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Vegetative propagation of *Schizolobium parahyba* var. *amazonicum* (paricá) using field grafting and mound layering techniques

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ABSTRACT

Schizolobium parahyba var. *amazonicum* (paricá) is an economically and environmentally important leguminous tree in the Brazilian Amazon, primarily used for wood. No efficient cloning techniques are available for this species, therefore we evaluated the effectiveness of grafting and mound-layering techniques for vegetative propagation of paricá. We carried out two field experiments. The grafting experiment utilized cleft grafting on rootstocks with scion diameters of 0.8 ± 0.2 and 1.5 ± 0.2 cm, collected from basal epicormic sprouts, in a completely randomized design. The mound-layering experiment involved basal epicormic sprouts induced by coppicing, with a randomized complete block design and five concentrations of indole-3-butyric acid (IBA) (0, 6, 12, 24, 48 g kg^{-1}). Scions with larger diameter resulted in significantly higher survival rates, and greater shoot diameter and length. Grafted plants showed high vegetative vigor and weakly visible callus formation. With mound-layering, rooting of basal epicormic sprouts increased significantly with IBA concentrations up to 12 g kg^{-1}, but decreased at higher concentrations. The high survival rate of grafted plants indicated successful graft union, differentiation of new vascular tissue and the formation of a vascular system for vegetative growth. Mound-layering was also successful as shown by the increase in rooting when treated with IBA. The decline in rooting at higher IBA concentrations suggests that excessive auxin may inhibit root formation. Our results indicate that cleft grafting and mound-layering have potential to be used in the vegetative propagation of paricá.

KEYWORDS: clonal forestry, rejuvenation, timber species, Brazilian Amazon, epicormic sprouts, scion diameter

Propagação vegetativa de *Schizolobium parahyba* var. *amazonicum* (paricá) usando técnicas de enxertia e mergulhia de cepa

RESUMO

Schizolobium parahyba var. *amazonicum* (paricá) é uma árvore leguminosa de importância econômica e ambiental na Amazônia brasileira, principalmente utilizada para produção madeireira. Não existem técnicas de propagação vegetativa eficientes para paricá, portanto avaliamos a eficácia das técnicas de enxertia e mergulhia-de-cepa na propagação vegetativa de paricá. Conduzimos dois experimentos de campo. No experimento de enxertia em fenda cheia utilizamos porta-enxertos e diâmetros de enxertos de 0,8 ± 0,2 e 1,5 ± 0,2 cm coletados de brotações epicórmicas basais, em desenho completamente casualizado. No experimento de mergulhia-de-cepa usamos brotações epicórmicas basais induzidas por decepa em desenho de blocos completos casualizados e cinco concentrações de ácido-indol-3-butírico (AIB) (0, 6, 12, 24, 48 g kg^{-1}). Enxertos com diâmetros maiores resultaram em taxas de sobrevivência significativamente mais altas e maior diâmetro e comprimento dos brotos. As plantas enxertadas mostraram alto vigor vegetativo e formação de calo pouco visível. Na mergulhia-de-cepa, a formação de raízes das brotações aumentou significativamente com concentrações de AIB até 12 g kg^{-1}, mas diminuiu com concentrações mais altas. A alta sobrevivência das plantas enxertadas indicou sucesso na união do enxerto, diferenciação de novo tecido vascular e formação de um sistema vascular para crescimento vegetativo. A mergulhia-de-cepa também mostrou-se bem-sucedida, como mostra o aumento na formação de raízes tratadas com AIB. A redução de enraizamento em concentrações mais altas de AIB sugere que auxinas em excesso podem inibir a formação de raízes. Nossos resultados indicam que enxertia em fenda cheia e mergulhia-de-cepa são técnicas potenciais para a propagação vegetativa de paricá.

PALAVRAS-CHAVE: silvicultura clonal, rejuvenescimento, espécies madeireiras, Amazônia brasileira, brotações epicórmicas, diâmetro do enxerto

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INTRODUCTION

Schizolobium parahyba var. *amazonicum* (Huber ex Ducke) Barneby (Caesalpinaceae) (known in Brazil as paricá) is a large-sized tree species (Souza *et al.* 2003). It has been the primary source of timber for the plywood industry in Brazil (Silva *et al.* 2015; Silveira *et al.* 2017), with over 90,000 ha of plantations (IBA 2019), mainly in the Brazilian Amazon. Paricá has been planted commercially since 1993, typically established through planting or sowing without any improvements (Sales 2018; Silva and Sales 2018; Sales *et al.* 2021), wich contributes to varying productivity and timber properties and the evolution of pests and diseases (Terezo *et al.* 2015; Modes *et al.* 2020).

