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Translated from the original in spanish **Original article**

Evaluation of the rooting of cuttings of Carapa guianensis Aublet. in response to the type of planting and the development phase

Evaluación del enraizamiento de estacas de Carapa guianensis Aublet. en respuesta al tipo de siembra y la fase de desarrollo

Avaliação do enraizamento das estacas da Carapa guianensis Aublet. em resposta ao tipo de semea e fase de desenvolvimento

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ABSTRACT

The cutting down of forests has caused the densities of *C. guianensis* to have decreased significantly in the Colombian Pacific. For this reason, the rooting of its cuttings was evaluated in response to the type of planting and the development phase. Cuttings were collected from branches with herbaceous, semi-woody and woody development phases. The harvested cuttings were immersed in ascorbic acid and preserved in moistened newspaper. Sowing was carried out in six germination beds; three using a substrate and three outdoors. The rooting substance was hormonegro 1 (0.05 g/stake). A randomized factorial design was used, composed of three factors (rooting hormone, planting site and cutting development phase). Monitoring was carried out every eight days. A rooting rate of 37.5 % was obtained, which was not significantly affected by the type of cutting used (herbaceous = 38.5 %, semi-woody = 32.3 and woody = 41.7 %), while the place of Sowing did have an effect on the rooting of the cuttings (organic substrate eras = 27.1 % and in-temperature soil = 47.9 %). It is concluded that cuttings from woody branches turn out to be the most suitable for the propagation of *C. guianensis,* because it experienced a better rooting response and survival in the evaluated treatments.

Keywords: Tree species, cutting, rooting hormone, Güino, vegetative propagation.

RESUMEN

La tala de los bosques ha ocasionado que las densidades de *C. guianensis* se hayan disminuido significativamente en el Pacífico colombiano. Por tal motivo, se evaluó el enraizamiento de sus estacas en respuesta al tipo de siembra y la fase de desarrollo. Se colectaron estacas de ramas con fases de desarrollo herbáceo, semileñoso y leñoso. Las estacas cosechadas fueron sumergidas en ácido ascórbico y conservadas en papel periódico humedecido. La siembra se realizó en seis camas de germinación; tres utilizando un sustrato y tres a la intemperie. La sustancia enraizadora fue hormonagro 1 (0,05 g/estaca). Se empleó un diseño factorial aleatorizado, compuesto por tres factores (hormona enraizadora, sitio de siembra y fase de desarrollo de estacas). El monitoreo se realizó cada ocho días. Se obtuvo un enraizamiento del 37,5 %, el cual no fue afectado significativamente por el tipo de estaca utilizado (herbáceas = 38,5 %, semileñosas = 32,3 y leñosas = 41,7 %), mientras que, el lugar de siembra si tuvo un efecto en el enraizamiento de las estacas (eras-sustrato orgánico = 27,1 % e intemperie en el suelo = 47,9 %). Se concluye que Las estacas de ramas leñosas, resultan ser las más adecuadas para la propagación de *C. guianensis,* debido a que experimentó mejor respuesta de enraizamiento y supervivencia en los tratamientos evaluados.

Palabras clave: Especie arbórea, estaca, hormona enraizadora, Güino, propagación vegetativa.

RESUMO

A tala das florestas tem ocasionado que as densidades de *C. guianensis* teriam diminuído significativamente no Pacífico colombiano. É por isso que se avaliou o enraizamento das suas estacas em resposta ao tipo de semea e a fase de desenvolvimento. Coletaram se estacas de ramas com fases de desenvolvimento herbáceo, semiplenos e lenhoso. As estacas semeadas foram submergidas no ácido ascórbico e conservadas em papel de jornal humedecido. A semea fez se em seis camas de germinação; três utilizando um substrato e três para intempérie. A sustância emprazadora foi hormonagro 1 (0,05 g/estaca). Se empregou um desenho fatorial aleatorizado, composto por três fatores (hormona emprazadora, sítio de semea y fase de desenvolvimento de estacas). O monitório se realizou cada oito dias. Se obtive um enraizamento de 37,5 %, ele não foi afetado significativamente pelo tipo de estaca utilizado (herbáceas = 38,5 %, semilenhosas = 32,3 y lenhosas = 41,7 %), mientras que, o lugar de semeado sim obtive um efeito no enraizamento das estacas (eras-substrato orgânico = 27,1 % e intempérie no solo = 47,9 %). Se conclui que as estacas de ramas lenhosas, resultam ser as mais adequadas para a propagação de *C. guianensis,* devido a que experimentou se melhor resposta de enraizamento e supervivência nos tratamentos avaliados.

