Research article

Growth and development of the vegetative phase of local cherimoya (*Annona cherimola*, Annonaceae) materials under premontane moist forest conditions in Colombia

Crecimiento y desarrollo de la fase vegetativa de materiales locales de chirimoya (*Annona cherimola*, Annonaceae) en condiciones de bosque húmedo premontano en Colombia

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Abstract:

Background and Aims: Cherimoya (*Annona cherimola*) cultivation in Colombia relies on seed-propagated trees, resulting in high variability within orchards characterized by limited technical management and unknown growth patterns. Therefore, the objective of this study was to characterize the vegetative budding behavior and development of six local materials under premontane moist forest conditions in Tibacuy, Cundinamarca. Specifically, the study evaluated the influence of branch type (primary *vs.* secondary), spatial distribution of budding, shoot typology, growth dynamics (BBCH scale), and the thermal requirements associated with each phenological phase.

Methods: Trees in the productive phase were selected within a commercial orchard, and their architecture was standardized through selective pruning. Following manual defoliation, phenology was monitored weekly according to the BBCH scale, and the growth of 88 new shoots was analyzed. Data were processed using Generalized Linear Models (GLM) for bud break, non-parametric tests (Kruskal-Wallis) for branch classification, and Spearman correlations for climatic response.

Key results: Observed phenology validated the applicability of the subtropical BBCH scale. Budding was predominantly single-type (>77%) and acrotonic, being significantly higher in secondary branches compared to primary ones. Morphometric analysis statistically differentiated four branch categories (Short, Medium, Long, and Very Long). Notably, the Very Long category exhibited a biphasic growth pattern. Longitudinal growth showed thermal regulation, where the mean temperature recorded 8-14 days prior negatively affected the elongation rate (r_s = -0.471, P = 0.031).

Conclusions: This study provides the first phenological characterization of cherimoya in the premontane moist forest, indicating that the vegetative cycle responds to local variability: precipitation triggers bud break, while temperature modulates elongation speed. Morphologically, the identification of branches with biphasic growth and genotypes with homogeneous lateral distribution reflects an adaptive plasticity valuable for optimizing pruning strategies and agronomic management in the region.

Key words: BBCH, phenology, shoots, sympodial branching, tree architecture.

Resumen:

Antecedentes y Objetivos: El cultivo de chirimoya (*Annona cherimola*) en Colombia, basado en árboles de semilla, presenta alta variabilidad y desconocimiento técnico. Por lo tanto, el objetivo de este estudio fue caracterizar el comportamiento de la brotación y el desarrollo vegetativo de seis materiales locales en condiciones de bosque húmedo premontano en Tibacuy, Cundinamarca. Específicamente, se evaluó la influencia del tipo de rama (primaria *vs.* secundaria), la distribución espacial de la brotación, la tipología de los brotes, la dinámica de crecimiento y los requerimientos térmicos asociados a cada fase fenológica.

Métodos: En un huerto comercial se seleccionaron árboles en etapa productiva y se estandarizó su arquitectura mediante poda selectiva. Tras una defoliación manual, se monitoreó la fenología semanalmente según la escala BBCH y se analizó el crecimiento de 88 brotes nuevos. Los datos se procesaron mediante Modelos Lineales Generalizados (GLM) para la brotación, pruebas no paramétricas (Kruskal-Wallis) para la clasificación de ramas y correlaciones de Spearman para la respuesta climática.

Resultados clave: La fenología observada validó la aplicabilidad de la escala BBCH subtropical. La brotación fue predominantemente de tipo simple (>77%) y acrótona, siendo significativamente superior en ramas secundarias respecto a las primarias. El análisis morfométrico diferenció estadísticamente cuatro categorías de ramas (Cortas, Medianas, Largas y Muy Largas). Notablemente, la categoría “Muy Larga” exhibió un patrón de crecimiento bifásico. El crecimiento longitudinal mostró una regulación térmica, donde la temperatura media registrada 8-14 días previos afectó negativamente la tasa de elongación (r_s = -0,471, P = 0,031).

Conclusiones: El ciclo vegetativo en el bosque húmedo premontano responde a la variabilidad local: la precipitación detona la brotación y la temperatura modula la elongación. La identificación de ramas con crecimiento bifásico y distribución lateral homogénea refleja una plasticidad útil para optimizar el manejo agronómico regional.

Palabras clave: arquitectura del árbol, BBCH, brotes, fenología, ramificación simpodial.

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Received: October 27, 2025.
Reviewed: November 18, 2025.
Accepted by Marie-Stéphanie Samain: February 4, 2026.

Published: Acta Botanica Mexicana 133 (2026).

To cite as: Borbón-Guevara, J. and D. Miranda-Lasprilla. 2026. Growth and development of the vegetative phase of local cherimoya (*Annona cherimola*, Annonaceae) materials under premontane moist forest conditions in Colombia. Acta Botanica Mexicana 133: e2528. DOI: https://doi.org/10.21829/abm133.2026.2528

e-ISSN: 2448-7589

Introduction

Cherimoya (*Annona cherimola* Mill., Annonaceae) is a fruit tree that, although historically associated with the Andean region, has recent molecular evidence identifying Mesoamerica as its center of origin, establishing the Andes as a secondary center of diversity (Larranaga et al., 2017; 2024). Currently, it is widely distributed in subtropical and cool highland regions, such as the slopes of the Andes (Datiles and Acevedo-Rodriguez, 2014). It is highly valued globally as an important commercial crop, extensively cultivated in Spain, Peru, and Chile for fresh fruit export (Datiles and Acevedo-Rodríguez, 2014; Larranaga et al., 2024).

Technified cherimoya cultivation begins with the selection of genetic materials, grafting seed-derived plants or generating disease-resistant rootstocks (George and Nissen, 1987). The grafted cultivars are varieties selected for their high yield and fruit quality, with materials such as ‘Fino de Jete’, ‘Cumbe’, White’, and ‘Bays’ (Grossberger, 1999; Guirado et al., 2003; Flores, 2013).

Cultivation in the subtropics exhibits seasonal growth; its management begins with pruning after leaf shedding. Subsequently, budding occurs in May and June in California (USA) and the Costa del Sol (Spain; Grossberger, 1999; Lora et al., 2006) and in November and December in Chile (Ibacache et al., 1999; Razeto and Díaz de Valdés, 2000). These shoots can be vegetative or mixed when they bear flowers (Guirado et al., 2003). Existing cultivation in the tropics is located in mountainous areas, favored by temperatures between 15 and 25 °C and a precipitation regime between 600 and 1700 mm annually (Larranaga et al., 2024). In Ecuador, it has been observed that budding responds to defoliation and precipitation or irrigation, allowing for the adjustment of associated management practices (Vásquez et al., 2024). However, this type of information remains non-existent in Colombia, where the cultivated materials are mostly local, seed-propagated, non-grafted, and adapted to the environmental conditions (Borbón, 2021), for which reason their budding and vegetative growth pattern is unknown.

Cherimoya is a perennial plant, with a development cycle in continuous stages: growth – maturity – senescence and dormancy – growth. Furthermore, its leaves are deciduous, tending to shed before spring, and it is considered a semi-deciduous species (Rosell et al., 1997; Vásquez et al., 2024). Budding cannot begin until the leaves have been removed or have shedded, as the buds are covered by the base of the petiole (Paull and Duarte, 2025). The buds are compound or multi-buds (Vásquez et al., 2024). In the ‘Fino de Jete’ variety, the buds contain three to five meristems that originate vegetative or mixed shoots (Soler and Cuevas, 2009). In the atemoya hybrid (*Annona cherimola* × *Annona squamosa* L.), shoot growth exhibits sympodial branching (Olesen and Muldoon, 2009).