One potential solution is the use of vegetative propagation methods to obtain the fixation of selected genotypes for uniform clonal plantations that improve productivity and the quality of wood and other products (Xavier *et al.* 2021). Despite these potential advantages, so far no effective system of vegetative propagation for paricá has been developed. There are a few studies on the vegetative propagation of paricá, mostly involving experimental tests of cuttings/mini-cuttings in clonal/mini-clonal hedges and *in vitro* propagation (Dias *et al.* 2015; Souza 2015; Lima *et al.* 2018), but no protocol for applying these two techniques to paricá has been established. Grafting and mound layering techniques can be alternatives for the vegetative propagation of paricá plants, as cuttings and *in vitro* methods were not efficient for this species (Paiva and Gomes 2011; Souza 2015; Lima and Ohashi 2016; Lima *et al.* 2018).

Grafting techniques have been successfully applied to *Araucaria angustifolia* (Bertol.) Kuntze for wood production (Wendling *et al.* 2017) and *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. for latex (Xianhong *et al.* 2020) and wood production (Okino *et al.* 2004; Leonello *et al.* 2012). The cleft grafting method has been the most widely used due to its simple application and the rapid response of grafted plants (Xavier *et al.* 2021). Typically, this method uses rootstocks (seedlings) grown in plant nurseries or in the field, the latter having the advantage of not requiring the complex structures of plant nurseries (Borelli 2016; Rickli-horst *et al.* 2019). It is also important to consider variables that may influence the success of grafted plants, such as the diameter of scions and rootstocks at the time of grafting, which can influence the survival of grafted plants and the number, length and diameter of shoots (Espindola *et al.* 2004; Gomes *et al.* 2010).

The mound layering method involves inducing adventitious rooting of basal epicormic sprouts (induced by coppicing) still attached to their mother trees that form roots where they come into contact with a rooting medium (substrate) (Rymbai 2009). This method is generally successful because it minimizes water stress, maintains high carbohydrate and mineral nutrient levels, and takes into account the correlation between adventitious rooting capacity and the vegetative phase of plant development (Paiva and Gomes 2011; Wendling *et al.* 2014).

The efficiency of the mound layering method is affected by factors such as stem treatment, plant growth regulators, humidity, type of substrate and a suitable time for disconnection from the mother tree (Paiva and Gomes 2011). It has been successfully applied for fruit and seed production in *Psidium* spp. (Callovy Filho *et al.* 1995; Mishra *et al.* 2007; Rymbai 2009), *Persea* spp. (Oliveira *et al.* 2000) and *Annona* spp. (Rathore 1976; Gupta and Brahmachari 2004), among other species.

Considering the potential of grafting and mound layering for paricá vegetative propagation, this study aimed to evaluate the effectiveness of cleft grafting as a function of basal propagule (scion) diameter, and of mound layering with plant growth regulators on the vegetative propagation of paricá.

MATERIAL AND METHODS

Environmental conditions

The study was carried out at Fazenda Jaspe (altitude 160 m, 4°0′58″S, 47°52′32″W) and at Área Experimental do Centro Urbano (altitude 250 m, 04°17'36"S, 47°33'15"W), located in the municipalities of Ulianópolis and Dom Eliseu, respectively, state of Pará, in the southeastern Amazon region of Brazil.

The original vegetation of the study areas consisted of submontane tropical rainforest (Veloso *et al.* 1991), whereas the current land use is dominated by commercial plantations of paricá. The predominant type of soil is yellow latosol with clayey texture, and the relief is flat to gently undulating (Santos *et al.* 2018). The climate is classified as mesothermal and humid, typology Aw (Köppen classification) (Dubreuil *et al.* 2018). Average annual temperature is 27 °C, average daily relative humidity ranges between 42 and 92%, and average annual rainfall is 2,200 mm, with a rainy season from December to May (INMET 2021). Temperature, rainfall, and water balance data during the period of this study (from January 2020 to January 2021) are presented in Figure 1.

Field grafting experiment

The field grafting experiment was conducted in a completely randomized design with two treatments (two scion diameters: 0.8 ± 0.2 cm and 1.5 ± 0.2 cm). For each treatment level we used 10 plots (repetitions) containing eight grafted plants each. The grafted plants were monitored at 7, 15, 30, 60, 120 and 240 days after grafting. Response variables measured were survival (%), number of shoots per scion, shoot length and diameter, callus formation and vegetative vigor. Shoot length (cm) was measured from the base of the shoot to the apical bud using a graduated ruler and shoot diameter (cm)

