Trinidad and Tobago, and Costa Rica, where many growers observed extended periods of low precipitation. Overall, these weather conditions can

disrupt key physiological processes (Nath *et al.*, 2019; Fraga Junior *et al.*, 2021), negatively affecting the growth of the aerial parts of the plants, although the response is influenced by the genetic material. Additionally, studies on other species have shown that the effects of isolated stresses differ from those of combined stresses (Borjas-Ventura *et al.*, 2019). However, few studies have investigated the impact of both stresses on cacao (Borjas *et al.*, 2019) following pruning.

The number of buds was recorded throughout the experiment. The higher temperatures and lower precipitation observed between August and October did not limit the vegetative growth of the cacao trees after pruning, although the response varied depending on the genotype (Table 2). All buds that appeared up to 45 DAP were counted, and soon after, most were removed, leaving only those that would form the new structure of the trees. After 45 DAP, any new buds that grew were counted and immediately removed on each sampling day.

In general, up to 45 DAP, all genotypes exhibited a steady increase in the number of buds over time. At the end of this period, CCN 51 had more buds than the other genotypes ($p \leq 0.05$), with nearly 100% more than VRAE 99 and 300% more than both VRAE 15 and Porcelana. From 60 to 180 DAP, the appearance of new buds was similar ($p \leq 0.05$) across all genotypes.

The length, diameter, number of leaves, and number of plagiotropic branches of the buds chosen to reconstitute the cacao trees were evaluated (Table 2). At 90 DAP (October), CCN 51 and VRAE 99 exhibited the most notable values for both bud length and diameter. In contrast, Porcelana showed the lowest values for these parameters. At the end of the experiment (180 DAP), the same trend was observed: Porcelana presented the lowest values ($p \leq 0.05$) for all the aforementioned variables. Conversely, CCN 51 and VRAE 99 were the most remarkable, although statistically similar to each other, indicating that they possess high vegetative vigor, enabling them to withstand harsh conditions such as high temperatures and reduced rainfall.

Overall, vegetative vigor (VG) is defined as the recovery ability of plants after both abiotic and biotic stresses, or following excessive fruit set or other intensive agronomic practices such as pruning (Krohling *et al.*, 2021). In some cases, VG is associated with productivity (Akpertey *et al.*, 2019), although VG alone does not guarantee an increase in yield, as demonstrated in other cacao genotypes (Pang & Lockwood, 2008). These results suggest that, in the case of Porcelana, it may produce a lower number of flowers and pods (Báez, 2019). The greater vigour of CCN 51 was reported by Leiva-Rojas *et al.* (2019).

Table 2. Quantitative traits evaluated in different days after the pruning (DAP) in Satipo, Peru.

