

Architecture of Cocoa Genotypes in Colombia as Affected by Bud Type, Grafting Technique, and Pruning

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Abstract

Organization of plant aerial parts and root distribution, environmental conditions such as light, temperature, humidity and agronomic practices (grafting and pruning) influences the final architecture of the plant. Most of cocoa plantations in Colombia belong to the plagiotropic type that emit branches and suckers in a disorderly way, which leads to an unbalanced development, this makes it difficult to manage. To search for cocoa plants with better architecture, we evaluated the effect of the type of the bud (orthotropic and plagiotropic), the grafting techniques (approximation and patch grafting) and pruning (structural and conventional) on ICS 95 and CCN 51 clones. The monitoring was carried out at an open greenhouse and field. Plants obtained from orthotropic buds and approximation grafting had lower bifurcation angles, 42% more leaves and 50% more branches. The structural pruning had a positive influence on the architectural variables, which presented a higher conversion (8.68%) of fresh weight of cocoa pod into dry weight of cocoa beans, meanwhile CCN 51 trees showed a higher conversion (9.76%) compared to ICS 95 (7.34%). CCN 51 had the highest bean index (1.30) and the lowest pod index (22.0). This study demonstrated that structural pruning improved bean index and pod index. We concluded that for CCN 51 by approximation grafting technique is a good alternative for a tropical dry forest, as its production between 1995 and 2277 kg of dry cocoa beans ha⁻¹ year⁻¹.

Keywords: orthotropic plants, plagiotropic plants. *Theobroma cacao*. plant architecture, approximation graft, patch graft

INTRODUCTION

The architecture of a plant depends on the nature and relative arrangement of all plant structures, which is the expression of a balance between endogenous and exogenous factors (those limitations are exerted by the environment) (Reinhardt & Kuhlemeier, 2002). Plant performance has a crucial link between phenotype and ecological nature. The architecture of the canopy is crucial

for the capture of light and the distribution of that light for each photosynthetic unit (Chindi *et al.*, 2015).

Dimorphism of cocoa trees has been reported in many studies, those are plagiotropic and orthotropic growth. The juvenile orthotropic growth (upright) of the main trunk with spiral phyllotaxis (3/8) contrasts dramatically with the plagiotropic (lateral) fan shaped branches with distal phyllotaxis

(1/2) (Miller, 2009). There is a demand for the use of orthotropic material, due to the more erect type of plant. Therefore, greater efforts are required in the generation of knowledge using various tools (Miller & Gultinan, 2003). The search for methodologies to achieve orthotropic plants in cocoa has been addressed previously (Muller & Valle, 2012; Miller & Gultinan, 2003; Miller, 2009). As organs for growth, orthotropic shoots can give sun-adapted species an advantage, growing directly upward and helping to prevent plant overflow, while plagiotropic plants shoot direct growth outward, this may be advantageous for species adapted shade.

Defining architecture of a plant is important to be implemented in plantation management, such as spacing, irrigation, fertilization, and light input, as the plantation architecture strongly influences the parameters of yield and harvest (Kufa-Obso, 2006; Chindi *et al.*, 2015). Plagiotropic materials form unbalanced canopies that require strong pruning or shoring up the plants with supports. Furthermore, these types of plants are more susceptible to periods of soil humidity stress since the distribution of their roots is unbalanced (Lee, 1998; Moolleedhar, 2000). Cocoa plant has a dimorphic growth characteristic that affects the architecture of the tree.

Around the world, most of cocoa genotypes available in the fields, as well as in conventional gardens or propagation nurseries, are plagiotropic (Miller, 2009). In Colombian cocoa plantations, the majority of cocoa plants are plagiotropic as well, and this negatively influences the harvest and phytosanitary management of the crops (Osorio *et al.*, 2022). Tree pruning is a strategy to keep plants healthy and extend their lifespan. There are different types of pruning. Elevation pruning eliminates low branches to create free space around the trunk, reduction pruning seeks to lower the height of trees and thinning pruning that looks to reduce the density on the trees.

Pruning of cocoa trees is essential in the management of a plantation. When pruning is done efficiently, it helps to increase the productivity of the tree by facilitating its management and enabling harvest. This practice facilitates the entry of sunlight, which is essential for pollination, increasing the concentration of soluble solids and the growth of the pods. Pruning also influences the formation of new leaves (Konam *et al.*, 2008; Colodetti *et al.*, 2020).

The objective of this research was to study the effect of using buds from branches with vertical growth (orthotropic) and buds from branches with lateral growth (plagiotropic) and two types of grafting (approximation and patch) on morphological and productive development of two cocoa clones (ICS 95 and CCN 51) with two types of pruning (conventional and structural).

MATERIALS AND METHODS

Location: The study was carried out at the Nataima Research Center of AGROSAVIA, located in Espinal-Tolima Colombia at 4°12' N and 74°52' E, at an altitude of 421 meters above sea level, with an average temperature of 28°C and rainfall of 1,300 mm year⁻¹, those represent forest conditions of tropical dry.

