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Evaluation of different compositions of stimulating paste in a closed resin system in 10-year-old *Pinus elliottii* var. *elliottii*

Avaliação de diferentes composições de pasta estimulante em sistema fechado de resinagem em *Pinus elliottii* var. *elliotti* com 10 anos de idade

Evaluación de diferentes composiciones de pasta estimulante en un sistema cerrado de resina en *Pinus elliottii* var. *elliottii* de 10 años

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Abstract
Resin tapping is an activity that aims to extract resin from trees, and thus use this product industrially. The species most used for resin tapping in Brazil is *Pinus elliottii* var, *elliottii*. The extracted resin is basically composed of rosin and turpentine, which are used by the chemical industry. Although the main resin processes currently used are well known, new systems must be tested, such as the closed system and new compositions of stimulating pastes. These new processes and the new compositions of stimulating pastes can make the resin tapping even more efficient and profitable. Therefore, our goal was to evaluate the effect on resin production with different compositions of stimulant pastes in resin extraction, in a closed "borehole" resin system, at different collection times, in trees from a population of 10-year-old *Pinus elliottii* var. *elliottii* planted in Itapetininga, São Paulo. According to results, the effect of stimulating paste 4 (30% jasmonate, 4% naturoil and water) and paste 6 (30% jasmonate, 4% adhesive spreader and water) was evident in the highest production average resin per tree. Resin tapping in a closed process can be a good alternative for producers to better control the resin production system. The development of the chemical industry that uses products derived from resin and the growth of different markets, with considerable social, economic and environmental impacts, depends on future research and generation of technology for the production of resin and its derivatives.
Keywords: Pine; Resin; Production system; Resin production.

Resumo

A resinagem é uma atividade que visa extrair a resina de árvores, e assim utilizar esse produto industrialmente. A espécie mais utilizada para resinagem no Brasil é o *Pinus elliottii* var. *elliottii*. A resina extraída é composta basicamente por breu e terebintina que são utilizados pela indústria química. Apesar de serem bem conhecidos os principais processos de resinagem utilizados atualmente, novos sistemas devem ser testados, como por exemplo, o sistema fechado e novas composição de pastas estimulantes. Esses processos novos e a novas composições das pastas estimuladoras podem tornar a atividade da resinagem cada vez mais eficiente e rentável. Sendo assim, objetivamos avaliar o efeito na produção de resina com novas composição de pastas estimulantes na extração de resina, em um sistema fechado de resinagem "borehole", em diferentes épocas de coleta, em árvores de uma população de *Pinus elliottii* var. *elliottii* de 10 anos de idade plantadas em Itapetininga, São Paulo. De acordo com os resultados observados, ficou evidenciado o efeito da pasta estimuladora 4 (30% de jasmonato, 4% de naturóleo e água) e a pasta 6 (30% de jasmonato, 4% de espalhante adesivo e água), na maior produção média de resina por árvore. A produção de resina em um processo fechado pode ser uma boa alternativa para os produtores controlarem melhor o sistema produtivo de resina. O desenvolvimento da indústria química que utilizada produtos derivados da resina e o crescimento de diferentes mercados, com os consideráveis impactos sociais, econômicos e ambientais, depende de futuras pesquisas e geração de tecnologia para produção de resina e seus derivados.
Palavras-chave: Pinus; Resina; Sistema produtivo; Produção de resina.

Resumen

La resinación es una actividad que tiene como objetivo extraer resina de los árboles, y así utilizar industrialmente este producto. La especie más utilizada para resinas en Brasil es *Pinus elliottii* var. *elliottii*. La resina extraída está compuesta básicamente por colofonia y trementina, que son utilizados por la industria química. Aunque los principales procesos de resinas utilizados actualmente son bien conocidos, se deben ensayar nuevos sistemas, como el sistema cerrado y nuevas composiciones de pastas estimulantes. Estos nuevos procesos y las nuevas composiciones de las pastas estimulantes pueden hacer que la actividad resinera sea aún más eficiente y rentable. Por lo tanto, nuestro objetivo fue evaluar el efecto sobre la producción de resina con nuevas composiciones de pastas estimulantes en la extracción de resina, en un sistema cerrado de resina "borehole", en diferentes tiempos de recolección, en árboles de una población de Pinus elliottii var. elliottii de 10 años plantada en Itapetininga, São Paulo. De acuerdo con los resultados observados, el efecto de la pasta estimulante 4 (30% jasmonato, 4% aceite natural y agua) y la pasta 6 (30% jasmonato, 4% esparcidor de adhesivo y agua) se evidenció en la mayor producción promedio de resina por árbol. La producción de resina en un proceso cerrado puede ser una buena alternativa para que los productores controlen mejor el sistema de producción de resina. El desarrollo de la industria química que utiliza productos derivados de la resina y el crecimiento de diferentes mercados, con considerables impactos sociales, económicos y ambientales, depende de futuras investigaciones y generación de tecnología para la producción de resina y sus derivados.
Palabras clave: Pino; Resina; Sistema de producción; Producción de resina.