Vegetative growth of cherimoya shoots is affected by ambient temperature. Experiments in Okinawa (Japan) observed that seedlings from seeds of the ‘Big Sister’ variety had greater growth under a 30/25 °C day/night temperature regime compared to seedlings growing at 20/15 °C day/night (Higuchi et al., 1998). In three-year-old plants, during the first month of budding, vegetative shoots grew faster under the warm temperature regime; however, their length was shorter, whereas, at three months, shoot length, leaf number, and leaf area were greater at 20/15 °C (Higuchi et al., 1998). It has been observed that, under greater shade, shoot length and leaf thickness decrease, but specific leaf area increases (Higuchi et al., 2001). Meanwhile, under field conditions in Chile, at a latitude of 29°S, plants of the ‘Concha Lisa’ variety had shoots that grew between 70 and 82 cm in length over a period of about five months, a period during which there was also rapid root growth (Ibacache et al., 1999). Knowledge of growth and branching processes allows for the optimization of tree architecture manipulation (Costes et al., 2006). In this context, analyzing the branch type is essential, as the architectural model of tropical trees (Hallé et al., 1978) suggests that structural axes (primary branches) and reiteration units (secondary branches) may exhibit distinct physiological behaviors. Cautín (2008) noted categories of branches in the ‘Concha Lisa’ variety according to their vigor and their response to two pruning systems, indicating that shoots in the weak and semi-vigorous categories have a higher fruiting capacity index, associated with a greater quantity of fruits.

In Colombia, the production zones for *A. cherimola* are found in productive niches in the departments of Boyacá, Cundinamarca, Nariño, and Antioquia at elevations between 1800 and 2200 m a.s.l. (Delgado Ortiz, 2005). However, the technical management of this species is deficient, both in the productive niches and in the rest of Colombia (Borbón, 2021). Moreover, its edaphoclimatic requirements and the phytosanitary management of identified pests and diseases are lacking (Franco and Villamil, 1988). In addition to these challenges, Toro (2009) added that there is no infrastructure such as specialized nurseries, the market is unknown, both in its supply and demand, specialized labor is absent, postharvest handling problems exist, and there is no technology adoption or entrepreneurial leadership. The NRC (1989) indicated that cultural practices for cherimoya management are complex. Therefore, one of the research lines should be the simplification of crop management. These structural problems have kept cherimoya cultivation in a position of little relevance in the Colombian context, leading to a scenario in which the disappearance of the species is perceived by both farmers and consumers, possibly due to the current supply and demand situation, or due to changes in consumption habits (Avendaño et al., 2022).

Given the lack of knowledge about the vegetative shoot growth pattern of local cherimoya materials in Colombia, this study aimed to characterize the vegetative budding behavior and its development in six local cherimoya materials under premontane moist forest conditions in Tibacuy, Cundinamarca. Specifically, the study aimed to evaluate the influence of branch type (primary *vs.* secondary) and spatial distribution on budding success, analyze shoot typology, determine growth dynamics based on the BBCH scale (Cautín y Agustí, 2005), and establish the thermal requirements associated with each phenological phase. This information allowed for the establishment of a basis for proposing agronomic management strategies adapted to the local materials in their environment.

Materials and Methods

Location and plant material

Observations were conducted between October 2023 and June 2024 on cherimoya trees existing in an orchard located in the municipality Tibacuy, Cundinamarca (4°20'53.22''N, 74°27'29.89''W) at an elevation of 1786 m a.s.l. and with a slope of 39.5%. The trees were planted in October 2018, at a spacing of 6 × 6 m. The plant material was obtained through sexual reproduction, from seeds obtained from fruits of local materials or from fruits from the Bogotá market.

The study site has a mean annual temperature of 22 °C and a bimodal precipitation regime (1152.8 mm annual average; IDEAM, 2024), typic of a premontane moist forest. *In situ* temperature and relative humidity were logged hourly using a UNI-T Function UT330B datalogger (August 2023-August 2024, Dongguan, China), and daily precipitation data was obtained from IDEAM pluviographic station 21190030. The soil was characterized as deep to shallow with good drainage, and its fertility status is presented in Table 1.

Selection and management of plant material.

In the orchard, six cherimoya trees (materials A-F) were selected from a homogeneous stand free of shade. Since the trees were seed-propagated and exhibited natural variability, experimental units were standardized through formative pruning to establish a common architecture, all tertiary branches were removed, leaving three primary branches on each tree. Each primary branch retained three secondary branches. This resulted in a uniform load of approximately 39 nodes per primary branch used for the study. Manual defoliation was performed on September 10, 2023 (Day 0), to expose the buds and synchronize shoot development. Fertilization followed a standard protocol adapted from Villavicencio and Vásquez (2008) consisting of the application of 100 g of urea, 40 g of DAP, and 100 g of KCl and 20 g of Agrimins 8-5-0-6 per tree every six months.

Measurement of vegetative budding and shoot development

The total number of nodes above 50 cm from the ground was counted on the primary and secondary branches of the

Table 1: Soil fertility analysis in the plot with the cherimoya crop, June 2018, Cundinamarca, Colombia.OM: Organic Matter; CEC: Cation Exchange Capacity; EC: Electrical Conductivity.

pH	OM	Ca	K	Mg	Na	CEC	P	S	Cu	Fe	Mn	Zn	B	EC
	%	meq/100g					mg/kg							dS/m
5.66	12.6	7.76	0.21	2.23	<0.14	10.43	6.78	3.65	<1.0	337.3	4.75	1.64	0.09	0.14

six trees. At 204 days after defoliation, the total number of new shoots was counted, and the budding percentage was calculated by branch type. Shoot types were categorized as single, double, or triple based on the number of buds sprouted at each node (Fig. 1). Budding location was classified into three categories: basal (0-32%), medial (33-66%), and terminal (67-100%) sections of the branch length.

Additionally, during the onset of budding, 25 days after defoliation, four nodes with buds in mesostage 07 (beginning of bud burst: first green leaf tips just visible) or 09 (green leaf tips about 5 mm above bud scales) of the BBCH phenological scale (Cautín and Agustí, 2005) were selected from each of the three primary branches of each tree, reaching a total of 72 selected nodes. All vegetative shoots emerging from these nodes were marked and monitored (resulting in a final sample size of n = 88, accounting for multiple shoots per node). At each node, the length of each shoot was measured *in situ* with a 6-inch Ubermann® digital caliper (China), starting from the base of the shoot to the base of the petiole of the last unfolded leaf or to the scar left by the shedding of the active growing point (Fig. 2). Shoot length, number of leaves, and number of nodes formed were measured weekly until senescence (BBCH mesostage 97: All leaves shed). Basal diameter was measured at the final monitoring.

Phenological observations were conducted weekly based on the BBCH scale established for cherimoya by Cautín and Agustí (2005). Given the non-seasonal tropical conditions, specific adaptations to the original scale were implemented: the "summer" and "spring" references were replaced by the onset of the wet season as the physiological trigger, and stage transitions were defined by organ development rather than calendar dates.

Finally, shoots were grouped by length into four categories established in this study based on the final length observed at 245 days after defoliation (DAD): Short (<60 mm), Medium (61-160 mm), Long (161-650 mm), and Very Long (continuously growing shoots >651 mm) for comparative analysis.

Estimation of degree days

For the calculation of accumulated growing degree days (GDD), the daily mean temperature (Tmean) was first calculated as the average of the hourly temperature recordings:

$$Tmean = \frac{\sum_{i=1}^{24} Ti}{24} \qquad (1)$$

Where *Ti* is the temperature recorded at hour *i*. Subsequently, the accumulated GDD were calculated as follows:

$$GDA = \sum_{i=1}^{n} Tmean - Tb \qquad (2)$$

Where *Tb* is the base temperature established at 14 °C (Soler and Cuevas, 2013) and *n* represents the number of

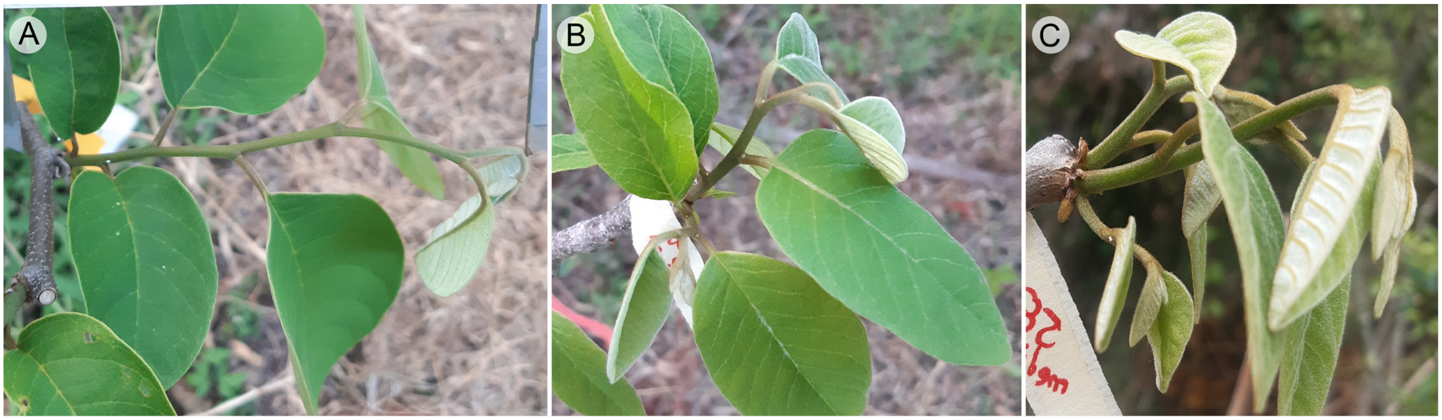


Figure 1: Photographs of shoot types according to the number of shoots at a node of cherimoya, Cundinamarca, Colombia. A. single; B. double; C. triple. Photographs: Javier Borbón-Guevara.

days it took for the shoot to reach the corresponding phenological stage. Accumulation began at defoliation, excluding days where mean temperatures fell below *Tb*.