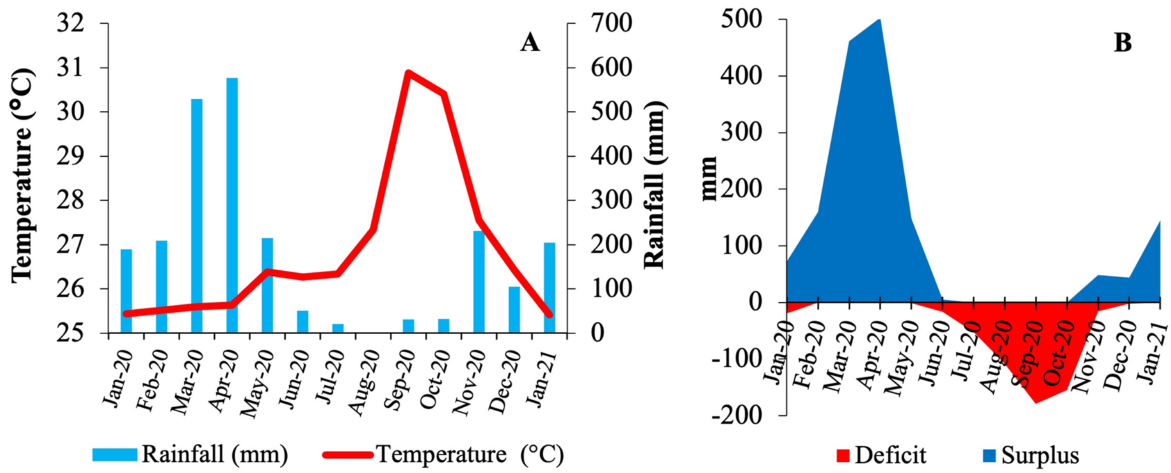

Figure 1. Environmental conditions in southeastern Pará state, Brazil, during the study (January 2020 to January 2021). **A** – average air temperature and rainfall; **B** – water balance.

was measured at the base of the shoot using a digital caliper. Callus formation and vegetative vigor were assessed visually at 120 and 240 days. Callus formation was categorized as 1) no visible callus; 2) small callus; or 3) large callus. Vegetative vigor was categorized as 1) high vigor without any signs of damage, pests, disease, or nutrient deficiency symptoms; 2) medium vigor with one of the latter signs; and 3) low vigor with two or more signs.

Grafting was applied to seedlings planted (density = 1 plant per 4 m^2) in Área Experimental do Centro Urbano, which had a total area of 2,500 m^2, corresponding to 625 plants. Before the experiment was set up, soil analysis was carried out according to Teixeira *et al.* (2017) (Table 1).

Table 1. Chemical and physical analysis of a composite soil sample (depth 0-20 cm) collected from each experimental area of *Schizolobium parahyba* var. *amazonicum* (paricá): Área Experimental do Centro Urbano, Dom Eliseu town, state of Pará, Brazil (for the field grafting experiment), and Fazenda Jaspe, Ulianópolis town, state of Pará, Brazil (for the mound stratification experiment).

Field grafting experiment												
pH	**OM**	**N**	**P**	**K**	**Ca**	**Mg**	**Al**	**H+Al**	**Na**	**SB**	**t**	**T**
	g kg^{-1}	%	mg dm^{-3}		cmol$_c$ dm^{-3}							
4.4	1.34	0.36	4.7	35.2	2.0	0.6	0.2	5.8	0.13	1.7	1.9	7.5
Mn	**Fe**	**Zn**	**Cu**	**V**		**m**		**Sand**		**Silt**		**Clay**
mg dm^{-3}				%				g kg^{-1}				
1.2	76.1	0.7	0.1	22.6		10.5		340		110		550
Mound layering experiment												
pH	**OM**	**N**	**P**	**K**	**Ca**	**Mg**	**Al**	**H+Al**	**Na**	**SB**	**t**	**T**
	g kg^{-1}	%	mg dm^{-3}		cmol$_c$ dm^{-3}							
5.2	2.72	0.56	14.7	74.2	3.2	0.9	0.2	2.83	0.21	4.5	4.7	7.3
Mn	**Fe**	**Zn**	**Cu**	**V**		**M**		**Sand**		**Silt**		**Clay**
mg dm^{-3}				%				g kg^{-1}				
6.6	98.1	2.1	0.3	61.6		4.6		360		120		520

pH = hydrogen potential of water; OM = organic matter; N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; H+Al = hydrogen + aluminum; Mn = manganese; Fe = iron; Zn = zinc; Cu = copper; Na = sodium; SB = sum of bases; t = effective cation exchange capacity; T = cation exchange capacity at pH 7; V = base saturation; m = aluminum saturation.

The soil was prepared with harrowing and 2,950 kg ha^{-1} of dolomitic limestone (RNV 95%) to increase its base saturation to 60%. The control of leafcutter ants was carried out by applying 10 g of sulfluramid-treated bait per m^2 of loose soil at a distance of about 50 cm from the ant hills.

Paricá seeds were sourced from the southeast of Pará state (Brazilian Amazon) and supplied by the forestry company Grupo Arboris®. Prior to planting, the seeds were mechanically scarified with an emery machine. The seeds were sown in January 2020. We applied NPK (05-30-15 formulation) at 200 g hole^{-1} in order to supply the macronutrient requirements of the seeds. Reseeding was performed after 14 days, when necessary. On the 50th day, manual top-dressing was carried out by applying 150 g of ammonium sulfate ($(NH_4)_2 SO_4$) in a lateral hole 25 cm away from each plant to supply nitrogen and sulfur. Manual weed control was done in the total area. On rainless days, the plants were manually irrigated with a manual watering can (10 L plant^{-1}). Grafting was done in May 2020, when the height of the plants varied between 45 and 159 (measured with a graduated ruler from the base of the shoot to the apical bud) and the diameter at the root collar varied between 2.2 and 5.5 cm (measured with a digital caliper). The graft union was established between 13 and 109 cm to match the graft diameters.