Palavras chave: Espécie arbórea, estaca, hormona enraizadora, Güino, propagação vegetativa.

INTRODUCTION

The development phase of woody plants is a very important issue in the management of tropical forests (Jeník, 1994). This factor together with the type of sowing determine various aspects, such as the capacity for vegetative propagation, the rate and form of growth, as well as the quality and speed of root formation (Wendling and Xavier, 2001). It is therefore crucial to identify in which phase of development the greatest propagation success is achieved, as this has direct implications on the effectiveness of vegetative propagation and other stages of forestry (Sasaki, 2008).

However, to present day there is little information on the characteristics that favor the propagation of many tropical forest species (Tarnowski, 2021), among which *Carapa guianensis* Aublet stands out, which due to its attractive characteristics has been overexploited in natural forests of the Colombian Pacific, which has directly affected its presence in these ecosystems (Klínger *et al.,* 2011; Martínez *et al.,* 2015).

The main limitations in the propagation of *C. guianensis* are due to the fact that its seeds are recalcitrant, which causes them to lose viability quickly after dispersal or harvest (Magnitskiy and Plaza, 2007; Bacca *et al.,* 2021). Likewise, the phenological processes of this species are asynchronous, which makes it difficult to obtain and collect exact seeds and fruits (Morales-Puentes, 1997). Furthermore, in regions such as the Colombian Pacific, there are no in situ or ex situ germplasm banks that contain plant material throughout the year, which limits the research, propagation and management of the species (Román *et al.*, *2012*; Rivers *et al.,* 2017).

In this way, the propagation of this species is still an unclarified process (Bacca *et al.,* 2021), so understanding the effect that the type of planting and the development phase has on the rooting process of the cuttings, could contribute to increasing the prospects for successful propagation of adult trees, which will result in greater efficiency in the selection,

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improvement and propagation process (Wendling and Xavier, 2001). Therefore, the objective of this study was to evaluate the rooting of cuttings from *C. guianensis* in response to the type of planting and the development phase

MATERIALS AND METHODS

Study area

The research was carried out in the back part of block eight (8) of the Technological University of Chocó "Diego Luís Córdoba", located in the municipality of Quibdó, central part of the Chocó Biogeographic, under the coordinates 05°40'56,43'' N and 76°38'51.9'' W (Figure 1). It is located in the Tropical Rainforest (Bp-T) life zone, which is characterized by having an average temperature of 28ºC, average annual precipitation of 10,000 mm, relative humidity of 90% and an altitude of 43 meters above sea level (Alcaldía de Quibdó, 2020).