1. Introduction

The use of products generated from resin derivatives extracted from *Pinus* spp. has shown a linear growth in Brazilian and world economy, where their presence is increasingly observed in the most varied industrial sectors. Therefore, research for the development of processes or technologies that can contribute to an increase in resin production and quality is encouraged throughout the entire production chain. These incentives have stood out in the last five years, mainly due to market's demand for resin. The price paid per ton of resin in Brazil has been an important stimulus to these demands for innovations and technologies that are applied not only to increase production, but to offer a higher quality product to the market (Candaten et al., 2021). Brazil is the second most resin producing country in the world (ARESB, 2018).

All *Pinus* spp. produce resin, but many are not economically exploited for this purpose due to low production (Aguiar et al., 2012). The most exploited species in Brazil is *Pinus elliottii* var. *elliottii* (Kronka et al., 2005; Sebbenn et al., 2008). Environmental effects, mainly biotic, such as beetle attacks, induce resin production in greater quantities (Zas et al., 2020a). The resin generates indirect income for small and medium-sized producers who exploit wood, and it has been the main product of many companies in the Brazilian forestry sector. There are still few results how resin influence wood volume in trees. Even if this interference occurs, resin tapping is economically advantageous and viable (Lima et al., 2021).

Two main products are extracted from the resin, turpentine, which is the liquid fraction, and rosin, which is the solid fraction. From these two derivatives, numerous chemical components can be obtained that are used for various purposes in the chemical, pharmaceutical and other industries (Cunningham, 2012; Lima et al., 2016). Turpentine and rosin percentage can vary with the species and/or individual (5 - 25% and 75 - 95%, respectively) (Kronka et al., 2005; Fusatto et al., 2013; Salvador et al., 2020). In the traditional resin tapping method used in Brazil, resin is extracted from live trees via repeated wounds or grooves, per small cuts to remove the bark and cambium, in the tree trunks, from these cuts, resin exudation occurs. Then resin is collected from plastic bags or collectors attached to tree trunks (Cunningham, 2012; Candaten et al., 2021). There are several methods for extraction in the world (Cunningham, 2012). In general, the method used is defined based on the economic and environmental advantages during the gum-resin exploration process. Those that lead to the least degree of impurities, reduced labor and least effect on tree longevity are preferred. Within these requirements, the "borehole" method may present some advantages compared to the conventional system (Aoki and Cruz, 1998).

The greater resin production per tree and year could bring economic benefits to the producer and the environment, by avoiding the plantation area and, consequently, the cutting of native vegetation. The silvicultural practices applied for this purpose include the use of genetically improved seeds or seedlings, management of plantations based on fertilization, spacing and control of invasive vegetation, as well as the use of methods or stimulants in resin tapping. The use of stimulant methods and pastes at the appropriate concentration can also maximize yield without negatively impacting product quality and tree growth (Vázquez-González et al., 2021).

Therefore, present study investigated the most suitable types and concentrations of paste to be used in closed resin tapping system, also known as "borehole" proposed by Hodges (1993) in plantations of *P. elliottii* var. *elliottii*. In this context, to enable improvements in resin tapping, new compositions of stimulating pastes have been developed and treated trees can yield about 30 to 40% more than extraction without pastes (Fusatto et al., 2013). Our goal was to compare different compositions of stimulant pastes for the closed resin tapping system in a population of 10-year-old *Pinus elliottii* var. *elliottii* planted in Itapetininga-SP.