Experimental design, data processing and statistical analysis

Data were collected and organized in Microsoft Excel (Office 365), and graphs were generated using SigmaPlot v. 14.0 (Systat Software, San Jose, CA, USA). Statistical analyses were performed using R software v. 4.4.3 (R Core Team, 2024) with the 'agricolae', 'car', 'emmeans', and 'tidyverse' packages. The analytical procedure consisted of three stages.

First, regarding bud break dynamics and architecture, a Generalized Linear Model (GLM) with a binomial distribution and logit link function was fitted to evaluate the interaction between material and branch type on bud break percentage. Significance was determined via Analy-

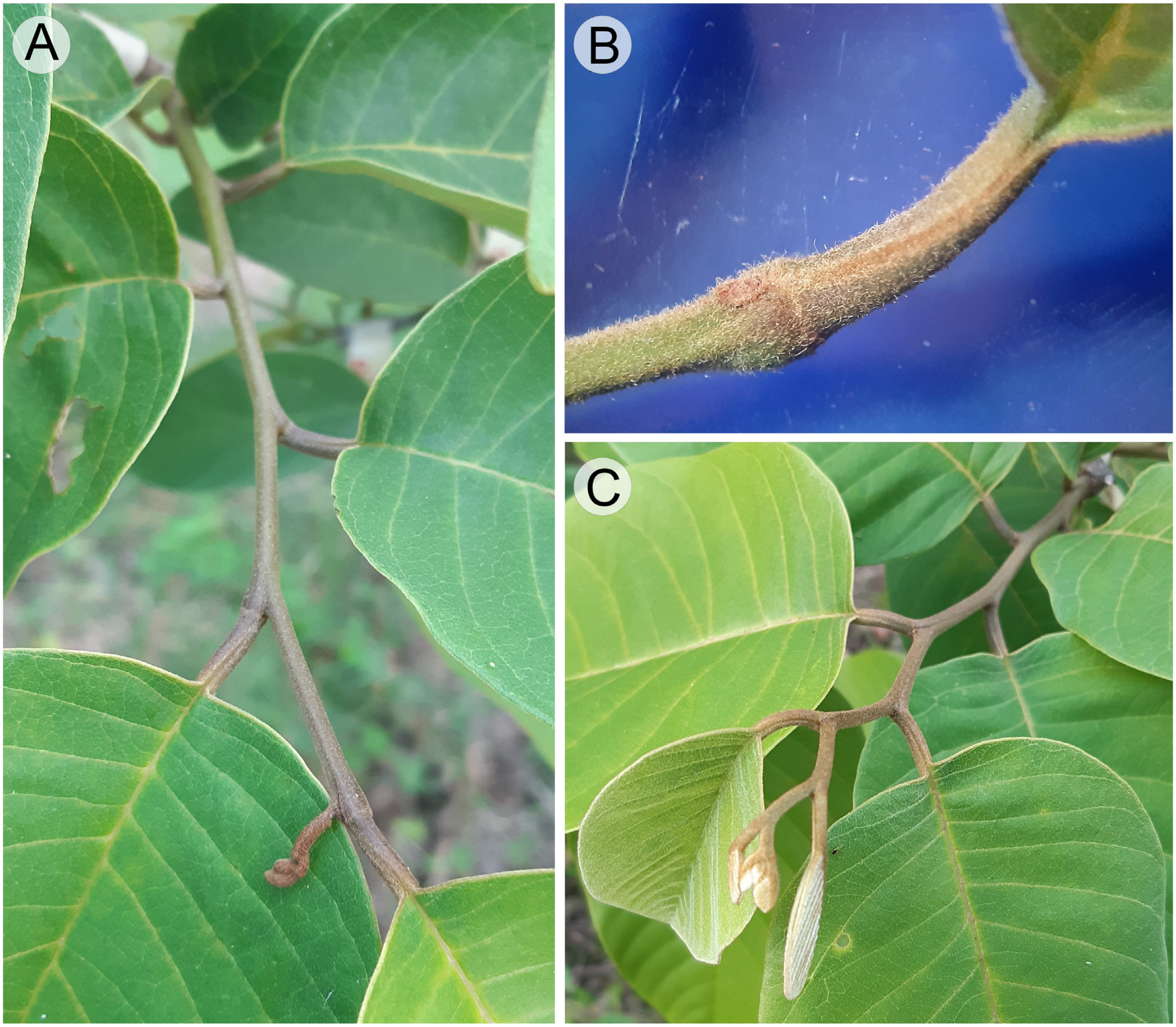


Figure 2: Photographs of vegetative shoot apices of cherimoya, Cundinamarca, Colombia. A. apex with an oxidized growing point about to shed; B. detail of the apex with the scar where the growing point was located; C. shoot apex with an active growing point. Photographs: Javier Borbón-Guevara.

sis of Deviance (Type II ANOVA), and mean separation was performed using estimated marginal means (emmeans) at *P*<0.05. Furthermore, for shoot typology (single, double, triple) and topological distribution (basal, medial, terminal), pairwise proportion tests with Bonferroni correction were used for multiple comparisons within each material (α = 0.05).

Second, for longitudinal growth variables, normality and homoscedasticity were assessed using Shapiro-Wilk and Levene tests, respectively. Based on data distribution, differences were analyzed using ANOVA (parametric) or Kruskal-Wallis (non-parametric) tests. Post-hoc multiple range tests were applied where significant differences were found (*P*<0.05).

Finally, the association between growth rate and environmental variables was evaluated using Spearman's rank correlation coefficient (*r*s), including time lags for precipitation (0-7 days) and mean temperature (8-14 days). This analysis focused specifically on the weekly shoot growth rate (Δ mm) of the most vigorous shoots (Long and Very Long categories) to capture the maximum physiological potential.

Results

Climatic conditions of the study area

The daily variation in temperature and precipitation in the study area during the vegetative shoot growth and development period is shown in Fig. 3. The mean temperature (Tmean) was 19.87 °C (± 4.07), with a variation between the average minimum temperature (Tmin) of 15.79 °C (± 0.96) and the average maximum (Tmax) of 27.68 °C (± 3.52). The highest mean and maximum temperatures were recorded during September-October 2023 and January-March 2024 (Fig. 3). The average relative air humidity during the observed period was 88.65% (± 12.72), with the lowest averages recorded in September 2023 and January 2024.

Regarding precipitation, two peaks were recorded: one between the months of October, November, and December 2023, with precipitation of 113.5, 133.1, and 115.3 mm, respectively; while the second was recorded between April and May 2024, with 104.3 and 101.9 mm of rain, respectively. The driest months were September 2023, January 2024, and July 2024.

Distribution, type, and location of vegetative shoots

The analysis of deviance of the Generalized Linear Model (GLM) revealed a significant interaction between material and branch type regarding the probability of bud break (χ2 = 12.42, df = 5, *P* = 0.029). In general, secondary branches showed a statistically higher bud break percentage than primary branches across most materials (Table 2). Specifically, primary branches of materials A, B, C, and D exhibited a higher bud break percentage compared to materials E and F. In contrast, secondary branches showed variable behavior among materials.