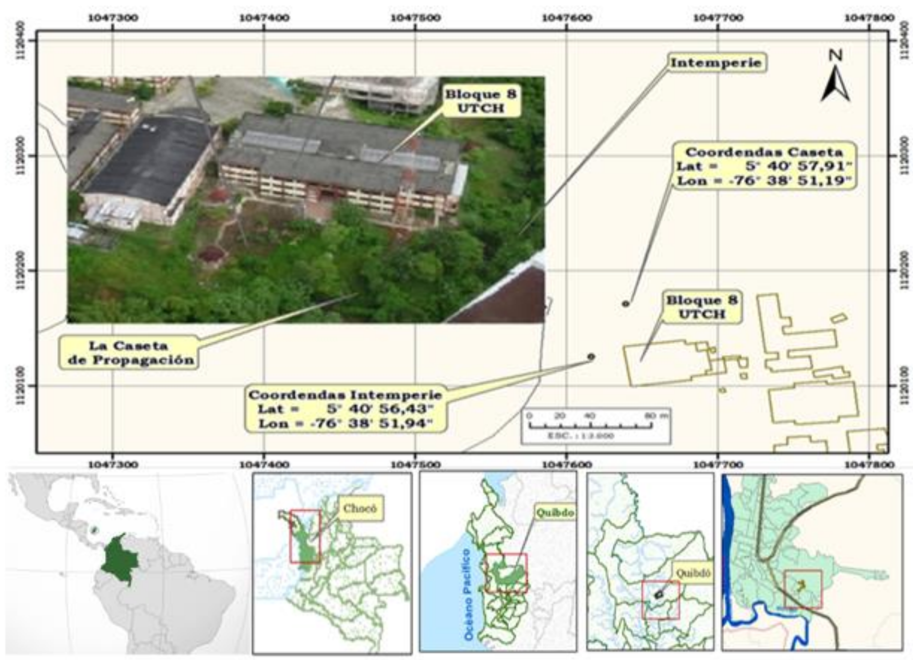

Figure 1. - Geographic location of the study area

Vegetal material

C. guianensis tree branches were used (24 per development stage) from the Casa Blanca farm, located in the municipality of Cértegui, department of Chocó, Colombia (coordinates 05°21'27.1'' N and 76 °37'05.9'' W). The plant material was collected from five trees that had the following characteristics: trees 1, 2 and 3 (herbaceous) $D_{1.30}$ = 1 cm and total height 2.5 meters; tree 4 (semi-woody) with $D_{1.30}$ = 9.5 cm and total height of 8 meters and tree 5 $D_{1,30}$ = 65 cm and total height 20 meters.

Experimental design

A completely randomized design was used with three fixed factors (factorial), which were: 1) application and non-application of IBA (rooting hormone at a concentration of 0.05 g/stake), 2) planting site (in beds of rooting-organic substrate and weathering in the soil) and 3) development phase (herbaceous, semi-woody and woody). The combination of these resulted in 12 treatments with three repetitions each, for a total of 36 experimental units (group of eight cuttings) (Figure 2).

Adequacy of the area for rooting the cuttings

The present investigation was carried out in two different sites. The first consisted of an area of 16 m^2 (2 x 8 m), where six rooting beds measuring 1 m long by 1 m wide were built. To protect this site, a 2 m wide by 8 m long shelter was built and covered with black plastic. The other part of the experiment was established in an area adjacent to a 20 x 30 m home garden. At this site the cuttings were planted directly in the ground without any type of cover (outdoors).