2. Methodology

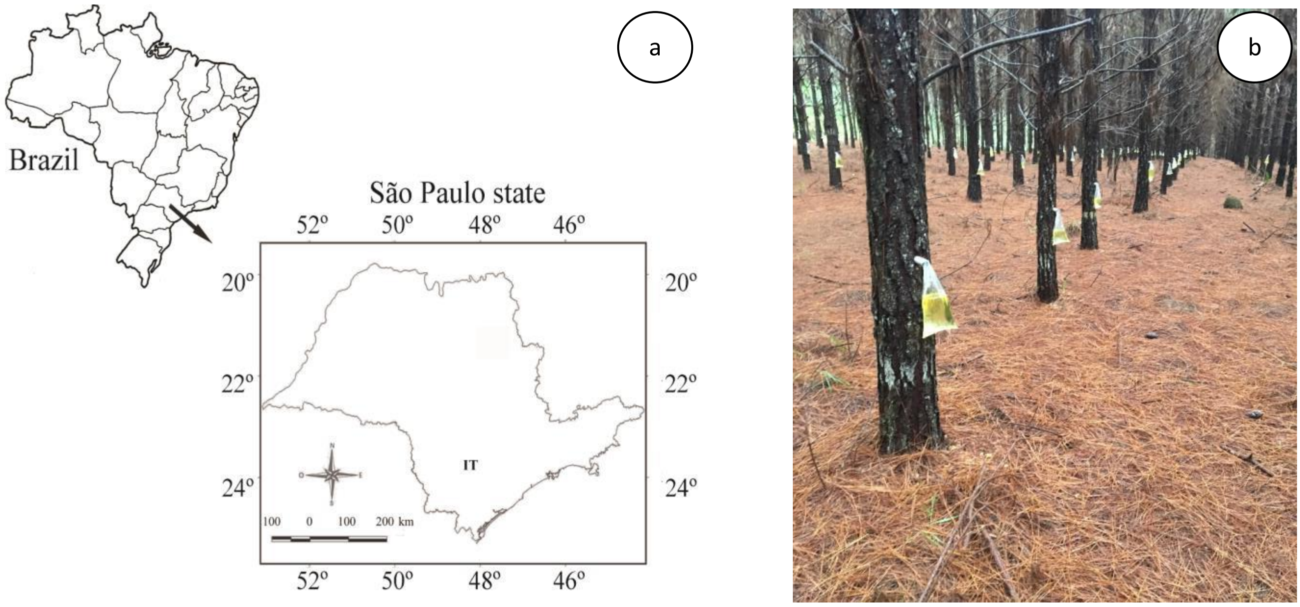
2.1 Planting area, sampling, and resin collection

Resin tapping tests were carried out in a population of 10-year-old *Pinus elliottii* var. *elliottii* planted in Experimental Station of Itapetininga, located in Itapetininga City (Figure 1a), São Paulo State, Brazil (23º40´53.56" S and 48º01´52.94" W, and average altitude of 671 m) (Instituto Florestal, 2023). The climate is Cfa according to Köppen classification, with an average annual temperature is 19.3ºC and average annual rainfall is 1,245 mm (Alvares et al., 2013). The topography is gently undulating and has extensive floodplains, with red yellow and hydromorphic podzolic soils (Santos et al., 2018 and Rossi, 2017). The seedling production in planting was established with open-pollinated seeds from a first-generation clonal seed orchard.

The planting was established with design spacing 3.0 x 3.5 m. The experimental design was randomized complete blocks, with six treatments (six different compositions of stimulant pastes) and three blocks. For each treatment, 12 plants were used within each block. Over a period of one year, four resin collection were carried out, with each collection the pastes were applied. The method of use for resin extraction was borehole. Treatments with different stimulant pastes, average DBH and average tree height are presented in Table 1.

To collect the resin, a 10-micron-thick plastic bag measuring 40 x 12 cm was used, glued with adhesive tape to a 125-mL tube of seedlings. A hole 12 cm deep and 2.5 cm in diameter was opened (Figure 1b). For spraying the stimulant, a 300 mL spray bottle was used. The product was sprayed four times into the hole, making an average of 4 mL of the stimulant for each hole. Resin was collected and weighed every 70 days, making a total of four collections in a period of 240 days. Each collection lasted about 10 days, and at each new collection a new hole 15 cm deep was made above the previous one.

Figure 1 - Location in municipality of Itapetininga (IT) in São Paulo State, Brazil (a). Borehole system in *Pinus elliottii* (b).