	Days after the pruning											
	15	30	45	60	75	90	105	120	135	150	165	180
	Number of buds											
T1	0.0 B	27.4 A	40.6 A	5.0 AB	3.8 A	3.6 A	3.6 A	6.8 A	3.2 A	3.4 A	8.8 A	10.8 A
T2	4.8 A	12.2 B	20.3 B	4.5 AB	4.4 A	3.2 A	3.2 A	6.0 AB	1.2 A	2.0 A	10.0 A	7.6 A
T3	0.3 B	6.5 C	10.4 BC	5.6 A	3.8 A	4.2 A	4.2 A	3.4 BC	2.2 A	2.8 A	7.4 A	5.8 A
T4	0.5 B	7.1 C	11.1 BC	3.0 B	1.8 B	3.0 A	2.0 B	1.8 C	0.6 A	0.8 B	7.0 A	6.0 A
SD	2.639	8.98	13.36	1.509	1.621	0.889	1.164	2.838	2.042	2.074	3.435	5.22
	Length of buds (cm)											
T1	-	9.8 A	19.5 A	21.9 A	28.6 A	43.7 A	44.3 A	63.4 A	64.3 A	73.6 AB	82.7 AB	89.1 AB
T2	-	12.5 A	21.1 A	21.8 A	28.7 A	36.6 AB	39.3 A	62.0 A	65.5 A	80.4 A	100.9 A	101.7 A
T3	-	11.7 A	16.1 A	17.2 A	20.7 A	29.2 B	32.0 A	35.4 B	36.0 B	60.2 B	71.0 BC	76.0 BC
T4	-	12.3 A	15.0 A	19.4 A	21.3 A	22.3 B	28.0 A	30.6 B	32.8 B	38.0 C	50.2 C	63.4 C
SD		3.628	5.20	4.156	6.49	12.51	11.83	16.80	17.72	18.04	22.41	14.82
	Diameter of buds (cm)											
T1	-	-	0.44 AB	0.44 AB	0.65 A	0.82 A	0.95 A	1.20 A	1.33 A	1.39 A	1.53 A	1.74 A
T2	-	-	0.48 A	0.53 A	0.64 A	0.79 A	0.69 AB	1.10 A	1.35 A	1.42 A	1.51 A	1.9 AB
T3	-	-	0.39 AB	0.38 B	0.46 AB	0.68 B	0.72 B	0.86 B	0.92 B	0.96 B	1.21 B	1.51 B
T4	-	-	0.34 B	0.36 B	0.34 B	0.38 C	0.56 B	0.76 C	0.76 C	0.72 B	0.86 C	1.04 C
SD			0.0841	0.1003	0.1913	0.2530	0.2148	0.1996	0.3020	0.3556	0.3088	0.4281
	Number of leaves											
T1	-	-	6.4 A	6.4 AB	12.6 A	14.2 A	8.9 C	21.1 A	22.9 A	26.5 A	26.2 A	28.1 A
T2	-	-	6.4 A	7.7 AB	10.6 AB	14.4 A	11.2 BC	21.3 A	21.5 AB	21.3 AB	28.6 A	30.0 A
T3	-	-	4.9 A	5.2 B	6.7 B	13.7 A	16.6 A	17.0 AB	17.8 AB	18.8 B	22.2 B	22.1 B
T4	-	-	6.1 A	8.4 A	6.5 B	12.4 A	14.4 AB	12.0 B	11.4 B	12.0 C	12.6 B	16.0 C
SD			1.213	1.808	3.401	3.450	3.519	4.76	5.79	6.05	7.40	6.17
	Number of plagiotropic branches											
T1	-	-	-	3.6 A	2.6 A	6.3 A	8.7 A	2.5 BC	7.2 A	7.8 A	5.79 AB	9.4 A
T2	-	-	-	2.7 A	3.4 A	5.6 A	8.9 A	5.4 A	8.1 A	7.5 A	8.4 A	7.5 AB
T3	-	-	-	2.7 A	0.5 B	1.9 A	3.0 B	4.2 B	7.0 A	7.6 A	6.4 AB	4.8 B
T4	-	-	-	2.4 A	0.0 B	1.9 A	2.2 B	0.8 C	5.2 A	2.4 B	3.4 B	1.7 C
SD				0.813	1.856	3.968	3.965	2.392	4.319	3.126	3.005	4.043

T1 = CCN 51; T2 = VRAE 99; T3 = VRAE 15 y T4 = Porcelana. SD : Standard Deviation. Different letters into the column indicates statistical differences.

The number of nodes per bud and the length of internodes in each bud were measured at the end of the experiment (Table 3). For both variables, the Porcelana genotype exhibited lower values compared to the others ($p \leq 0.05$), with 14.20 nodes per bud and 2 cm internode length. In contrast, the highest values for the number of nodes per bud were recorded in CCN 51 (28.10 nodes) and VRAE 99 (32.10 nodes), while the longest internodes were observed in CCN 51 (3.4 cm), VRAE 99 (3.22 cm), and VRAE 15 (2.94 cm) ($p \leq 0.05$). These results, particularly for CCN 51 and VRAE 99, help explain the longer buds observed in both genotypes at the final sampling (180 DAP) (Table 2).

Other variables quantified were the length and width of fully mature leaves (Table 3). These measurements are commonly used to estimate leaf area and serve as indicators of the effects of external factors on cocoa seedlings (Cabezas-Gutiérrez *et al.*, 2009; Dorado, 2019), or as descriptors of cocoa cultivars (Restrepo & Urrego, 2018). It was observed that both the length and width of the leaves were smaller in VRAE 15 compared to the other genotypes ($p \leq 0.05$). In contrast, CCN 51 and VRAE 99 exhibited the highest values for these variables. This suggests that both CCN 51 and VRAE 99 may have a larger leaf area and greater capacity to intercept light (Weraduwege *et al.*, 2015) compared to VRAE 15 ($p \leq 0.05$) (Table 3). In the case of CCN 51, Rojas (2020) reported leaf lengths ranging from 28.7 to 36.6 cm, with widths

between 10.6 and 12.7 cm. Similarly, in creole cocoa, Ramos *et al.* (2020) found comparable results for the leaf width of Porcelana. Regarding the length from the base to the widest point of the leaves (LBWP), no significant differences were observed.