Plant genotype: CCN 51 and ICS 95 clones were used. CCN 51: Castro Naranjal Collection, cross between ICS 95 and IMC 67 genotypes, and later it was crossed with a regional genotype (eastern Ecuador) called "Canelos" (Quintana & Gómez, 2011). The ICS 95: "Imperial College Selection" collection, is a hybrid result of the crossing of a Trinidadian genotype with a Criollo genotype, the large and robust trees with abundant leaves, the branches tend to grow open with a lot of foliage that quickly closes the space between the rows (Phillips-Mora *et al.*, 2012).

The IMC 67 genotype was used as graft holder (rootstock), selected for its adaptability to different soil and climate conditions, and its tolerance to different pests and diseases (*Ceratocystis* and *Phytophthora*), and good vegetative vigor (Arguello, 2000).

Greenhouse procedure: As substrate a mixture of soil: sand: vermicompost was used in proportion (1: 1: 1). It was disinfected with copper oxychloride and mefenoxam using a drench and then it was exposed to sunshine for 20 days. Then, bags were filled with the substrate and the IMC 67 seed was sown. The seedlings were placed under 47% black shade net. To obtain buds, the branches with vertical growth (orthotropic) and the branches with lateral growth (plagiotropic) were selected. The approximation grafting technique was carried out using a 7 cm piece of stick as bud-holder with three to four viable buds. The bud-holder was then attached to the stock. The diameter of the bud-holder was similar to the

stem of the stock. The terminal of the stock was eliminated, leaving five leaves in it; the graft was placed about 20 cm high from the base of the stock (Figure 1A). For the patch graft technique, a single bud was used, introduced into the stem of the stock according to the traditional technique (Figure 1B).

In the nursery, bifurcation angle, graft length, graft diameter, number of leaves plant⁻¹, number of secondary branches plant⁻¹ at 30 and 60 days after of grafting were evaluated. The graft diameter was measured at 3 cm from the graft base.

Treatments were defined in a 2 x 2 x 2 x 2 factorial arrangement in which the factor consisting of cocoa genotype (CCN 51 and ICS 95), types of grafting (approximation and patch), types of the graft (orthotropic and plagiotropic) and types of pruning (conventional and structural) with 4 replications where each replications had 9 plants for a total of 288 trees.



Figure 1. Types of grafts used in this study. Approximation grafting (A) and patch grafting (B)

Field procedure: Four months before transplanting, to provide shade for the cocoa plants, the forest trees were planted, *Cordia gerascanthus* and *Gliricidia sepium* (Jacq) at a distance of 12 m x 12 m and 3 m x 3 m, respectively. The trees were periodically pruned.

The cocoa seedlings were planted in the field on December 5, 2014. For the evaluation of the effect of pruning on the development and production, 16 treatments were defined (Table 1). Each treatment consisted of 18 trees for a total of 288 trees. The trees were planted in spacing 3 m x 3 m rows (1000 plants ha⁻¹). Seventeen months after transplanting, the first pruning was carried out, with a second pruning at 23 months. The pruning was done according to the treatments.

Conventional pruning: It was defined as the low intervention on the trees in their formation, in which the crown increases its volume due to the free growth of the main branches. Practices such as plucking, guiding, and tying of thin branches around the main branches were carried out, this is most used practice by most producers (Figure 2A, B)

Structural pruning: it consisted in the elimination of any tendency of lateral growth (plagiotropic) and enhancement of the lower branches, to establish a defined production area with three to five strong and robust orthotropically oriented branches, adequately spaced. This process was done to shape the future structure of the adult tree and allow the management of a greater number of plants per hectare, decreasing the difficulty of carrying out management practices and facilitating harvesting (Figure 2C, D).

Table 1. Types of treatments applied in this field study

Treatments	Types of pruning	Graft techniques	Types of the graft	Cocoa clones
1	Conventional	Approximation	Orthotrópico	CCN 51
2	Conventional	Approximation	Plagiotrópico	CCN 51
3	Conventional	Patch	Orthotrópico	CCN 51
4	Conventional	Patch	Plagiotrópico	CCN 51
5	Conventional	Approximation	Orthotrópico	ICS 95
6	Conventional	Approximation	Plagiotrópico	ICS 95
7	Conventional	Patch	Orthotrópico	ICS 95
8	Conventional	Patch	Plagiotrópico	ICS 95
9	Structural	Approximation	Orthotrópico	CCN 51
10	Structural	Approximation	Plagiotrópico	CCN 51
11	Structural	Patch	Orthotrópico	CCN 51
12	Structural	Patch	Plagiotrópico	CCN 51
13	Structural	Approximation	Orthotrópico	ICS 95
14	Structural	Approximation	Plagiotrópico	ICS 95
15	Structural	Patch	Orthotrópico	ICS 95
16	Structural	Patch	Plagiotrópico	ICS 95



Figure 2. Types of pruning; cocoa cultivation with conventional pruning (A), tree subjected to conventional pruning (B), crop with structural pruning (C), and tree subjected to structural pruning (D)

Growth and development evaluation:

Periodically after transplanting, the bifurcation angle, graft length (primary branch), graft diameter, number of branches (secondary branches) were measured. The pruning process was carried out between 26 and 45 months after transplanting in the field. After pruning, the plant height, treetop height, and treetop diameter were evaluated. The treetop height was measured from soil surface of the to where the treetop begins and the treetop diameter was assessed at two equidistant points (North-South, East-West). The data were processed by ANOVA and the mean difference using the Tukey HSD alpha 0.05 multiple range test protected by Fisher (Figure 3).