Scions of paricá were collected from epicormic sprouts (induced by the coppicing technique) of five-year-old trees of different genotypes from a commercial reforestation located at Fazenda Jaspe, as described by Sales (2018). Scions were collected according to the methodology used by Mendes (2019) by wrapping them in moist paper and aluminum foil to reduce loss of turgidity and then packing them in a thermal box.

The cleft grafting protocol consisted in: 1) cutting the base of the semi-hard scions (two buds) into a wedge-shape (Figure 2a); 2) removing the semi-hard top section of the rootstock and making a vertical cut into the stem around the depth of the wedge (Figure 2b); and 3) joining the scion and rootstock end to end, wrapping the graft union and graft with Parafilm® tape, except the petiole, and the graft union with grafting tape (Figure 2c). The grafting tape was removed after 60 days. It was not necessary to remove the Parafilm® tape, as it naturally degraded and fell off the graft.

As the success rate of grafting is influenced by the skill of the grafter (Mendes 2019), the grafting was done by well-experienced personnel. Additionally, measures were taken to keep the planting area free of weeds and to create a favorable environment for the proper growth and development of the grafted plants, including manual irrigation (15 L plant^{-1}) on rainless days.

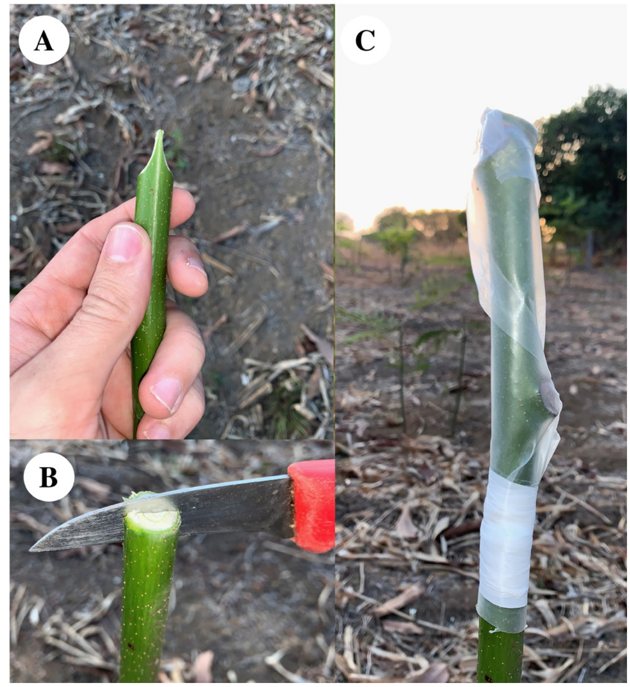

Figure 2. Cleft grafting method applied to *Schizolobium parahyba var. amazonicum* (paricá) in May 2020 in Pará (Brazil). **A** – The base of the scions (two buds) was cut into a wedge-shape; **B** – The top section of the rootstock was removed, and a vertical cut was made into the stem around the depth of the wedge; **C** – Scion and rootstock were joined end to end, wrapped with Parafilm®, except for the petiole, and wrapped with grafting tape.

Mound layering experiment

The mound layering experiment was carried out in a completely randomized block design with one treatment (application of the plant growth regulator indole-3-butyric acid – IBA). IBA was applied as powder in five concentrations (0, 6, 12, 24 and 48 g kg^{-1}) with four plots (repetitions) each (10 stumps per plot). At 30 days after the start of the experiment, we visually inspected the rooting of basal epicormic sprouts (%).

Before the experiment was set up at Fazenda Jaspe, soil analysis was carried out as for the grafting experiment (Table 1). Five-year-old trees of different genotypes were chosen from a commercial reforestation located at Fazenda Jaspe, as described by Sales (2018). The mound layering method was applied in January 2020 using basal epicormic sprouts induced by the coppicing technique. Manual weed control was carried out to favor stump survival and bud development.

Mound layering was applied to tree stumps 60 days after cropping and consisted in: 1) retaining the most vigorous sprouting (diameter 1.2 ± 0.4 cm and length between 20 and 60 cm, and without visible damage); 2) total girdling near the base of the sprout, about 1 cm wide; 3) applying the IBA concentrations using a 0.5-inch wide silk brush (bristle length 5 mm) (Figure 3a) that was immersed in the container until it reached the full length of the bristle and this measurement of IBA was applied to each sprout; and 4) burying the tree stump and sprout up to 15 cm above the girdled part using soil from the surroundings of the stump (Figure 3b).