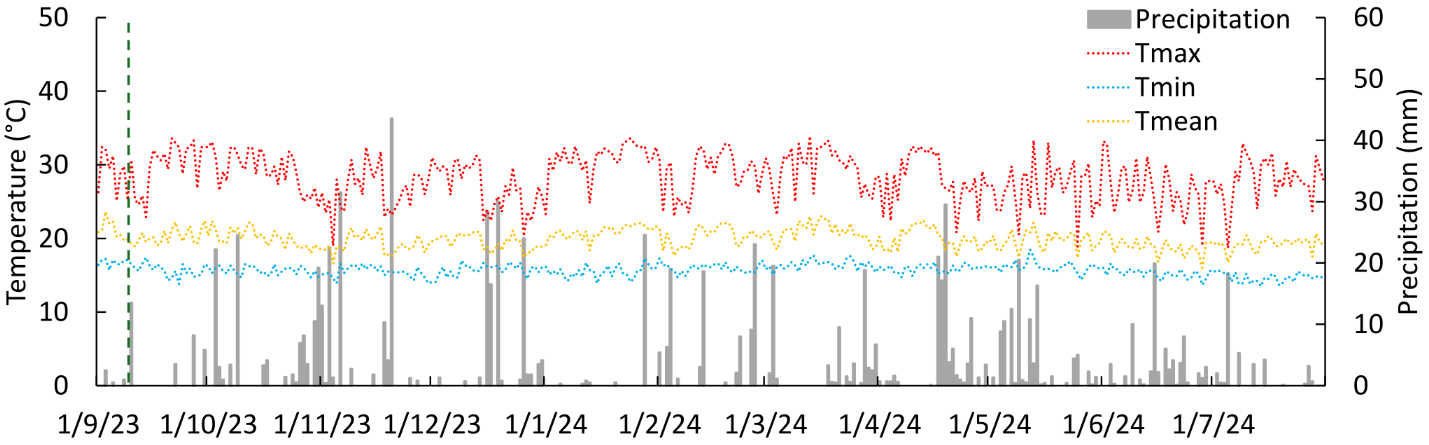


Figure 3: Daily maximum, minimum, and average temperatures, along with daily precipitation, in the study area, Cundinamarca, Colombia, between September 1, 2023, and July 31, 2024. The dashed vertical line indicates the defoliation event for trees.

Regarding shoot typology, pairwise proportion tests confirmed that the frequency of single shoots was significantly higher than that of double and triple shoots in all materials ($P<0.05$). Single shoots accounted for 69.2% to 90.9% in primary branches and 73.7% to 95.8% in secondary branches. Double shoots were present in all materials (ranging from 4.2% to 26.3%), while triple shoots were only observed in primary branches of two materials, with low proportions (2.6% and 7.7%). No nodes with four or more shoots were observed.

Concerning spatial distribution, an acrotonic pattern (increasing gradient towards the terminal part) was observed in materials A, D, and F ($P<0.05$). In these cases, the terminal zone presented bud break percentages statistically superior to those of the basal zone. However, this behavior was not uniform; for instance, in the primary branches of material B or secondary branches of material C, the distribution was statistically homogeneous despite numerical differences between the base and the tip.

Vegetative growth dynamics and shoot characterization

The phenological progression observed in the local materials, which were differentiated into four branch vigor categories (Fig. 4), successfully validated the applicability of the BBCH scale described for subtropical conditions (Cautín and Agustí, 2005), confirming that Colombian cherimoya follows the same four principal developmental stages despite the climatic differences (Table 3; Figs. 5, 6, 7, 8).

Longitudinal growth across all branch categories followed a sigmoid pattern (Fig. 9), characterized by rapid elongation followed by stabilization. Bud break (BBCH 07-09) occurred in all six materials at 28 DAD. The cessation of elongation (BBCH 91) varied by category: earliest in Short branches (56-69 DAD), followed by Medium and Long categories (83-108 DAD).

After elongation and lignification (245 DAD), a total of 88 branches (emerging from the 72 nodes) were classified into four discrete categories based on their final length. Morphometric analysis revealed a significant interaction between material and branch category (Table 4). Non-parametric tests confirmed marked statistical differences for length (Kruskal-Wallis, H = 78.66, df = 19, $P<0.001$), number of nodes (H = 73.36, $P<0.001$), and basal diameter (H = 73.96, $P<0.001$).

The Very Long branches (exclusive to materials A and B) exhibited the maximum values, differing statistically from the rest. In material A, they reached an average length

Table 2: Vegetative bud break and shoot architecture in primary and secondary branches of six local cherimoya materials (Cundinamarca, Colombia). Bud break values represent mean ± SE. Different letters indicate significant differences ($P<0.05$): uppercase (primary) and lowercase (secondary) compare materials (GLM, emmeans); letters for 'Shoot type' and 'Location' compare categories within rows (Bonferroni proportion test). Location segments: Basal (0-33%), Medial (34-66%), Terminal (67-100%).

Tree	Branch type	Bud burst (%)	Type of shoot (%)			Location of shoot (%)		
			Single	Double	Triple	Basal	Middle	Terminal
A	Primary	27.1±4.8 AB	87.0 A	13.0 B	0 C	3.6 B	32.1 A	44.8 A
	Secondary	46.9±7.1 a	91.3 a	8.7 b	0 c	0 b	42.9 ab	81.0 a
B	Primary	31.1±4.5 A	90.9 A	9.1 B	0 C	17.6 A	37.1 A	37.8 A
	Secondary	47.1±7.0 a	95.8 a	4.2 b	0 c	13.3 b	37.5 ab	80.0 a
C	Primary	27.5±4.7 AB	84.0 A	16.0 B	0 C	3.3 B	26.7 AB	51.6 A
	Secondary	48.7±8.0a	73.7 a	26.3 b	0 c	18.2 a	61.5 a	60.0 a
D	Primary	32.8±4.3 A	87.2 A	10.2 B	2.6 C	15.4 B	25.0 B	57.5 A
	Secondary	53.2±6.3 a	93.9 a	6.1 b	0 c	0 c	50.0 b	92.3 a
E	Primary	12.7±2.7 BC	90.0 A	10.0 B	0 C	6.1 AB	4.0 B	23.5 A
	Secondary	35.4±5.9 a	88.2 a	11.8 b	0 c	0 b	27.3 ab	58.3 a
F	Primary	9.0±2.4 C	69.2 A	23.1 B	7.7 C	0 B	4.2 AB	22.9 A
	Secondary	49.1±6.7 A	81.5 a	18.5 b	0 c	0 b	47.1 a	86.4 a

Figure 4: Photographs of the different branch categories of cherimoya, Cundinamarca, Colombia. A. short; B. medium; C. long or very long. Photographs: Javier Borbón-Guevara.

Table 3: Phenological stages and mesostages identified in vegetative shoots of cherimoya, Cundinamarca, Colombia, according to the BBCH scale by Cautín and Agustí (2005). References to summer (*) and spring (**) originate from the original subtropical scale. In this study, conducted under non-seasonal, these references are associated with: * the beginning of the wet season, and **between 137 and 230 days after bud break (DAD), depending on the branch category (see detailed development in subsequent sections).

Code / Stage	Mesostages	Description
0. Bud development	00	Leaf buds are closed and covered by brown scales.
	01	Beginning of leaf bud swelling: bud scales begin to separate early in the summer*.
	03	End of leaf bud swelling: brown scales slightly separated.
	07	Beginning of bud burst: first green leaf tips just visible.
	09	Green leaf tips about 5 mm above bud scales.
1. Leaf development	10	First leaves separating: brownish scales slightly opened; leaves emerging.
	11	Visible leaves unfolded.
	12 to 18	Two to eight or more leaves visible, but not yet at full size.
	19	First leaves fully expanded.
3. Shoot development	31	Beginning of shoot growth—axes of developing shoots visible.
	32	Shoots about 20% of final length.
	35	Shoots about 50% of final length.
	39	Shoots about 90% of final length.
9. Senescence and beginning of the rest period	91	Shoot growth complete.
	92	Beginning of the senescence of old leaves; leaves shed.
	95	Leaves shedding.
	97	All leaves shed. Brief late spring rest period**.

of 881 ± 176 mm with significantly higher node production (18 ± 5 to 20 ± 0 nodes). The Long branches, present in all materials, formed a second statistical group with lengths between 211 ± 37 mm and 410 ± 143 mm and intermediate node production (9 ± 1 to 13 ± 4).