Evaluation of reproductive variables:

Two years after establishing the crop, biweekly monitoring of the production variables was carried out: number of flower cushions tree⁻¹, number of viable gherkins tree⁻¹ (pods less than 10 cm), number of pod tree⁻¹ (pods larger than 10 cm). The follow-up was carried out from December 2016-October 2020. The results were analyzed in three growth times through areas under the progress curve as follows:

Area under the cumulative curve of the variable =

$$S\left[\frac{(V_2 + V_1)}{2} * (t_2 - t_1) \dots + \frac{(V_n + V_{n-1})}{2} * (t_n - (n-1))\right]$$

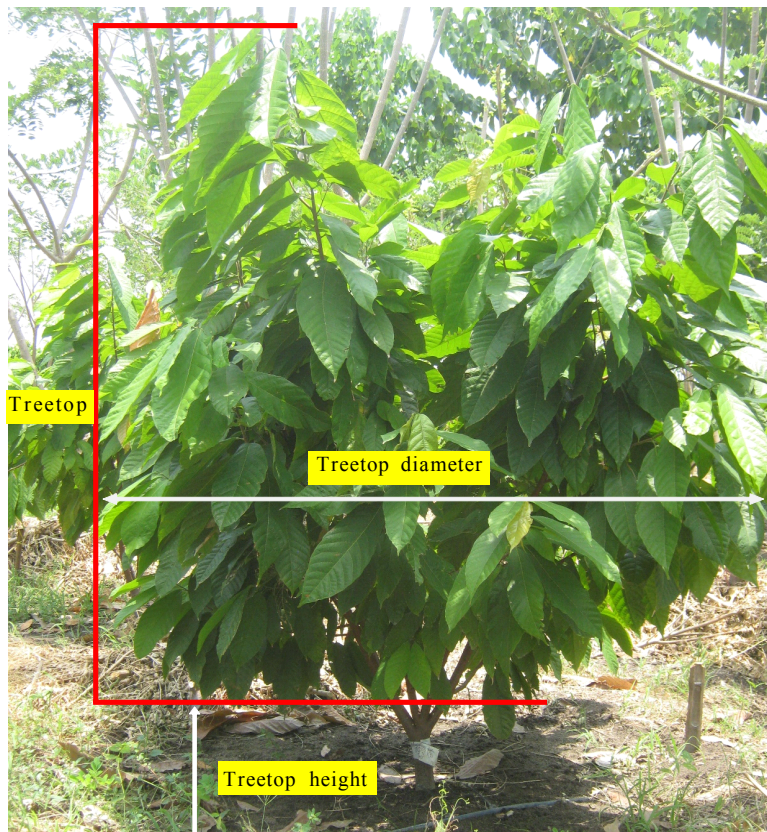


Figure 3. Development variables at the field level after pruning. The treetop height was taken from the base of the soil to where the treetop begins, and the treetop diameter was taken at two orienteering (North-South and East-West)

Where V_1 = initial value of the variable at moment of first evaluation, V_2 = value of the variable at moment of second evaluation, t_1 = initial moment of evaluation (week 1), t_2 = moment of second evaluation (week 2), n = number of weeks of evaluation. The data of the area under the accumulated curve were subjected to analysis of variance (ANOVA). The mean difference was established using the Tukey HSD alpha 0.05 multiple range test protected by Fisher.

Harvest: Four years after establishing the crop in the field, the harvest variable was monitored, for which the pods were periodically harvested from all the trees that were part of each treatment (18 trees treatment⁻¹), they were counted and weighed per treatment, in total 22 harvest were carried out (January 15/2019 to October 14/2020).

Productive indices: The production indices were determined on seven harvests. PI (pod index: number of pods necessary to obtain one kilograms of dry beans), BI (bean index: average weight of one cocoa bean, obtained from the weight of 100 cocoa beans), for each treatment took three replications composed of 10 pods replication⁻¹ for a total of 30 pods treatment⁻¹ and 480 pods harvest⁻¹. The production ha⁻¹ year⁻¹ was estimated considering 1000 trees ha⁻¹ year⁻¹.