Data analysis

The response variables complied with the requirements of parametric analysis for homogeneity of variance (Bartlett's test) and for normality of residual distribution (Shapiro-Wilk test). The variables of the grafting experiment were compared between diameter categories at each measuring day using analysis of variance (ANOVA) by F-test. Rooting of epicormic sprouts (mound layering experiment) at increasing IBA concentrations was analyzed by regression. RStudio® software (RStudio Team 2022) was used for all analysis using a 5% significance level.

RESULTS

Field grafting

Graft survival and shoot length did not significantly differ between scion diameter categories at 7 and 15 days after grafting, but were significantly higher for larger scion diameters at 30, 60, 120, and 240 days for graft survival (respectively $F_{(1, 18)}$ = 9.000, p = 0.024; $F_{(1, 18)}$ = 7.736, p = 0.031; $F_{(1, 18)}$ = 7.736, p = 0.031; $F_{(1, 18)}$ = 7.736, p = 0.031) and shoot length (respectively $F_{(1, 18)}$ = 11.693, p = 0.014; $F_{(1, 18)}$ = 30.979, p = 0.001; $F_{(1, 18)}$ = 6.045, p = 0.0491; $F_{(1, 18)}$ = 46.068, p = 0.001) (Figure 4a,c). Average number of shoots per scion varied from 1.4 to 1.7, with no significant difference between diameter categories (Figure 4b). Shoot diameter was significantly higher for higher scion diameters at 7 and 240 days after grafting ($F_{(1, 18)}$ = 6.270, p = 0.046; $F_{(1, 18)}$ = 62.461, p = 0.001, respectively) (1.1 and 13.3 cm, respectively) (Figure 4d).

Average frequency of callus type did not vary significantly between scion diameter groups at 120, nor at 240 days after grafting (Figure 5a), and differed significantly at 120 days within each scion diameter group, except between small and large calluses in the 1.5-cm diameter group. In the group of smaller scion diameters, an average 60% of shoots had no visible callus, 32% had a small callus and 8% had a large callus. In the group of larger scion diameters, most (56%) had no visible callus, while small and large calluses shared 22% each. At 240 days, all shoots had no visible callus.

Average vegetative vigor level also did not vary significantly between scion diameter groups at 120 and at 240 days (Figure 5b). Both at 120 and 240 days, the frequencies of vegetative vigor levels differed significantly within each scion diameter group. Most shoots had high vigor. In the scion group of larger diameters, 88% of shoots had high vigor, and 12% medium vigor. In the small diameter group, 80% had high vigor and 20% medium vigor.

Mound layering

The regression of rooting of basal epicormic sprouts at 30 days after mound layering on IBA concentrations resulted in a quadratic effect (Figure 6). Rooting increased up to 12 g kg^{-1} of IBA and decreased from then on. The best results (93 and 78% rooted basal epicormic sprouts) were obtained between 12 and 24 g kg^{-1} of IBA concentration, respectively. The regression curve estimated maximum rooting of 90% (R^2 = 0.73) at a concentration of 26 g kg^{-1} of IBA.

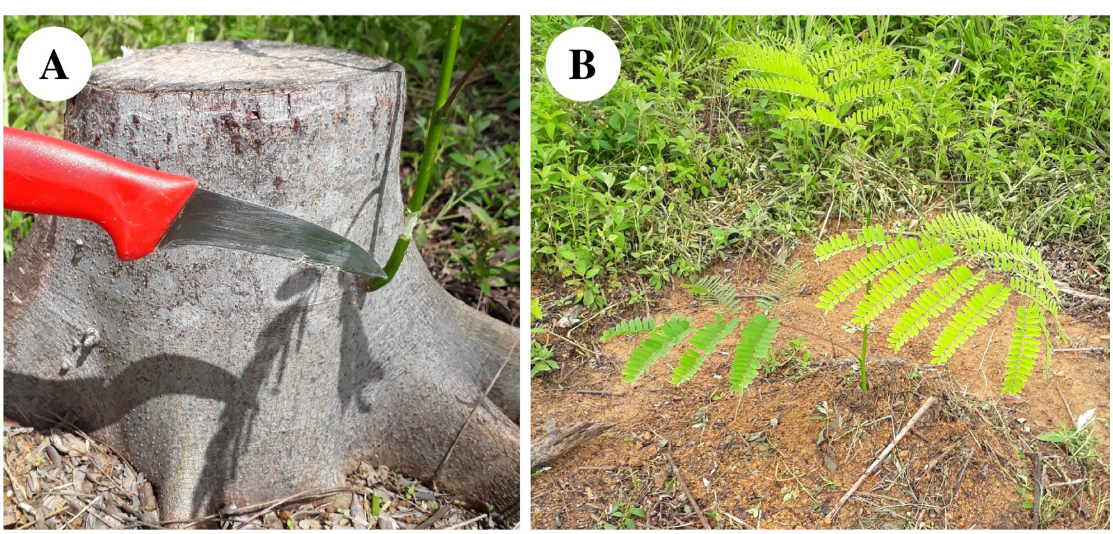

Figure 3. Mound layering applied to *Schizolobium parahyba* var. *amazonicum* (paricá) in January 2020 in Pará (Brazil). **A** – Only the most vigorous sprout was retained on each tree stump, performing total girdling near its base, and applying plant growth regulator; **B** – The sprout and stump were buried up to 15 cm above the girdled part using soil from the surroundings.