The length-width ratio is closely correlated with leaf shape (Shi *et al.*, 2021) and is also used to distinguish different cocoa cultivars (Bermúdez *et al.*, 2015; Gutiérrez, 2020). Our results showed that CCN 51, VRAE 99, and Porcelana had higher length-width ratios compared to VRAE 15, with values being two to three times greater (Table 3).

A structure that has been relatively understudied in cocoa is the petiole. As part of the leaf, the petiole is designed to support the leaf blade (Pasini & Mirjalili, 2006). In addition to leaf size, plants employ other strategies to capture light, such as the development of longer petioles (Black, 1960). In this study, VRAE 15 (3.32 cm) and Porcelana (1.95 cm) exhibited the longest and shortest petioles, respectively ($p \leq 0.05$) (Table 3).

On the other hand, no significant differences were observed among the genotypes studied in terms of petiole diameter (Table 3). Similarly, for both fresh and dry weight, Porcelana exhibited lower values compared to the other genotypes. However, this difference was significant when compared to VRAE 99, with Porcelana's weight being nearly half that of VRAE 99.

Table 3. Quantitative traits related to nodes and leaves of genotypes of cocoa measured in this experiment in different days after the pruning (DAP) in Satipo, Peru.

	Number of nodes per buds	Length of internodes (cm)	Length of leaf blade (cm)	Width of leaf blade (cm)	LBWP (cm)
T1	28.10 A	3.40 A	33.70 A	12.31 A	16.00 A
T2	32.10 A	3.22 A	34.75 A	12.41 A	16.41 A
T3	22.70 B	2.94 A	11.95 C	9.05 B	13.90 A
T4	14.20 C	2.00 B	27.64 B	11.95 A	14.70 A
SD	1.64	0.93	9.61	1.81	2.14
	Length/width	Length of petiole (cm)	Diameter of petiole (cm)	Fresh matter of branches	Dry matter of branches
T1	2.73 A	2.85 B	0.37 A	0.40 A	0.19 AB
T2	3.09 A	2.78 B	0.34 A	0.46 A	0.21 A
T3	1.00 B	3.32 A	0.39 A	0.34 AB	0.16 AB
T4	2.73 A	1.95 C	0.33 A	0.21 B	0.12 B
SD	0.9	0.75	0.06	0.13	0.05

LBWP: Length from base to widest point. T1 = CCN 51; T2 = VRAE 99; T3 = VRAE 15 y T4 = Porcelana. Different letters into the column indicates statistical differences. SD: Stantard Deviation.

Qualitative characteristics were recorded (Figures 1 and 2), which are commonly used to distinguish differences among genotypes (Phillips-Mora *et al.*, 2012; Restrepo & Urrego, 2018; Ramos *et al.*, 2020). Variability was observed in certain leaf traits. For instance, CCN 51, VRAE 99, and VRAE 15 primarily exhibited rounded leaf shapes with short acuminate apices, while Porcelana presented leaves with an acute base and a long acuminate apex. Regarding leaf shape, CCN 51, VRAE 99, and Porcelana displayed an ovate form, whereas VRAE 15 had oblong leaves. Interestingly, all genotypes studied had stiff leaves. Additionally, the color of terminal buds varied by genotype: CCN 51, VRAE 99, VRAE 15, and Porcelana showed red, dark red, red, and light green terminal buds, respectively.