RESULTS AND DISCUSSION

Nursery-level evaluation: The viability of grafting variable registered values between 85.2% and 89.0%, no differences were observed between the factors (Table 2). For the variable number of leaves plant⁻¹ at 45 days after grafting, the results indicate highly significant statistical differences in the technique of graft. The approximation graft registered an average of 8.5 leaves plant⁻¹, while the patch graft registered an average of 5.7 leaves plant⁻¹. Similarly, statistical differences were recorded

between the type of bud (orthotropic branch and plagiotropic branch), the grafts of orthotropic branches developed more leaves (7.7 leaves plant⁻¹) (Table 2). Three months after grafting, the cocoa clones showed statistical differences in the bifurcation angle variable where ICS 95 presented angles of 43.5 degrees compared to CCN 51 the angles of 34.0 degrees. The approximation graft technique registered the highest number of leaves (18.7), the highest number of branches (2.8) and the lowest bifurcation angles (31.8 degrees) (Table 2).

Evaluation of growth and development at the field level before pruning: At 4 months after transplanting, the bifurcation angle was variable on the treatment interaction between the type of bud, the type of grafting technique and the cocoa genotype. The plants grafted by the approximation grafting technique, with orthotropic buds and the CCN 51 clone showed less bifurcation angle (28.2 degrees), while the plants by patch grafting, the ICS 95 clone and with plagiotropic buds had the largest bifurcation angle (55.3 degrees) (Table 3). The plants of the CCN 51 clone, coming from orthotropic buds and grafted with approximation grafting technique showed faster growth with a shoot length of 228 cm and shoot diameter 63.4 mm, compared to the plants of the ICS 95 clone from plagiotropic buds and grafted with the patch technique, whose average height was 167 cm, and average diameter was 43.9 mm (Table 3).

Before pruning (22 months after transplantation in the field), the type of bud and clones indicated statistical differences on the plant height, being the trees grafted with orthotropic buds were taller (228 cm) and CCN 51 tree (230 cm) were higher than ICS 95. The CCN 51 tree had treetop diameter (233 cm) and treetop height (61.0 cm) whereas grafting technique cause a statistical differences in treetop height variable, the tree from approximation graft had the highest treetop (62.3 cm) (Figure 4).

Table 2. The effect of grafting type, cocoa clone, and grafting technique on viability of cocoa grafting, number of leaves, number of branches, and bifurcation angle of cocoa plants at 45 and 90 days after grafting in the nursery

Factors	Class	Viability of grafting	Number of leaves (45 DAG)	Number of leaves (90 DAG)	Number of branches (90 DAG)	Bifurcation angle (degree) (90 DAG)
Type of grafting	Orthotropic	85.2%	7.7 ± 0.37 A	16.3 ± 0.94 a	2.4 ± 0.20 a	37.0 ± 1.84 a
	Plagiotropic	85.2%	6.5 ± 0.31 B	16.2 ± 1.14 a	2.5 ± 0.18 a	40.5 ± 1.74 a
Cocoa clone	ICS 95	89.0%	7.3 ± 0.34 a	15.4 ± 0.78 A	2.3 ± 0.16 A	43.5 ± 1.57 A
	CCN 51	81.0%	6.8 ± 0.36 a	17.2 ± 1.24 A	2.7 ± 0.21 A	34.0 ± 1.76 B
Grafting technique	Approximation	88.2%	8.5 ± 0.38 A	18.7 ± 1.24 a	2.8 ± 0.22 a	31.8 ± 1.72 a
	Patch	82.2%	5.7 ± 0.14 B	13.8 ± 0.62 b	2.1 ± 0.14 b	45.6 ± 1.25 b

Notes: Each value is the average of four replicates with 3 plants each. DAG: days after grafting. The mean difference corresponds to column. Value with the same letter does not present statistical differences according to Tukey's HSD tests at P = 0.05 protected by Fisher's.

Table 3. Interaction between grafting technique, bud type and clone, 4 and 16 months after transplantation in the field (matf)

Grafting technique	Type of the graft	Clone	Bifurcation angle 4 matf (degrees)	Graft length, cm (16 matf)	Graft diameter, mm (16 matf)
Patch	Plagiotropic	ICS 95	55.3 a	167.7 b	43.9 B
Patch	Orthotropic	ICS 95	46.2 ab	183.7 ab	44.6 B
Patch	Plagiotropic	CCN 51	33.5 bc	201.0 ab	51.7 AB
Patch	Orthotropic	CCN 51	42.6 ab	208.0 ab	54.4 AB
Approximation	Plagiotropic	ICS 95	29.3 bc	214.0 a	57.2 AB
Approximation	Orthotropic	ICS 95	29.4 bc	197.5 ab	51.1 AB
Approximation	Plagiotropic	CCN 51	31.7 bc	187.5 ab	55.7 AB
Approximation	Orthotropic	CCN 51	28.2 c	228.3 a	63.4 A

Notes: Each value is the average of four replicates with 3 plants each. The mean difference corresponds to column. Value with the same letter does not present statistical differences according to Tukey's HSD tests at P = 0.05 protected by Fisher's.

Evaluation of growth and development at the field after pruning: After the pruning intervention, statistical differences between the factors were observed. The clones had statistical differences in tree height, treetop diameter and treetop height, CCN 51 were taller, with smaller treetop diameter and higher treetop height. The pruning influenced tree height, treetop diameter and treetop height. Trees intervened with structural pruning were shorter, with smaller treetop diameter and higher treetop height (Table 4).