Source: Authors.

Note that the borehole resin extraction method minimizes the damage caused to the trunks by resin extraction and simultaneously can increase the quality of the collected resin. The borehole wounds cause little damage to the tree bark and since these holes are near the ground level, only a healed scar can be seen in the converted woods. Therefore, there is no damage to the merchantable part of the tree (Bhandari, 2017).

Table 1 - Treatment with different stimulant pastes, average DBH and average tree height (HT) in 10-year-old *Pinus elliottii* var. *elliottii* planted in Itapetinga-SP.

Treatments	Stimulant pastes	DBH (cm)	HT (m)
1(Control)	20% jasmonate active ingredient	20.83	15,04
2	30% jasmonate active ingredient	19.90	15.16
3	20% jasmonate 4% naturoil and water	19.91	15.14
4	30% jasmonate 4% naturoil and water	20.41	15.19
5	20% jasmonate, 4% adhesive spreader and water	21.89	15.65
6	30% jasmonate, 4% adhesive spreader and water	19.61	15.07

Source: Authors.

2.1 Data analysis

Data were submitted to descriptive statistical analysis, analysis of variance considering the statistical block model and mean comparison test. Analyzes were performed using SAS® software for Windows (SAS Institute Inc., 1999). For resin production, a factorial scheme of 6 x 3 (paste x collection time) was considered.

3. Results and Discussion

The highest averages per collection were observed for pastes 4 (0.80 kg.tree^{-1}) and 6 (0.79 kg.tree^{-1}). Stimulating pastes 1 and 2 did not show good results (Figure 2a). The values obtained with the pastes from treatments 4 and 6 were higher than the average production (0.60 kg.tree^{-1}) compared with Red Eldorado Paste tested by Fusatto et al. (2013).

It is noteworthy that positive effect of chemical treatments on resin extraction is an important strategy to be adopted in the Borehole system. It was evident the improvement in resin exudation, due to chemical stimulants application. The positive effect of applying these new pastes will provide a greater economic benefit in the resin tapping (Lima et al., 2016).

In a *Pinus pinaster* population, there was a significant and negative correlation between tree height growth and resin yield. However, this relationship is more prevalent when resin-treated trees were exposed to treatment with stimulating paste, i.e., when resin yield was maximized (Vázquez-González et al., 2021).

Regarding the collections carried out over a period of about 10 days, it was verified that collection 1 (0.65 kg.tree^{-1}) was more productive than collection 4 (0.61 kg.tree^{-1}) (Figure 2b). This lower production is because of the extraction period, which took place in the coldest months of the year for collection 4.

Resining time (collection period) is a factor that should be further studied. Because the resin flow time and preparation of wounds or grooves must be optimized in the operational derivation. The resin flow time is modulated by the age of the tree, being shorter in younger trees than in older ones. Therefore, the wounds or grooves periodicity must consider the tree age (Zas et al., 2020a).