Medium branches showed significantly shorter lengths (104 ± 27 mm to 131 ± 16 mm). Although their node count was lower in absolute terms, statistical analysis showed similarities with the Long category in materials B, D, E, and F. Finally, Short branches exhibited the lowest

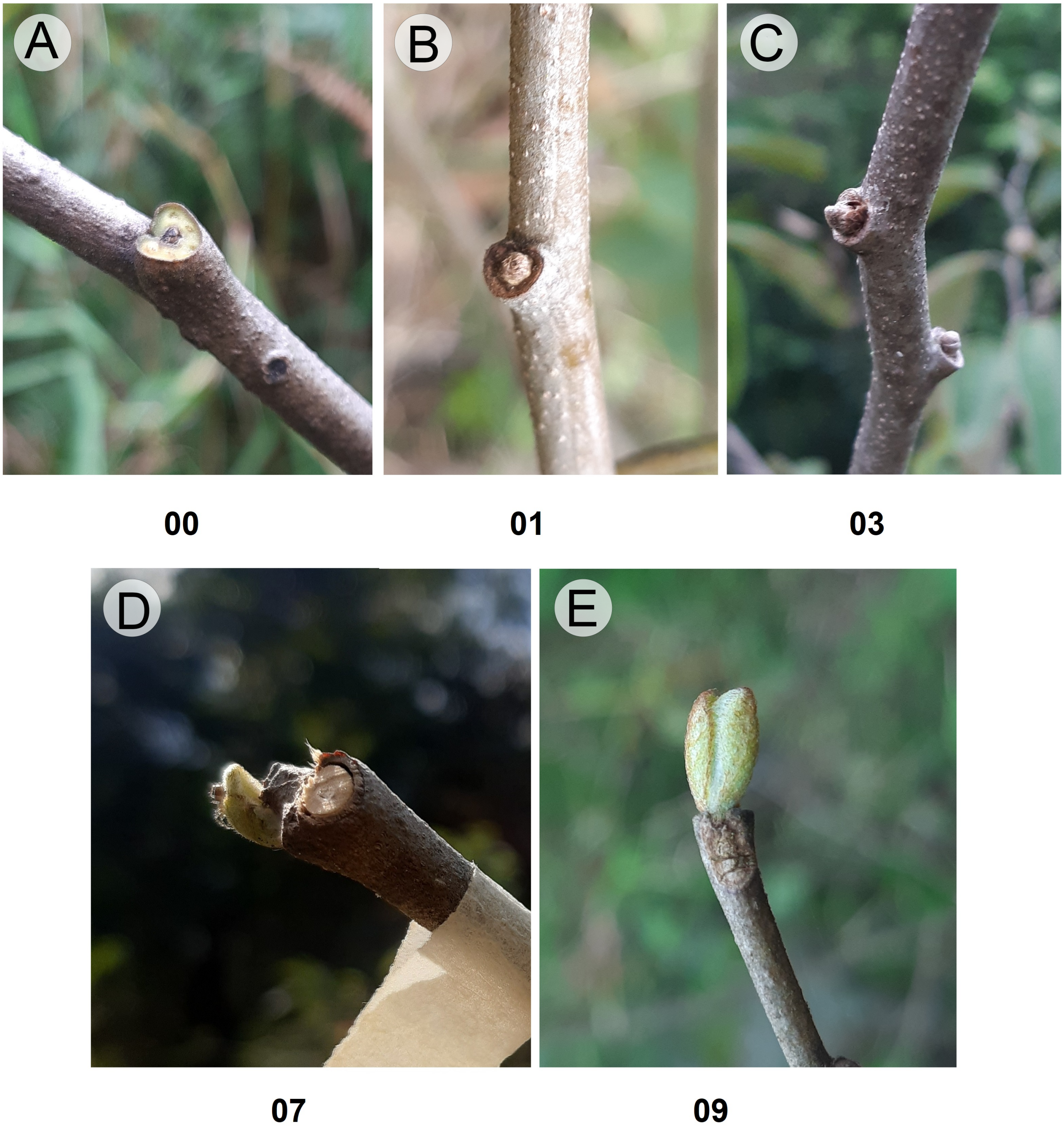


Figure 5: Photographs of observed mesostages in shoots belonging to stage 0 of cherimoya, Cundinamarca, Colombia. Bud development is based on the BBCH phenological scale by Cautín and Agustí (2005). Photographs: Javier Borbón-Guevara.

growth magnitude (average length 11 ± 5 to 37 mm) and reduced node number (3 ± 1 to 5 ± 2).

Regarding basal diameter, a positive allometric relationship with length category was confirmed. Very Long and Long branches exhibited the greatest thickness (6.2 ± 0.9 to 10.0 ± 1.7 mm), differing significantly from less vigorous branches.

Subsequently, shoots proceeded to senescence and dormancy (BBCH 92-97). Leaf retention duration was inversely proportional to branch vigor: Short branches lost

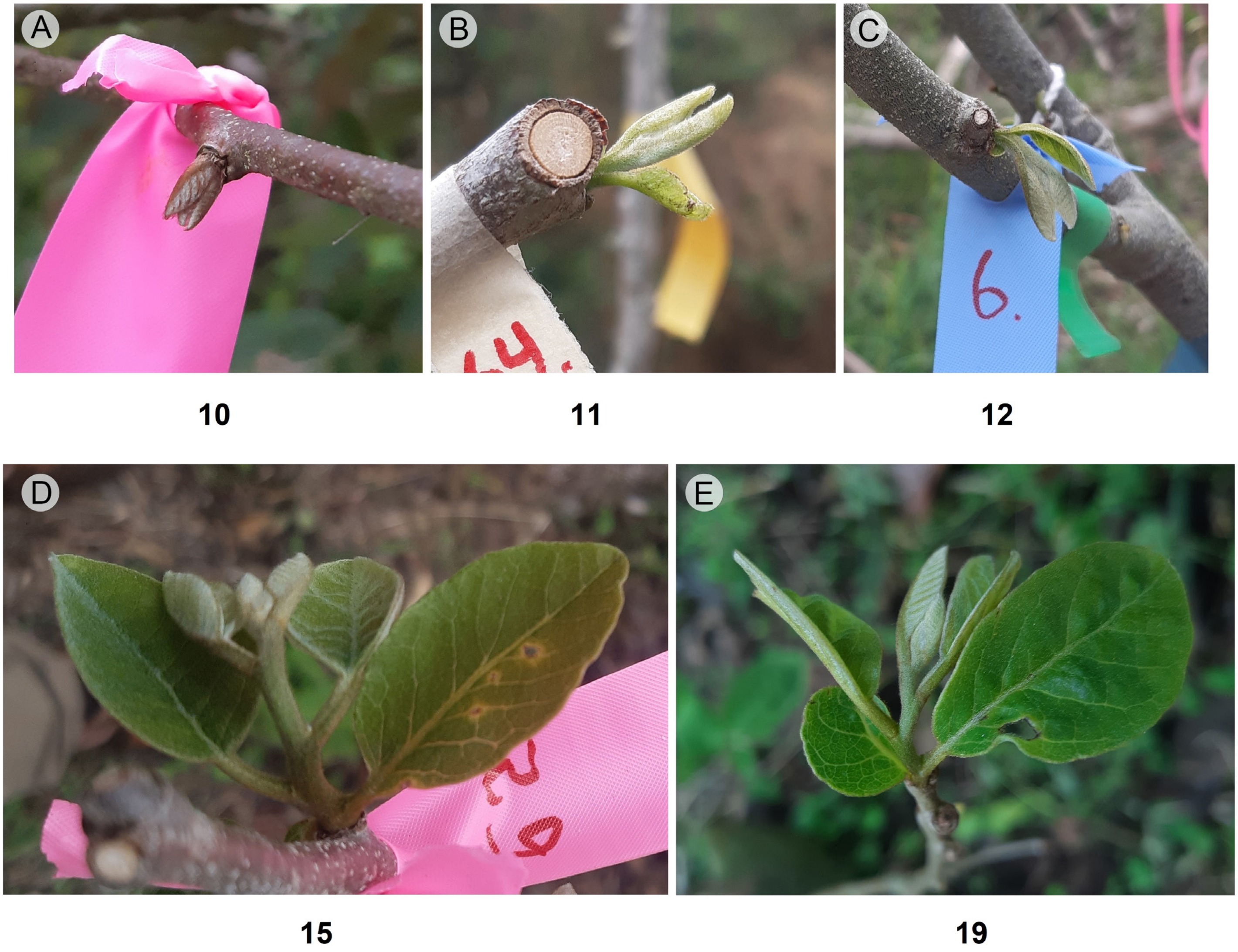


Figure 6: Photographs of observed mesostages in shoots belonging to stage 1 of cherimoya, Cundinamarca, Colombia. Leaf development is based on the BBCH phenological scale by Cautín and Agustí (2005). Photographs: Javier Borbón-Guevara.

leaves first (137-190 DAD), while Long branches retained them longest (166-230 DAD). The exception was the Very Long branches in trees A and B, which maintained an active growing point and exhibited a biphasic growth pattern, reactivating at 166 DAD while simultaneously shedding basal leaves.