Interactions and statistical differences were recorded between pruning and cocoa clone factors in the treetop height variable between 33 and 45 months after transplantation in the field. The CCN 51 trees with structural pruning presented higher treetop heights (162 cm) with an orthotropic tendency, the pruning improved the treetop heights of the ICS 95 trees, these had higher treetop height (128 cm) compared to the ICS 95 trees with conventional pruning (71 cm) (Figure 5).

Monitoring of reproductive variables:

Three periods were analyzed (27/12/2016-05/09/2017, 18/09/2017-05/03/2019 and 16/04/2019-19/10/2020). The data analysis fulfilled the assumptions of homogeneity of variance and normality. Positive interactions were observed between the cocoa genotype and the type of pruning on the production of flower cushions in the first and third period. The two genotypes responded positively to the structural pruning in the two periods (Table 5). No differences were observed between the factors in the second period.

The analysis of the area under the cumulative curve of viable gherkins for the first period recorded differences between the genotypes, being the CCN 51 the one with the highest production of viable gherkins and therefore the one with the largest area (678,40), being different from the ICS 95, while the other factors did not present statistical differences among themselves. In the second follow-up period no statistical differences were recorded between the factors,

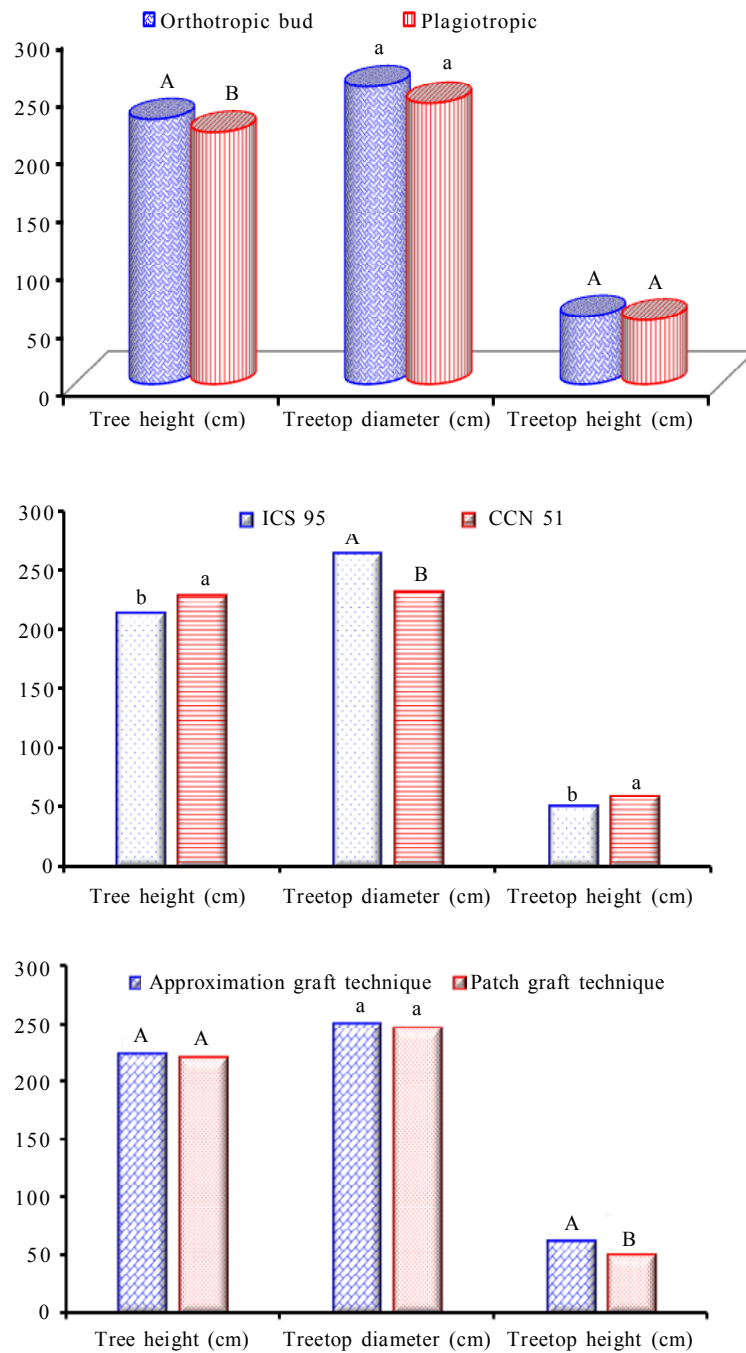


Figure 4. Architecture of cocoa with different bud type and grafting technique in the field before the pruning intervention (22 months after transplantation in the field). Value with the same letter does not present statistical differences according to Tukey's HSD tests at P = 0.05 protected by Fisher's. Uppercase and lowercase letters indicate factors analyzed independently. Averages obtained from 128 trees factor⁻¹