Conclusion

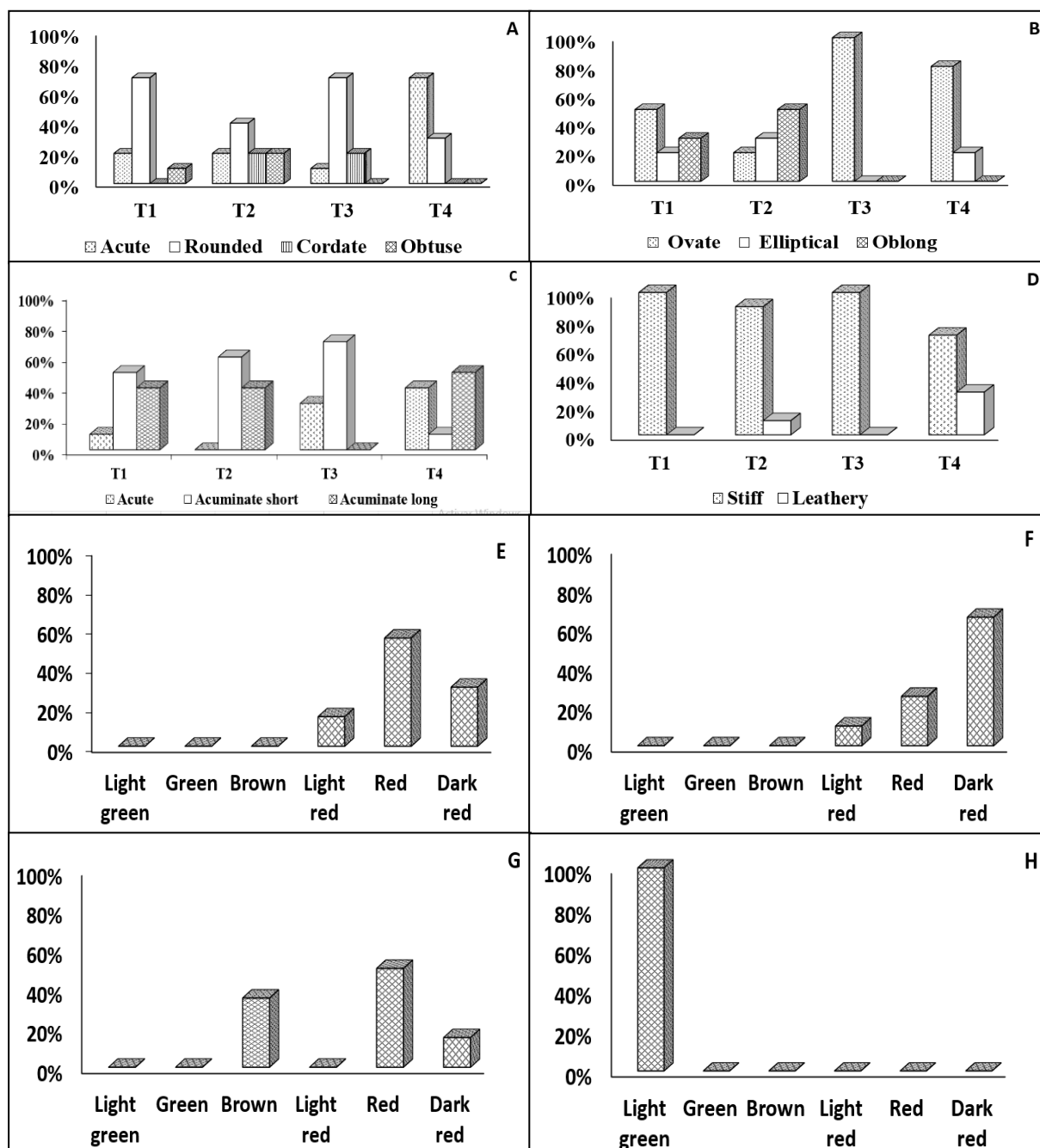
CCN 51 and VRAE 99 demonstrated the greatest vigour as evidenced by their higher number, length, and diameter of buds. Both genotypes maintained their vigor even when rainfall began. Throughout the experiment, Porcelana was the weakest. By the end of the study, CCN 51 and VRAE 99 exhibited the highest values for the number of nodes, internode length, leaf length and width, as well as fresh and dry weight of branches. Distinct qualitative traits were observed, such as the rounded shape of the leaf base in CCN 51, VRAE 99, and VRAE 15, which also displayed short acuminate apices, while all genotypes exhibited stiff leaf texture. The color of the terminal buds varied, with CCN 51, VRAE 99, VRAE 15, and Porcelana showing predominantly red, dark red, red, and light green terminal buds, respectively.

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T1 = CCN 51; T2 = VRAE 99; T3 = VRAE 15 y T4 = Porcelana.