Thermal units and days after defoliation for vegetative shoot growth and development

The Medium and Long branch categories were present in all six observed trees. In all cases, Long branches exhibited more prolonged growth than Medium branches, consequently requiring more days after defoliation (DAD) and accumulated degree-days (GDD) to reach key phenological stages, such as the end of shoot development (BBCH 39) and the onset of senescence (BBCH 97), as detailed in Table 5.

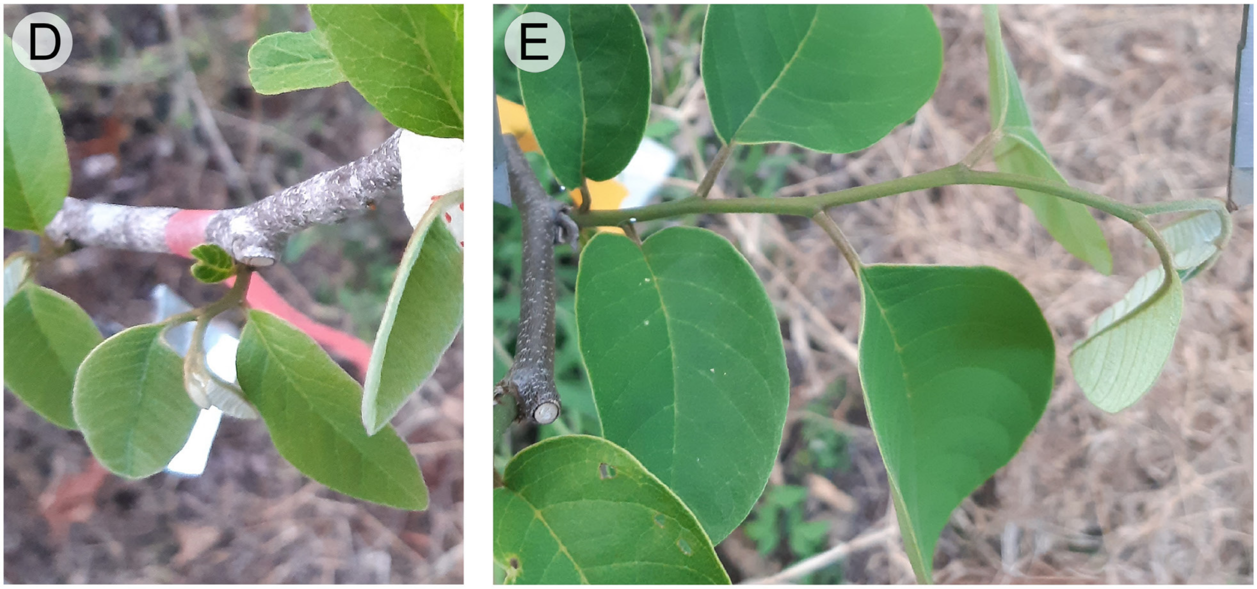
Influence of climatic variables on shoot growth rate

Shoot growth regulation was primarily driven by thermal conditions (Table 6). A significant negative correlation was

31

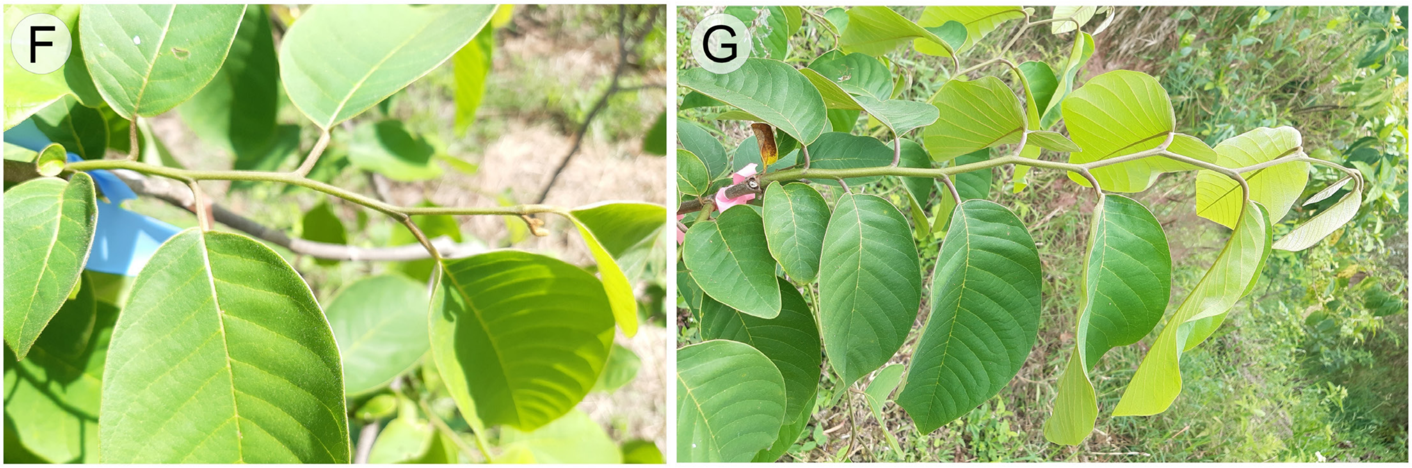
32 in Medium branch

32 in Long branch



35 in Medium branch

35 in Long branch



39 in Medium branch

39 in Long branch

Figure 7: Photographs of observed mesostages in shoots belonging to stage 3 of cherimoya, Cundinamarca, Colombia. Shoot development is based on the BBCH phenological scale by Cautín and Agustí (2005) for Medium and Long branch categories. Photographs: Javier Borbón-Guevara.