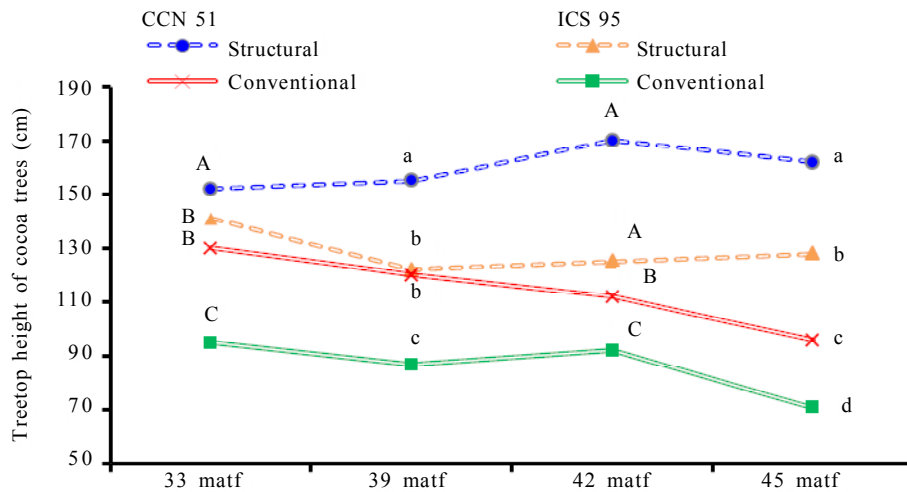


Figure 5. Interaction of pruning type and genotype factors in the treetop height of cocoa trees at 33, 39, 42, and 45 months after transplantation in the field. The mean difference corresponds to each moment of matf. Value with the same letter does not present statistical differences according to Tukey's HSD tests at P = 0.05 protected by Fisher's. matf: months after transplantation in the field.

Table 4. Development of the architecture of two cocoa clones with different bud type and graft technique after pruning intervention

Factor	Variable (cm)	Level	26 matf	30 matf	33 matf	39 matf	42 matf	45 matf
Bud graft type	Tree height	Orthotropic	254 a	275 A	283 a	302 A	312 a	328 A
		Plagiotropic	246 a	266 A	272 a	296 A	306 a	319 A
	Treetop diameter	Orthotropic	269 A	296 a	310 A	331 a	337 A	345 b
		Plagiotropic	257 A	280 a	299 A	320 a	338 A	362 a
Clones	Tree height	ICS 95	72 a	119 A	128 a	122 A	123 a	114 A
		CCN 51	77 a	122 A	130 a	120 A	127 a	115 A
	Treetop diameter	ICS 95	64 B	115 b	118 B	105 b	109 B	100 b
		CCN 51	85 A	127 a	140 A	137 a	141 A	129 a
Graft technique	Tree height	Approximation	257 a	274 A	286 a	305 A	317 a	327 A
		Patch	244 b	268 A	270 b	296 A	301 b	320 A
	Treetop diameter	Approximation	263 A	286 a	305 A	333 a	343 A	360 a
		Patch	263 A	290 a	303 A	317 b	332 B	348 a
Pruning	Tree height	Structural	78 a	123 A	133 a	123 A	130 a	115 A
		Conventional	72 a	118 A	125 a	120 A	120 b	113 A
	Treetop diameter	Structural	235 B	242 b	260 B	287 b	288 B	322 a
		Conventional	264 A	300 a	297 A	311 a	330 A	324 a
Notes:	Tree height	Structural	255 b	252 B	280 b	281 B	307 b	327 B
		Conventional	273 a	324 A	329 a	369 A	368 a	381 A
	Treetop diameter	Structural	74 A	139 a	146 A	147 A	147 A	145 a
		Conventional	75 A	102 b	112 B	104 b	102 B	84 b

Notes: Value with the same letter does not present statistical differences according to Tukey's HSD tests at P = 0.05 protected by Fisher's. Uppercase and lowercase letters indicate factors analyzed independently. matf: months after transplantation in the field.

Table 5. Accumulated area under the progress curve of viable cocoa gherkins and flower cushion

Factors		Accumulated area under the progress curve of viable cocoa gherkins	Accumulated area under the cocoa flower cushions progress curve	
Pruning	Genotype	16/04/2019-19/10/2020	*27/12/2016-05/09/2017	**16/04/2019-19/10/2020
Structural	CCN 51	246.6 AB	991.9 a	738.3 A
Structural	ICS 95	286.4 A	907.1 ab	783.4 A
Conventional	CCN 51	276.4 AB	953.2 ab	547.0 B
Conventional	ICS 5	239.5 B	742.1 b	475.3 B

Notes: Data accumulated for 9 months. **data accumulated over 19 months. Treatments with the same letter do not differ statistically according to Tukey HSD 0.05.

while in the third period, interactions were again recorded between the genotype and the type of pruning. Structural pruning improved the production of viable gherkins in ICS 95 (Table 5).