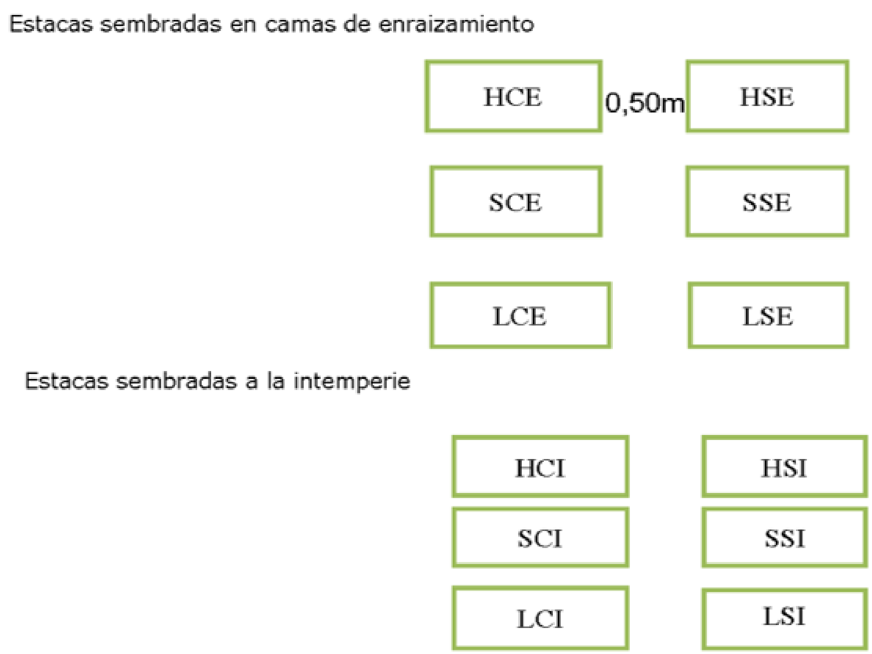

Figure 2. - Graphic representation of the experimental design

HCE =hormone-containing herbaceous cuttings in rooting beds; **HSE** =hormone-free herbaceous cuttings in rooting beds; **SCE** = semi-woody cuttings with hormone in rooting beds; **SSE** = semi-woody cuttings without hormone in rooting beds; **LCE** =woody cuttings with hormone in rooting beds; **LSE** = hormone-free woody cuttings in rooting beds; **HCI** = herbaceous cuttings with hormone outdoors; **HSI** =hormone-free herbaceous cuttings outdoors; **SCI** = semi-woody cuttings with hormone outdoors; **SSI** = semi-woody cuttings without hormone outdoors; **LCI** =woody cuttings with hormone outdoors; **LSI** =woody cuttings without hormone outdoors

Management of stakes and organic substrates

The cuttings were done to 30 cm in length and grouped according to their development phase. Subsequently, they were immersed in an ascorbic acid solution and wrapped in moistened newspaper. This material was transported to the Technological University of Chocó in fique sacks; where it was disinfected using a solution of 1% sodium hypochlorite and water, for 10 minutes, then they were washed three times with distilled water and finally a fungicide (Antracol) was applied to prevent the presence of fungi.

As an organic substrate, a combination of decomposed sawdust and sand in a 2:1 ratio was used, which were acquired in the study area. For disinfection, boiling water was used (temperature of 100ºC), with which the substrate was moistened. Subsequently, the mixture was covered with black plastic for 24 hours (Pinilla *et al.*, 2016; Torres-Torres *et al.*, 2018b).

Planting of plant material and monitoring

Sowing was carried out taking into account the development phase of the cuttings of the *C. guianensis species* (herbaceous, semi-woody and woody). The most mature part was impregnated with rooting powder (hormone 1 0.05 g/stake). The cuttings were planted in polyethylene bags at a depth of 10 cm.

The planted material was monitored every eight days. During this process, weed control (manual) and pest control (termites and leafhopper ant) were carried out. In addition, irrigation was applied once a day (Rengifo and Torres-Torres, 2016; Torres-Torres *et al.*, 2018a; 2018c). Root length measurements were made with a tape measure.

Variables evaluated

The following evaluation parameters were taken into account: rooting percentage (PE), survival percentage (PS), and root length. Specifically for the rooting percentage, the following Equation 1 was used:

$$PE = \frac{EE}{ES} * 100$$

Where:

PE: percentage of rooting of cuttings.

EE: number of rooted cuttings.

ES: number of stakes planted.

Table 1.* - *Rooting index

Rooting rate	Rooting levels
0	Null
0.1- 0.9	Low
1	Half
1-1.9	High

The rooting index was defined taking into account the values presented in table 1 and the calculation was carried out using the following Equation 2 and Equation 3 (Aparicio *et al*., 2014):

$$In = \frac{(0 * A) + (1 * B) + (2 * C) + (D * 3)}{N° \ total \ de \ estacas} * 100$$

Where:

In: rooting index.

A: unrooted cuttings.

B: cuttings with 1 to 4 roots.

C: cuttings with 5 to 8 roots.

D: cuttings with 9 to 11 roots

$$PS = \frac{EV}{EP} * 100$$

Where:

PS: Survival percentage.

EV: number of live cuttings

EP: number of cuttings planted

Statistical analysis

The assumptions of normality were verified in the R environment, using the Shapiro-Wilks test. In the R environment, a three-way analysis of variance was performed to identify differences between treatments (R Core Team, 2017). For the factors with a difference, a Duncan multiple range test was applied for the 12 treatments and their 3 repetitions, using

STARGRAPHICS 16.1.15 centurion XVI. Percentage formulas were applied for rooting and survival calculations (Medina *et al*., 2020).

RESULTS

Rooting of C. guianensis

The results of the Shapiro-Wilks test (F= 2.960; P =0.014) indicate that the data are normally distributed.

The highest percentage of rooting was experienced in plant material planted outdoors, being statistically different to the rest (P < 0.05), using cuttings in the woody development phase and without applying hormonal rooting agent (41.7%), while the lowest (27.1 %) was obtained in cuttings planted in rooting beds with substrate, in the herbaceous and semi-woody development phases without applying hormonal rooting agent (Figure 3; Table 2).