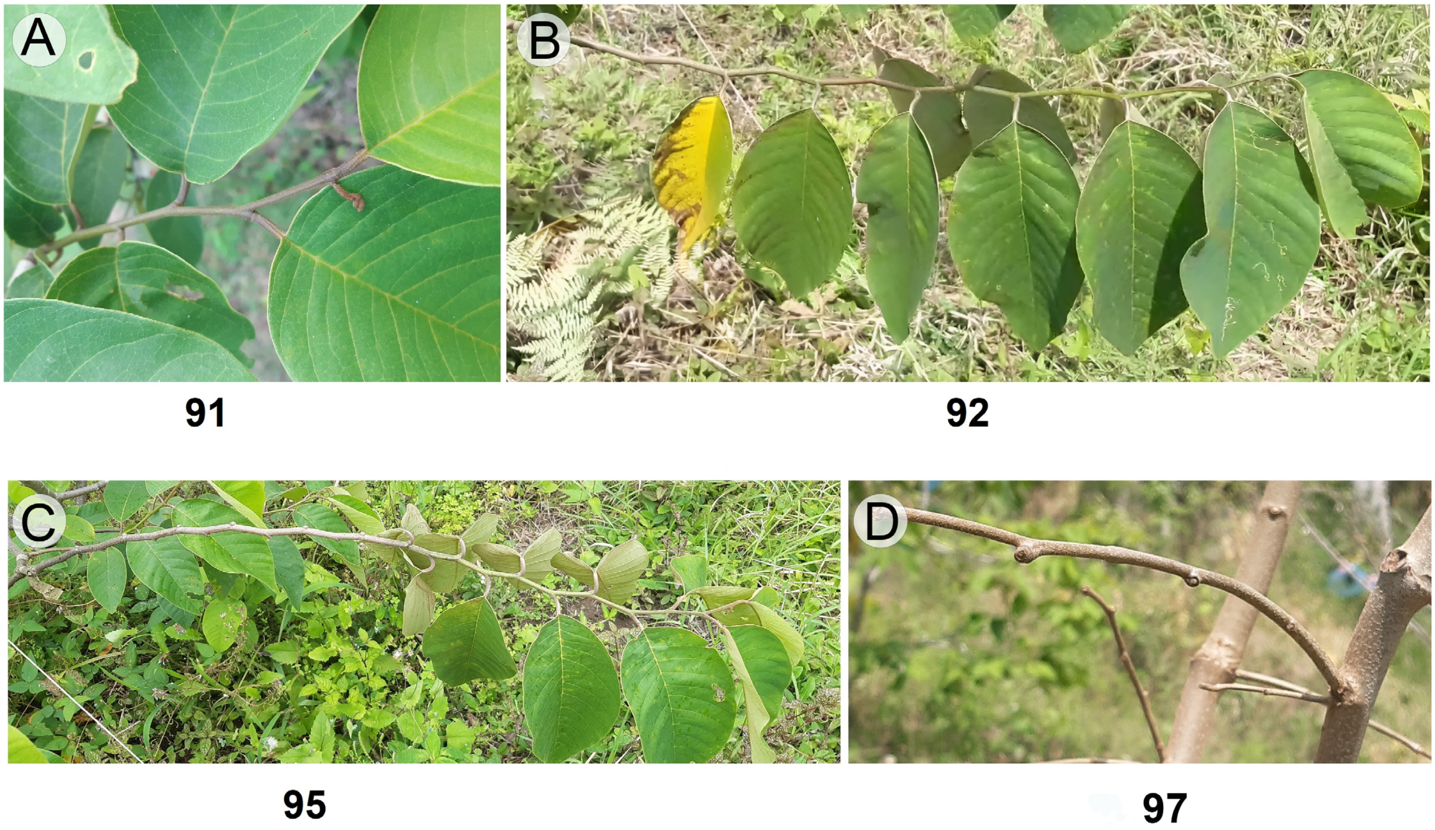


Figure 8: Photographs of observed mesostages in shoots at stage 9 of cherimoya, Cundinamarca, Colombia. Senescence and onset of dormancy are based on the BBCH phenological scale by Cautín and Agustí (2005). Photographs: Javier Borbón-Guevara.

found between shoot growth rate and the average temperature recorded 8-14 days prior to the measurement (r_s = -0.471, *P* = 0.031).

Regarding the immediate environmental window (0-7 days), although correlation coefficients with temperature and precipitation reached moderate values (*r*s ≈ 0.4), these associations did not reach statistical significance (*P*>0.05). Consequently, the statistically supported evidence points to a delayed physiological response, where high temperatures in the preceding week restrict current shoot elongation.

Discussion

The onset of bud break (20 DAD), coinciding with the accumulation of 82.1 mm of precipitation, is a key finding that can be interpreted through the dormancy classification proposed by Lang et al. (1987). Manual defoliation removed the paradormancy exerted by the leaves, bud break did not occur immediately, suggesting that the buds remained in a state of ecodormancy imposed by environmental constraints.

This observational link is supported by our correlation analysis, which revealed that shoot growth is positively associated with precipitation (*r*s = 0.40) and significantly restricted by high temperatures in the preceding weeks (*r*s = -0.47, *P* = 0.031), corresponding to periods of lower relative humidity and absence of rain observed in the climatic record (Fig. 3). These results statistically confirm that water availability (and the consequent relief of thermal stress) acts as the primary environmental trigger to overcome this ecodormancy in local materials. This mechanism is consistent with the physiological responses reported for *Annona* L. species under tropical conditions, where drought stress induces dormancy and subsequent rainfall stimulates growth (Paull and Duarte, 2025).

This behavior contrasts sharply with the temperate conditions of Chile, where summer photoperiod and rising temperatures are the factors that initiate bud break (Cautín

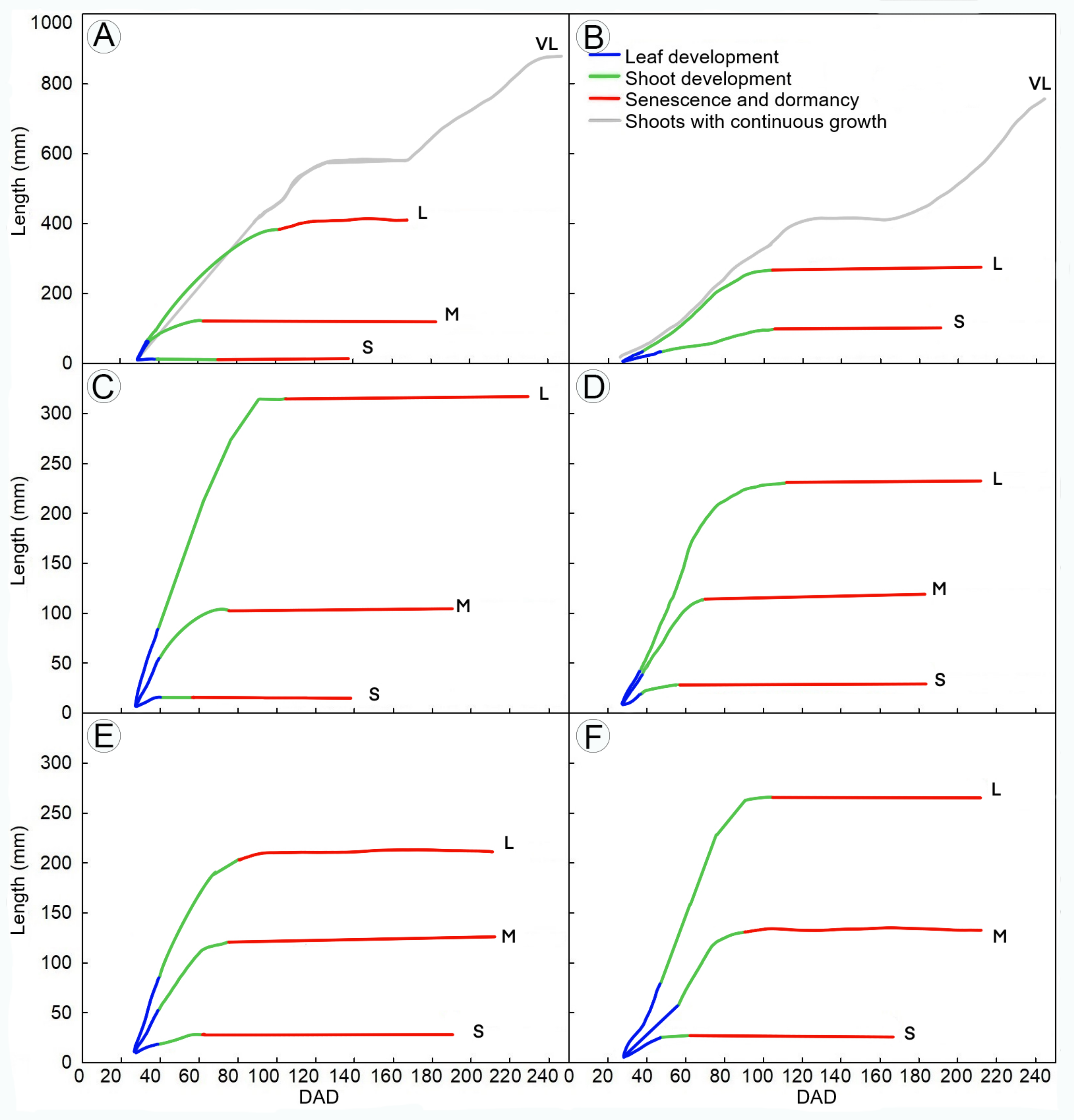


Figure 9: Length of vegetative shoots in the Short (S), Medium (M), Long (L), and Very Long (VL) branch categories, from six local cherimoya materials (A-F) based on days after defoliation (DAD), Cundinamarca, Colombia. Development mesostages are represented according to the BBCH phenological scale (Cautín and Agustí, 2005) by the line color: blue for leaf development, green for shoot development, and red for senescence and onset of dormancy. The end of the red line indicates the BBCH 97 mesostage (shedding of all leaves). The gray line represents shoots in continuous growth, which were not assigned a BBCH scale as they had not completed their development.

and Agustí, 2005). Instead, our results suggest that under the non-seasonal conditions of the premontane moist forest, the release from thermal-hydric stress is the primary phenological trigger, rather than thermal accumulation (GDD). This dependence on rainfall pattern aligns with reports from other tropical zones in Ecuador (Vásquez et al., 2024).