Production and productive indices:

The statistical analyzes of the production data indicated that there were no statistical differences between pruning factors, type of bud and type of grafting technique, but there were against the cocoa genotype factor, obtaining an average dry cocoa beans production per plot of 22.9 kg for the CCN 51 genotype, compared to the ICS 95 plots that obtained an average of 10.0 kg of dry cocoa beans for 22 months of harvest. The BI production index (bean index: weight of one cocoa bean) presented statistical differences in the cocoa clones, being the CCN 51 the one that showed the higher index (1.30) while that ICS 95 registered a lower one (1.11) (Table 6). In the same way, when the pod index was analyzed (PI: number of pods needed to obtain a kilogram of dry cocoa bean), differences were found in the cocoa genotype. ICS 95 registered the highest PI (29.6), while that of the PI for CCN 51 was 22.0 (Table 6). The conversion of the weight of fresh pod to dry cocoa beans was between 6.9% and 10.3%. Statistical differences were recorded between the pruning factors (structural and conventional pruning), being the structural pruning that presented the highest conversion percentage (8.68%), in the same way the cocoa genotype factor also presented

statistical differences, being the CCN 51 that registered the highest conversion (9.76%). According to these results, the projection of dry cocoa bean production $\text{ha}^{-1} \text{ year}^{-1}$ with 1000 trees ha^{-1} for CCN 51 was 1518 kg dry cocoa beans $\text{ha}^{-1} \text{ year}^{-1}$, while for the ICS 95 was 692 kg dry cocoa beans $\text{ha}^{-1} \text{ year}^{-1}$ (Table 6).

When the 16 treatments were analyzed, it was observed that the CCN 51 clone with structural pruning, orthotropic and patch grafting treatment presented the highest BI, i.e. 1.35 and the lowest PI with an average of 16.4 for last sampling. However, the highest production of pods $\text{tree}^{-1} \text{ year}^{-1}$ (43.5) was registered in the CCN 51 with conventional pruning, plagiotropic and approximation grafting treatment, with a projection between 1995 and 2277 kg of dry cocoa bean $\text{ha}^{-1} \text{ year}^{-1}$ (Table 7). The results indicated that trees from patch grafting responded positively to structural pruning while trees from approximation grafting responded to conventional pruning.

Several studies have indicated that the design of the architecture of a plant is important to implement the management options of a plantation such as spacing, irrigation and fertilization, since the architecture of a plantation strongly influences yield parameters and harvest opportunity (Kufa-Obso, 2006; Chindi *et al.*, 2015).

This research shows several aspects to highlight, among them the rapid regrowth and growth of the approximation grafting, compared to the patch grafting technique.

Table 6. Cocoa tree production. Variables under four study factors

Levels	*Dry cocoa beans production, kg plot ⁻¹	*(BI)	*(PI)	*The conversion of the weight of fresh pods to dry cocoa beans (%)	*Number of pods tree ⁻¹ year ⁻¹	**Projected dry cocoa production (kg ha ⁻¹ year ⁻¹)
Orthotropic	16.6	1.20 A	25.4 a	8.66 A	27.0 a	1063
Plagiotropic	16.3	1.21 A	25.9 a	8.45 B	26.6 a	1027
ICS 95	10.0	1.11 b	29.2 A	7.34 b	20.2 B	692
CCN 51	22.9	1.30 a	22.0 B	9.76 a	33.4 A	1518
Approximation	16.2	1.20 A	25.8 a	8.48 B	26.8 a	1039
Patch	16.7	1.29 A	25.6 a	8.62 A	26.8 a	1047
Structural	15.7	1.21 a	25.4 A	8.68 a	25.7 A	1012
Conventional	17.2	1.20 a	25.9 A	8.42 b	27.9 A	1077

Notes: *Average data from 144 trees; 22 months of fruit harvest; **Projected production ha⁻¹ year⁻¹ (1000 trees ha⁻¹; 3 m x 3 m planting distance); BI (bean index: average weight of one cocoa bean, obtained from the weight of 100 cocoa beans); PI (pod index: number of pods needed to obtain a kg of dry cocoa bean); Data with the same letter in the same column do not present statistical differences in Tukey HSD < 0.05 multiple range test.

Table 7. Cocoa tree production indices under 16 treatments

Treatments	Bean index		Pod index		Pod number tree ⁻¹ year ⁻¹	Projected dry cocoa production ha ⁻¹ year ⁻¹ (kg)	
	*	**	*	**		*	**
CCN 51 structural pruning, orthotropic patch grafting	1.35	1.50	19.9	16.4	32.12	1614	1959
CCN 51 structural pruning, orthotropic, approximation grafting	1.26	1.33	21.48	17.9	33.78	1573	1887
CCN 51 structural pruning, plagiotropic patch grafting	1.30	1.38	22.21	19.8	35.21	1585	1778
CCN 51 structural grafting plagiotropic approximation grafting	1.28	1.36	23.23	19.6	20.94	902	1068
CCN 51 conventional pruning orthotropic patch grafting	1.26	1.18	23.70	17.4	32.88	1387	1890
CCN 51 conventional pruning orthotropic approximation grafting	1.30	1.39	21.14	16.2	33.27	1574	2054
CCN 51 conventional pruning, plagiotropic, patch grafting.	1.30	1.25	22.76	17.4	35.45	1558	2037
CCN 51 conventional pruning plagiotropic, approximation grafting	1.29	1.28	21.82	19.1	43.50	1995	2277
ICS 95 structural pruning orthotropic patch grafting	1.11	1.17	29.16	28.2	22.15	760	786
ICS 95 structural pruning orthotropic approximation grafting	1.09	1.18	28.78	29.6	23.53	818	795
ICS 95 structural pruning plagiotropic patch grafting	1.11	1.13	28.42	27.62	20.12	708	729
ICS 95 structural pruning plagiotropic approximation grafting	1.14	1.25	29.48	22.4	17.99	610	803
ICS 95 conventional pruning orthotropic patch grafting	1.11	1.19	28.85	24.5	18.90	655	771
ICS 95 conventional pruning orthotropic approximation grafting	1.10	1.21	30.17	30.5	19.63	651	644
ICS 95 conventional pruning, plagiotropic, patch grafting.	1.09	1.22	28.55	29.7	16.90	592	569
ICS 95 conventional pruning plagiotropic, approximation grafting	1.14	1.27	29.99	32.9	21.81	727	663