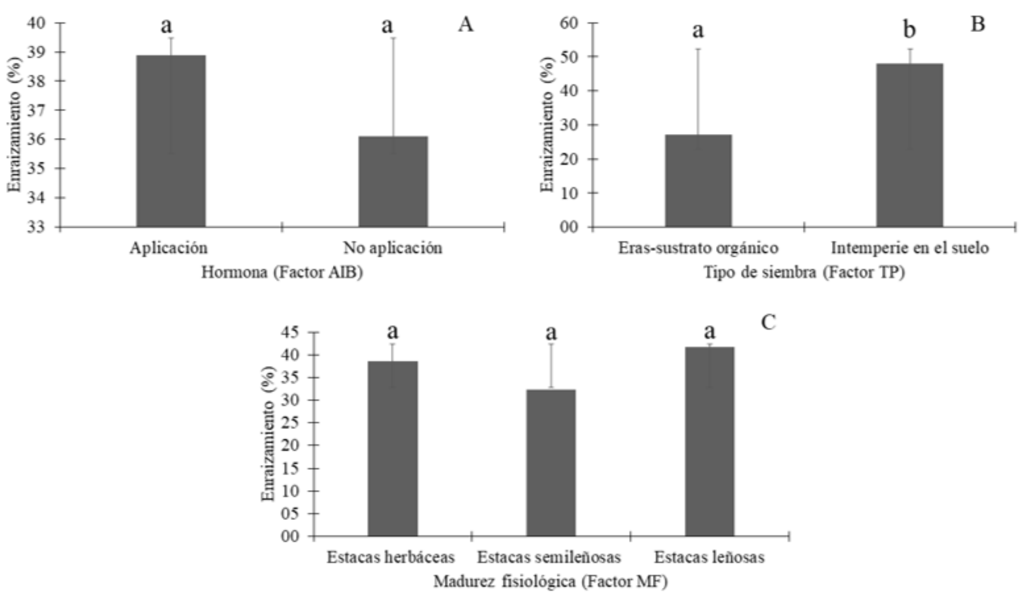

Figure 3. - Rooting percentage for (A) AIB Factor, (B) TP Factor and (C) MF Factor

Note: Lines in bars mean standard deviation. Different letters indicate significant differences at P< 0.05

For its part, the results of the interaction between the sowing type factors (outdoors and in rooting beds-substrate-TP) and the application or not of hormonal rooting agent (AIB; F= 5.26; P= 0.029), are be non-significant, without ignoring that, when changing from application to non-application, the rooting percentage for cuttings planted outdoors increases and for cuttings planted in rooting beds it decreases (Table 2).

Table 2. - Rooting (PE %), survival (PS %) and root length (LR) of cuttings by treatment used and interactions between factors

Treatment		**PE (%)**	**(%)**	**LR (mm)**
AIB	Application	38.9 a	66.7 a	77.7 a
	Non- application	36.1 a	57.6 a	87.6 a
TP	Eras- substrate organic	27.1 a	52.1 a	46.0 a
	Outdoor in the floor	47.9b	72.2b	119.2b
MF	Herbaceous cuttings	38.5 a	66.7 a	84.1 a
	Semi-woody cuttings	32.3 a	57.3 a	61.2 a
	woody stakes	41.7 a	62.5 a	102.5b
Interactions				
AIB vs TP		ns *	ns	ns
TP vs MF		ns	ns	ns
AIB vs MF		ns	ns	ns
AIB vs TP vs MF		ns	ns	ns

*AIB: Application or not of rooting hormones, TP: Type of planting, MF: Development phase of the cuttings * non-significant interaction. Different letters in the same factor indicate significant differences at P<0.05*

C. guianensis seedlings

The result of the analysis of variance suggests that the development phase factor (F=0.55; P=0.583) and the application or not of hormonal rooting (F=1.52; P=0.226) do not significantly affect the survival of the seedlings. However, for the type of sowing (outdoors and in rooting beds - substrate), significant differences were evident (F=7.58; P=0.010; Table 2).