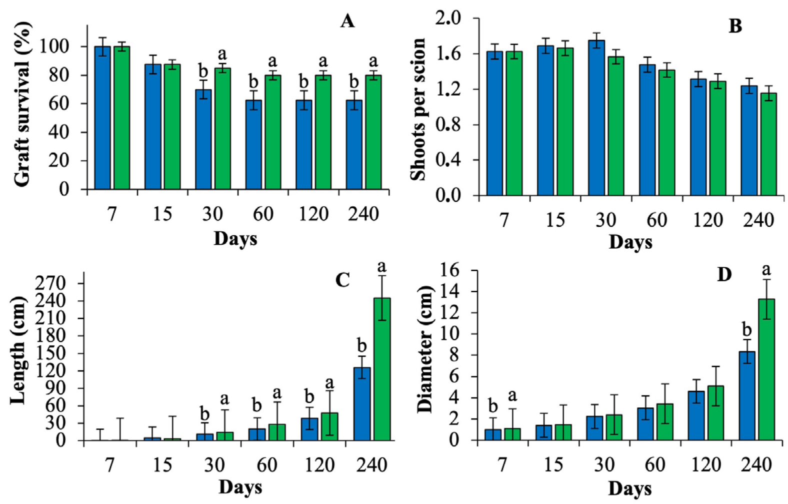

Figure 4. Graft survival (**A**), number of shoots per scion (**B**), shoot length (**C**) and shoot diameter (**D**) of *Schizolobium parahyba* var. *amazonicum* (paricá) plants with scion diameter around 0.8 and 1.5 cm from 7 to 240 days after grafting. Columns are the mean of 10 replicates. Different letters above the columns indicate significant difference between diameter categories within time points according to an F-test at 5% significance level.

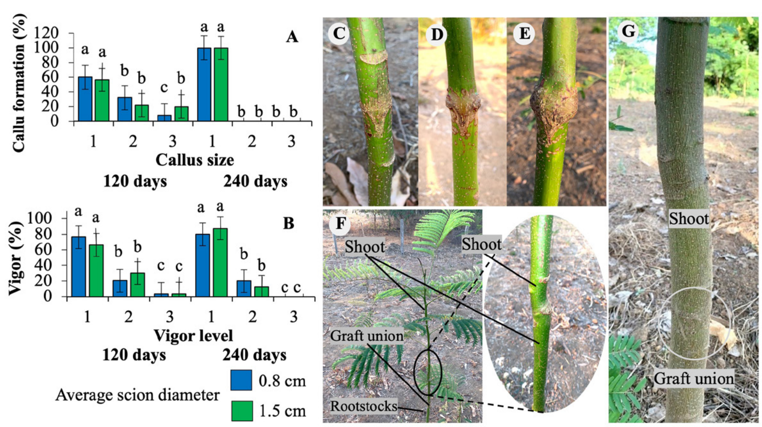

Figure 5. Callus formation (**A**) (1 = no visible callus; 2 =small callus; 3 = large callus; respectively shown in images 1, 2 and 3) and vegetative vigor (**B**) (1 = high; 2 = medium; 3 = low) of shoots of *Schizolobium parahyba* var. *amazonicum* (paricá) at 120 days (**C**-**F**) and 240 days (**G**) after cleft grafting from scions with average diameter of 0.8 and 1.5 cm. Columns are the mean of 10 replicates. At 120 or 240 days, different capital letters between scion diameter groups within callus type or vegetative vigor level, as well as different lowercase letters among callus types or vegetative vigor levels within diameter groups differ significantly according to a F-test at 5% significance level.

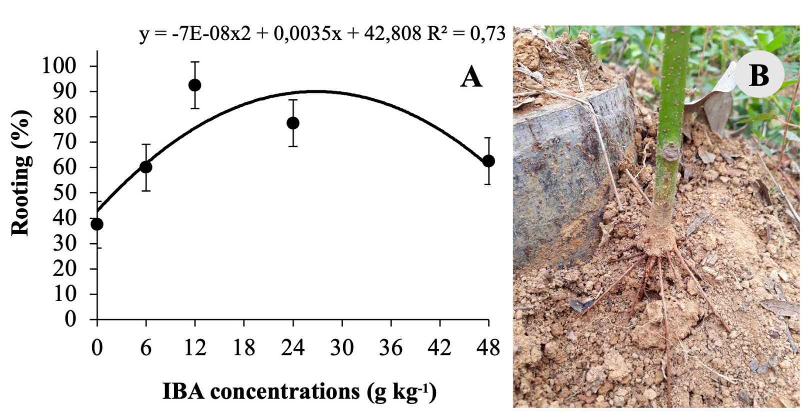

Figure 6. Regression of rooting rate (**A**) of basal epicormic sprouts (**B**) of *Schizolobium parahyba* var. *amazonicum* (paricá) by concentrations of IBA (0, 6, 12, 24 and 48 g kg^{-1}) at 30 days after the application of the mound layering method.