Notes: *Average data from 7 samplings (210 pods treatment⁻¹); **Last sampling data (30 pods treatment⁻¹ sampling⁻¹); Projected production (1000 trees ha⁻¹; 3 m x 3 m planting distance).

The type of grafting influenced the development of the variables (bifurcation angle, number of leaves and branches), the approximation grafting registered 42% more leaves and 50% more branches than patch grafting. The number of leaves and branches emitted by a plant had a positive correlation in the growth rate of the plants, influencing the assimilation rate and the increase in dry weight (Satori *et al.*, 2007). This allows to reduce the time in the nursery, which reduces management costs and lower bifurcation angles indicate better architecture too.

The evaluation of the bifurcation angle variable was important since the orientation of the grafted branch and the subsequent architectural formation depend on it. The orthotropic bud grafted with the approximation grafting technique formed a more closed bifurcation angle with the stem of the stock, which favored a greater tendency of vertical compact growth and a better architecture of the cocoa tree, which shows a greater favorability of the approximation grafting for the orthotropic growth of cocoa plants (Barthélémy & Caraglio, 2007). Like-

wise, the values of the insertion angles indicated the tendency of ICS 95 to colonize the horizontal space while CCN 51 directed its colonization to the vertical space, which indicates a greater tendency of ICS 95 towards plagiotropism. Grafting technique positively influenced treetop height. The variable treetop height understood as the height recorded from the base of the soil to the first branches of the lower third of the cocoa trees indicated that the approximation graft had a positive influence on the architecture of the cocoa plants. The trees with approximation grafting had a greater treetop height than those grafted using the patch technique. The type of grafted bud revealed statistical differences in the height of plants, specially the trees grafted with orthotropic buds were taller.

The structural pruning improved the treetop height of the trees of the ICS 95 clone, while the trees with conventional pruning registered lower treetop heights, being the ICS 95 clone the one with the highest plagiotropic growth with its lower branches closer to the ground level. Likewise, before pruning, statistical differences were observed in the tree height and treetop diameter and in the treetop height, being the CCN 51 trees of higher height, smaller diameter of treetop, and greater treetop height, than the ICS 95 trees. Positive interactions were observed between the genotype and the type of pruning, the two genotypes responded positively to the structural pruning, the ICS 95 improved the production of flower cushions equaling CCN 51. This indicates that trees from patch grafting responded positively to structural pruning while trees from approximate grafting responded to conventional pruning.

The production obtained in the conventional pruning treatment of CCN 51 with plagiotropic bud by approximation grafting indicated a good level of production if compared both

nationally or internationally production. Data from Indonesia indicate values of 655 kg ha⁻¹ year⁻¹, Malaysia on the other hand registers values of 1800 kg ha⁻¹ year⁻¹ and Ghana 360 kg ha⁻¹ year⁻¹ (Fahmid *et al.*, 2018).

CONCLUSIONS

CCN 51 clone grafted with the approximation grafting technique is a good alternative with productions can exceed 1500 kg of dry cocoa beans ha⁻¹ year⁻¹. The CCN 51 treatment with an approximation graft requires fewer pruning interventions since it responded positively to conventional pruning, in the same way the type of the bud does not influence the result. A similar situation was observed with the ICS 95 clone. The approximation graft presented faster regrowth and growth compared to the patch technique, therefore, it is a technique that reduces the residence time of the plants in the nursery and improves the architecture of cocoa plantations in the field. Bifurcation angles of approximation grafting was lower than those of the patch grafting, those indicated that there is a better join of graft and the rootstock. CCN 51 clone with approximation grafting from orthotropic buds had better architectural development, as shown by lower bifurcation angles, taller heights and greater graft diameter, lower treetop diameter and higher treetop height. The ICS 95 clone showed a tendency towards plagiotropic while the CCN 51 genotype was more orthotropic. Structural pruning improved the BI, PI, and the percentage of conversion of pod weight into dry cocoa beans.

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Conflict of Interests

The authors declare that they have no conflict of interest.

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