Figure 1. Qualitative characteristics of the leaves of the genotypes studied in Satipo, Peru. A) Leaves base, B) Leaves shape, C) Leaves apex, D) Leaves texture, E) Colour of terminal buds of CCN 51, F) Colour of terminal buds of VRAE 99, G) Colour of terminal buds of VRAE 15 and H) Colour of terminal buds of Porcelana.

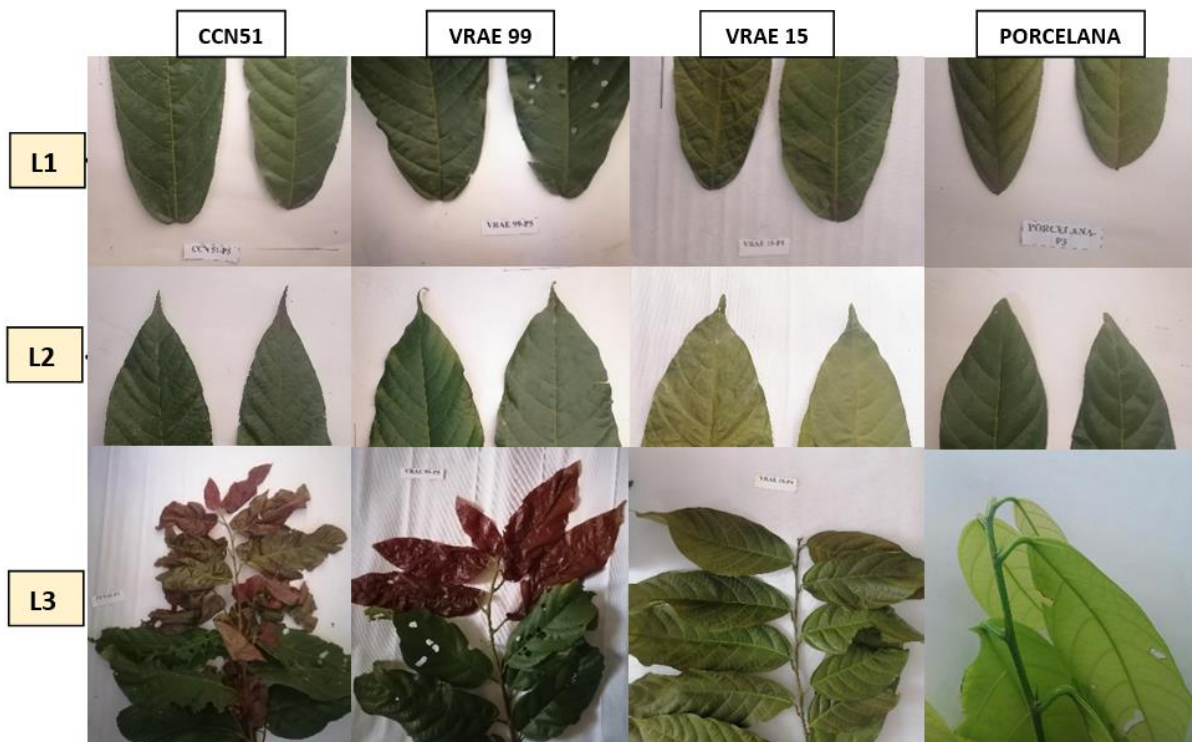


Figure 2. Photos of different qualitative characteristics of the cacao genotype studied in Satipo, Peru. L1: Leaf base; L2: Leaf apex; L3: Terminal buds.

¹ Programa de Maestría en Agricultura Sustentable. Universidad Nacional Agraria La Molina. Av. La Molina s/n, La Molina, Lima, Perú. tparionai77@gmail.com. <https://orcid.org/0000-0002-4881-4041>.

² Departamento de Fitotecnia, Facultad de Agronomía, Universidad Nacional Agraria La Molina. Av. La Molina s/n, La Molina, Lima, Perú.

³ ajo@lamolina.edu.pe. <https://orcid.org/0000-0002-3433-9032>.

⁴ jfalconi@lamolina.edu.pe. <https://orcid.org/0000-0002-5262-8209>.

⁵ Departamento de Biología, Facultad de Ciencias, Universidad Nacional Agraria La Molina. Av. La Molina s/n, La Molina, Lima, Perú. Viviana Castro: vcastro@lamolina.edu.pe. <https://orcid.org/0000-0001-8747-2665>.

⁶ rborjas@lamolina.edu.pe. <https://orcid.org/0000-0001-7819-1810>.