DISCUSSION

Field grafting

High survival of grafted plants indicates that the process of graft union, callus formation, differentiation of a new vascular tissue and development of a vascular system for the vegetative growth of the plant was successful (Rodriguez *et al.* 2015; Lei 2020). The survival rate of our grafted plants at 240 days was around 70-80%, which is compatible with grafting survival rates reported for other Amazonian native trees such as *Genipa americana* L. (100%) (Prado Neto 2006), *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. (73%) (Borelli 2016), *Hymenaea courbaril* L. (90%) and *Handroanthus heptaphyllus* Vell. Mattos (80%) (Mendes 2019), *Myrciaria dubia* Kunth McVaugh (65%) (Ferreira and Gentil 1997) and *Swietenia macrophylla* King (48-76%) (Barbosa Filho *et al.* 2016; Mendes 2019).

The vegetative growth potential of grafted plants depends on genetic factors and environmental conditions (Xavier *et al.* 2021), as well as the grafting protocol (Miao et al. 2019; Noor *et al.* 2019). One of the most important aspects of vegetative growth is shoot length. Grafted Brazilian native tree species varied widely in shoot length, ranging from 6 to 42 cm at 90 days after grafting for *Jacaranda mimosifolia* D. Don and *Cariniana legalis* Mart. O. Kuntze (Ferreira 2019), and from 53 to 95 cm at 240 days after grafting for *Bertholletia excelsa* (Mendes 2019). While shoot length can be influenced by the presence of endogenous or exogenous auxins (Kumar *et al.* 2015; Balliu and Sallaku 2017), scion diameter is a key factor in determining shoot length, as scions store energy reserves that promote rapid cell dedifferentiation and redifferentiation for callus formation and vascular connection (Gomes *et al.* 2010). In our study, average shoot length varied around 40-50 cm at 240 days after grafting, and plants grafted from scions of larger diameter resulted in higher shoot length, suggesting that using scions of larger diameter could be a useful strategy for improving shoot length in grafting of paricá.

The better performance of the shoots originating from scions with larger diameter may be related to that this experiment was carried out during the dry season. Grafted plants with a larger diameter have a higher internal energy reserve, which allows them to better resist the grafting process during the dry season (Mendes *et al.* 2021). Despite daily watering, humidity and soil water conditions do not match those of the rainy season, when plants generally use their internal energy reserves for vegetative growth and tissue formation (Melnyk 2017; Lei 2020). The higher performance of scions with larger diameter can also be due to the easier application of the cleft grafting method, which results in fewer mechanical damages and better quality of grafted plants, thereby reflecting positively on their overall performance (Espindola *et al*. 2004). In cleft grafting studies with *Spondias tuberosa*, grafts/rootstocks with larger diameters (0.7 to 1.0 cm) were also superior to those with smaller diameters (0.4 to 0.6 cm) (Espindola *et al.* 2004; Gomes *et al.* 2010).

Number of buds in the graft is another crucial factor for successful grafting methods. Number of buds in the propagule and the species' budding capacity determine the number of shoots per scion (Rodriguez *et al.* 2015; Mendes 2019). In this study, grafted plants had two buds per scion, leading to a higher number of shoots per scion than Brazilian native tree species that had more than two dormant buds per scion (Borelli 2016; Ferreira 2019; Mendes 2019). Furthermore, a higher number of shoots per scion leads to increased competition for carbohydrates and/or photoassimilates, resulting in shorter shoots (Malagi *et al.* 2012). Number of shoots per scion is inversely proportional to the shoot length (Rodriguez *et al.* 2015; Mendes 2019).

Although it significantly influenced shoot length, scion diameter did not influence shoot diameter in our study between 15 and 120 days after grafting. Shoot diameter is determined by species-specific genetic and intrinsic factors, as well as by the scion/rootstocks juvenility (Gomes *et al.* 2010). Although shoot diameter did not reveal any notable differences between 15 and 120 days after grafting, it is worth noting that the average value was higher than that of other Amazon native tree species. For example, at 240 days post-grafting, *Bertholletia excelsa* shoots had an average diameter of 0.4 cm (Ferreira 2019), while our paricá shoots had diameters between 8 and 13 cm. Likewise, 90 days post-grafting, *Hymenaea courbaril* and *Cariniana legalis* had average diameters of 0.4 cm, *Handroanthus heptaphyllus* of 0.6 cm, and *Swietenia macrophylla* of 0.8 cm (Mendes 2019), while our paricá shoots had diameters between 2-3 cm (at 60 days) and 4-5 cm (at 120 days).