The highest percentage of survival was obtained outdoors in the herbaceous development phase (72.2 %) with or without hormonal rooting agent (Table 2).

It is also observed that when changing from the application of hormonal rooting to non-application, the percentage of survival in the development phase of the herbaceous cuttings practically remains constant, but for the woody development phase, survival increases slightly, while for semi-woody cuttings decreases significantly, clarifying that these interactions are not significant (Table 2).

Root Length

It was observed that the type of sowing significantly affects the length of the roots (F=10.60; P=0.0027), that is, the average root length for *C. guianensis* varies from one type of sowing to another ($\bar{X}$= 46 mm in beds with organic substrate and $\bar{X}$ = 119.2 mm outdoors) and not with the application of rooting ($\bar{X}$ = 77.7 mm with application and 87.6 mm without application).

Root production using woody cuttings ($\bar{X}$ = 102.5 mm) was significantly greater than that obtained using herbaceous ($\bar{X}$ = 84.1 mm) and semi-woody cuttings ($\bar{X}$ = 61.2 mm) (Table 2).

DISCUSSION

Rooting

Greater rooting was obtained in the woody cuttings, while for the herbaceous and semi-woody cuttings the value was lower. This result differs from that obtained in other research with conifers (Haffner *et al.*, 1991; Mitchell *et al.*, 2004b), in which it has been indicated that the younger the cuttings are, the greater their rooting will be and therefore, older woody material tends to reduce the rooting percentage.

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According to Aparicio-Rentería *et al.* (2014), the main limitation of the rooting process of seeds of forest species is the age of the tree from which the plant material comes and the part of the tree from which the cuttings are obtained. In the case of the present investigation, the cuttings were obtained from branches with less than seven months of formation, which may help to explain the differences previously mentioned.

In other observations Giraldo *et al.* (2009) have documented that tender or younger plant material requires the application of hormonal rooting to maximize success in the propagation of some species. This observation differs from what was obtained in the present investigation, in which the application or not of rooting did not have a direct effect on the rooting process of the planted cuttings, which could be related to the origin of the cuttings, the age of the tree where the plant material is obtained and the time the cuttings take from harvest to planting (Mitchell *et al*., 2004 a). Therefore, Aparicio-Rentería *et al.* (2014) have suggested that it is important not to store plant material for long periods of time and to use organic substrates similar to those found in the environment where the species grows.

A rooting index of 0.26 was obtained, which means that the level of rooting is low, this result being similar to that obtained by Latsague *et al.* (2008), who also point out that this value tends to increase whenever semi-woody stakes are used.

C. guianensis seedlings

Better outdoor survival results were observed using herbaceous cuttings, which is different from what was suggested by Mitchell *et al.* (2004a), who have suggested a negative effect of age on the survival of conifers, however, these same authors have indicated that the response of the cuttings to the development phase will depend on the species, since for example with In *Pinus patula,* greater survival is obtained using older woody cuttings, so it is inferred that this issue should be explored for each specific forest species to define patterns in the process of vegetative propagation.

Root length

It could be observed that the root length for C. *guianensis*, varies from one type of planting to another and not with the application of rooting agent, the best results being evident in that material planted outdoors. In this regard, Mitchell *et al.* (2004a) have indicated that in these cases the type of soil and its moisture content are fundamental in root growth. However, the high humidity experienced by soils in rainforest areas where a high amount of water is retained must be considered, which can favor or negatively affect the decomposition of forest material (Serna-Mosquera *et al.*, 2020). In this case, it seems that planting the cuttings outdoors turns out to favor root growth because it favors the entry of light that facilitates the evaporation of part of the water that does not percolate or leach (Osorio, 2018).

CONCLUSIONS

Woody branch cuttings turn out to be the most suitable for the propagation of C. *guianensis*, since they do not require rooting hormones to achieve root regrowth for the survival of the plant. On the other hand, for herbaceous and semi-woody cuttings, rooting substance is required to fulfill this purpose and a sandy substrate.

The greatest root growth and survival of C. *guianensis* under vegetative propagation is obtained using woody branch cuttings without the application of rooting hormones and planted outdoors.

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The authors declare not to have any interest conflicts.

***Contribution of the authors*:**

The authors have participated in the writing of the work and analysis of the documents.