Table 4: Morphometric characteristics of vegetative branch categories in local cherimoya (Cundinamarca, Colombia) materials at 245 days after defoliation. Values are mean ± SD. Different letters within columns indicate significant differences (Kruskal-Wallis, *P*<0.05). Categories: Short (<60 mm), Medium (61-160 mm), Long (>161 mm), Very Long (indeterminate growth).

Tree	Branch category	No. of branches	Mean nodes	Mean length (mm)	Mean diameter (mm)
A	Short	2	3±1 g	12±5 h	2.8±0.2 gh
	Medium	1	7±0 fg	120±0.0 fg	3.4±0.0 fgh
	Long	8	13±4 ab	410±143 ab	7.5±1.5 bc
	Very long	3	18±5 a	881±176 a	9.8±1.9 ab
B	Short	1	4±0 g	37±0.0 fgh	2.9±0.0 gh
	Medium	4	11±6 de	119±27 f	4.4±0.4 fg
	Long	8	12±2 abc	273±76 cd	6.5±1.2 cde
	Very long	1	20±0 a	762±0.0 ab	9.4±0.0 ab
C	Short	3	3±1 g	19±8 h	2.3±0.6 h
	Medium	5	5±1 fg	104±27 fg	5.9±0.5 e
	Long	6	11±2 abc	316±91 bc	10.0±1.7 a
	Very long	0	-	-	-
D	Short	5	5±1 g	30±11 gh	3.0±0.5 gh
	Medium	5	7±1 f	117±33 f	4.9±0.6 f
	Long	4	10±1 cde	228±21 de	6.4±0.9 bcde
	Very long	0	-	-	-
E	Short	2	3±0 g	28±10 gh	2.3±0.4 h
	Medium	10	8±1 f	121±24 f	4.8±0.7 f
	Long	6	9±1 e	211±37 e	6.2±0.9 de
	Very long	0	-	-	-
F	Short	3	5±2 g	30±11 gh	2.2±0.8 h
	Medium	2	8±0 ef	131±16 f	4.4±0.4 fgh
	Long	9	11±1 bcd	265±79 cde	7.4±1.7 bcd
	Very long	0	-	-	-

The observed budding pattern—predominantly single-type, more frequent on secondary branches, and concentrated at the apices—confirms that defoliation broke apical dominance. The apical concentration aligns with reports in atemoya (George et al., 1998), where apical dominance is strong in upright branches. The combination of pruning and defoliation (Costes et al., 2006) appears to have facilitated the emergence of latent shoots, characteristic of the compound buds of *Annona* (Soler and Cuevas, 2009).

Furthermore, the statistical analysis confirmed that branch type is a determining factor in budding potential, with secondary branches exhibiting significantly higher bud break percentages than primary branches (Table 2). This behavior can be interpreted through the architectural principles of tropical trees described by Hallé et al. (1978). In cherimoya, which follows Troll's architectural model, primary branches often represent older structural axes that have transitioned towards a role of mechanical support and conduction. In contrast, secondary branches act as reiteration units with higher meristematic activity and physiological vigor. This hierarchy explains why the younger axes (secondary) showed a more consistent and prolific response to defoliation, maximizing the vegetative renewal capacity of the tree compared to the basal, older scaffold branches.

Although cherimoya generally exhibits strong apical dominance, the fact that materials such as B (in primary

Table 5: Vegetative shoot growth and development of cherimoya, Cundinamarca, Colombia, at development stages 3 and 9 of the BBCH phenological scale proposed by Cautín and Agustí (2005). S= Senescence. GDD = Accumulated Growing Degree Days. DAD: Days after defoliation.

Tree	Branch category	3. Shoot development (BBCH 39)		9. S. and onset of dormancy (BBCH 97)	
		GDD	DAD	GDD	DAD
A	Long	626	108	1105	182
	Medium	374	62	1002	166
B	Long	626	108	1298	211
	Medium	626	108	1171	190
C	Long	607	104	1421	230
	Medium	448	76	1171	190
D	Long	607	104	1298	211
	Medium	417	69	1105	182
E	Long	485	83	1298	211
	Medium	448	76	1298	211
F	Long	607	104	1298	211
	Medium	534	91	1298	211

Table 6: Spearman correlation coefficients (r_s) between the weekly vegetative shoot growth rate (Long and Very Long categories) and climate variables (Temperature and Precipitation) at two time-lag windows in cherimoya, Cundinamarca, Colombia. *Significant correlation at P<0.05.

Climatic variable	Time Lag (days prior measurement)	Spearma's r_s	P-value
Precipitation	0-7	0.400	0.072
	8-14	0.203	0.378
Average temperature	0-7	-0.391	0.080
	8-14	-0.471	0.031*

branches) and C (in secondary branches) showed a statistically homogeneous shoot distribution (with no significant differences between the basal and terminal zones) represents a favorable agronomic trait. This indicates a greater natural lateral budding capacity, which is desirable for tree architecture formation and could potentially reduce the need for severe pruning or the exogenous application of budding promoters often required in this crop.

Regarding shoot characteristics, the predominance of the Medium and Long categories is an expected result of pruning, which promotes the formation of vigorous shoots (Cautín, 2008). However, a central finding of this study is the discrepancy between the characteristics of these local materials and the vigor scales established for varieties like 'Fino de Jete' and 'Concha Lisa' (Cautín, 2008; González and Cuevas, 2008). Our five-year-old materials did not fit the scales designed for 16-year-old trees, strongly suggesting that vigor classifications are not universal and are influenced not only by genetics and environment (Higuchi et al., 1998), but also by the plant's age or juvenile state. Therefore, the length categories (Short, Medium, Long) are proposed as an initial practical characterization for these materials.

The final shoot length in the local materials was considerably shorter (< 60 cm) than that reported for technified varieties like 'Big Sister' (60-80 cm) or 'Concha Lisa' (70-82 cm) under optimal conditions (Higuchi et al., 1998; Ibacache et al., 1999). This difference underscores the impact of genetic selection and specialized agronomic management, which are absent in these local materials.

The most notable finding was the "Very Long" category, which exhibited a biphasic growth pattern (double sigmoid). These branches reactivated their growth after a dry period (January 2024), coinciding with the return of rainfall (Fig. 3). This indeterminate growth, coexisting with the senescence of basal leaves, resembles the adaptive sympodial growth reported in atemoya (Olesen and Muldoon, 2009), and demonstrates high vegetative plasticity, allowing the plant to leverage secondary pulses of water availability.

Finally, the application of the BBCH scale (Cautín and Agustí, 2005) required adaptations. The initiation of phenological events linked to rain (rather than summer) and minor differences in bud coloration highlight the need to adjust the scale's criteria for local materials under non-seasonal tropical conditions.

Conclusions

This study presents the first phenological characterization of cherimoya in the Colombian premontane moist forest. Results indicate that the vegetative cycle under these conditions is related to local environmental variability. The onset of bud break was observed to coincide with the rainy season, and statistical analysis revealed a significant negative correlation between growth rate and mean temperature of the preceding weeks, suggesting that thermal conditions modulate elongation speed.

Morphologically, although acrotony predominated, materials with a homogeneous lateral budding distribution were identified, representing a promising agronomic trait for optimizing tree architecture. Likewise, branch classification evidenced a Very Long category with biphasic growth, which reflects adaptive plasticity in response to bimodal water availability. Finally, the utility of the BBCH scale was validated for the zone, linking hydrological events as the primary phenological triggers instead of calendar dates.

Author contributions

Conceptualization: JBG, DM. Methodology: DM, JBG. Formal analysis: JBG. Investigation: JBG. Funding acquisition: JBG. Writing - original draft: JBG. Writing - review and editing: DM, JBG.

Funding

This study was supported by the Mariano Ospina Pérez Foundation, through its Graduate Credit-Scholarship program, awarded to JBG.

Acknowledgements

We thank Enrique Darghan (Universidad Nacional de Colombia) for his valuable methodological suggestions on the observational design of the study. We also thank the Instituto Nacional de Investigaciones Agropecuarias (INIAP) of Ecuador, especially Pablo Viteri, for the technical guidance that underpinned the defoliation management.

Data Availability Statement

The dataset supporting the results of this study was submitted to SciELO Data and can be accessed at https://doi.org/10.48331/SCIELODATA.XB0QDX

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