The notable differences in shoot diameters observed in grafting experiments can be explained by the distinct physiological characteristics of pioneering versus climax species. Paricá, a pioneering species, exhibits rapid growth due to its high metabolic rates (Sales 2018; Silva and Sales 2018; Sales *et al.* 2021), which enhance cell division and elongation, resulting in quicker graft establishment and more vigorous shoot development (Ferreira 2019; Pérez-Luna *et al.* 2020). This is evident in the larger shoot diameters of 2-3 cm at 60 days and 4-5 cm at 120 days post-grafting. In contrast, climax species such as *Bertholletia excelsa*, *Hymenaea courbaril*, *Cariniana legalis*, *Handroanthus heptaphyllus*, and *Swietenia macrophylla* show slower growth rates, reflecting their adaptation to stable, competitive environments with more gradual cell division and reduced growth rates (Souza and Soares 2013). This results in smaller average shoot diameters, ranging from 0.4 cm to 0.8 cm at similar or longer time intervals. The rapid growth observed in paricá versus the slower-growing climax species underscores how physiological traits and growth strategies influence grafting outcomes (Melo *et al.* 2017; Nanda and Melnyk 2018; Andrade *et al.* 2020).

The vegetative vigor of grafted plants has been associated with physiological condition and grafting techniques (Liao *et al.* 2020; Tedesco *et al.* 2020), scion/rootstock juvenility (Wendling *et al.* 2014; Robert *et al.* 2020) and callus formation (Scaloppi Junior and Martins 2003; Pereira *et al.* 2019). Our results for grafted plants at 240 days after grafting for callus formation (100% low callus visibility) And vegetative vigor (over 80% high vigor) indicate that cleft grafting using juvenile propagules directly in the field has high potential applicability for paricá.

Overall, this study provides valuable insights into the factors that influence grafting success and highlights the importance of careful selection of scions and rootstocks in this process. These findings can aid in the successful propagation of parica trees by grafting. Further research is needed to fully understand the complex interactions involved in grafting and to identify the most effective strategies for optimizing paricá growth and productivity.

Mound layering

Mound layering with IBA has resulted in improved rooting performance of basal epicormic sprouts of paricá when compared to untreated sprouts or those treated with excessive dosages (above 27 g kg^{-1}), as observed in other species such as *Persea* sp. (80%, 10 g L^{-1} of IBA concentration) (Oliveira *et al.* 2000), *Annona squamosa* L. (94 and 88%, 20 and 5 g kg^{-1} of IBA concentration, respectively) (Rathore 1976; Gupta and Brahmachari 2004), *Psidium* spp. (Mishra *et al.* 2007) (<85%, 5 g kg^{-1} of IBA concentration), *Actinidia chinensis* (Planch.) (71%, 5 g kg^{-1} of IBA concentration) (Lal *et al.* 2001). The positive response of basal epicormic sprouts to IBA application can be attributed to the presence of auxins and natural cofactors (Wendling *et al.* 2014). However, IBA concentrations above certain levels can increase auxin levels to supra-optimal concentrations that revert the tendency of increased rooting (Rymbai 2009; Xavier *et al.* 2021).

Apart from the application of plant growth regulators, mound layering alone promotes successful vegetative propagation because girdling interrupts sap flow and accumulates plant growth substances (carbohydrates, auxins, etc.) above the girdling point, and the substrate surrounding the stump provides a suitable environment (humidity, aeration, temperature and nutrients) for rooting (Lima *et al.* 2016; Davies Jr *et al.* 2017). It is also important to note that our mound-layering experiment on paricá was carried out during the wettest period of the year with lower average temperature compared to the dry season, providing more favorable conditions for the development of the mound-layered plants.

Our results indicate that mound layering with application of IBA is effective for the vegetative propagation of basal epicormic sprouts of paricá. In order to further the development of specific protocols for method for this species, future research should evaluate factors such as the removal period from the mother-tree and survival rates after transfer to the field or nursery over larger periods than that used in our study.

CONCLUSIONS

Cleft grafting showed potential for application in vegetative rescue and propagation of *Schizolobium parahyba* var. amazonicum (paricá), with higher shoot survival and shoot diameter/length when grafting with scions of around 1.5 cm in diameter compared to smaller ones. Mound layering also showed potential for use in vegetative rescue of paricá, especially with the use of 26 g kg^{-1} of the plant growth regulator IBA. To enhance the applicability of these techniques under varying Amazonian conditions, future research should focus on evaluating the impact of environmental and genetic variables on the effectiveness of grafting and mound layering. Additional studies are needed to explore the interactions between different rootstocks and scions, as well as to test these propagation methods across a range of edaphoclimatic conditions.

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