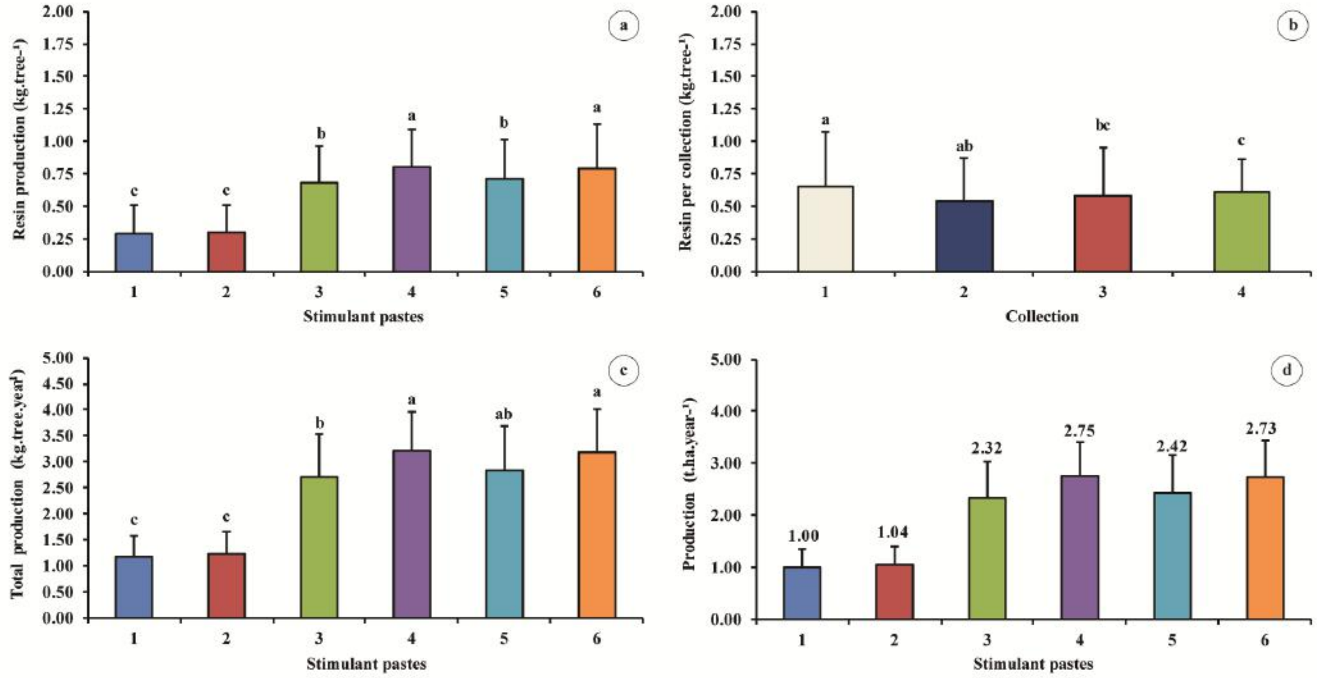
In the resin tapping, collection frequency impact on the tree's physiology should be evaluated, in addition to operational aspects (Zas et al., 2020b). Other aspects must also be considered, including climate changes that have caused frequent increases in temperature and occurrence of droughts, which will have negative effects on the growth, production, and survival of the trees. In addition to chemical treatments, edaphic and climatic factors also influence resin tapping. One of these factors would be the amount of rainfall and relative humidity, these effects have already been found in some research carried out in Brazil (Celedon and Bohlmann, 2019).

New research is recommended for silvicultural practices and forest management of resinous trees to these new growth conditions in *Pinus* forests (Du et al., 2021). In the total production of resin per treatment, considering the 4 collections carried out (harvests), treatments 4 (3.20 kg.tree.year^{-1}) and 6 (3.18 kg.tree.year^{-1}) presented the highest productions per year of collection. However, treatments 1 (1.17 kg.tree.year^{-1}) and 2 (1.22 kg.tree.year^{-1}) had the lowest values (Figure 2c).

In this study, when considering a survival rate 90% in 10-year-old *Pinus elliottii* var. *elliottii*, resin production is projected by comparing the different systems (Figure 2d). Treatment 4 can produce about 2.75 t.ha.year^{-1}, and treatment 1 (control) about 1 t.ha.year^{-1} (Figure 2d).

Currently, a company that has a pine plantation with a population density of around 800 trees.ha^{-1} produces about 3 kg.tree.year^{-1} of resin or 2.4 t.ha.year^{-1} (Lima et al., 2016). When compared with paste used in treatment 4 (30% jasmonate, 4% naturoil and water), it can produce about 0.35 t.ha.year^{-1} more than the pastes currently used.

Figure 2 - Resin production per tree as a function of the different types of stimulant paste (1 to 6) (a). Resin production as a function of different collection times (b). Resin production as a function of different types of stimulant paste per harvest (c). Resin production per ha/year, depending on the different types of stimulating pastes (d).



Source: Authors.

We highlight that significant differences between treatments for resin production were observed at 1% probability (Figure 2). This reinforces that different pastes and concentrations influence the resin productivity.

In general, we can highlight that resin casting performed in the closed "borehole" system can be a reality in Brazil. However, preliminary studies demonstrate that this method may have a higher initial investment than traditional resin-bonding systems (Oliveira et al., 2019).

The growth of different markets, with considerable social, economic, and environmental impacts, depends on future research and generation of technology to produce resin and its derivatives (Rodrigues-Corrêa et al., 2013).

4. Conclusion

There are significant differences between the pastes used for resin extraction by the closed system in plantations of *Pinus elliottii* var. *elliottii*. Stimulating pastes 4 (30% jasmonate, 4% naturoil and water) and 6 (30% jasmonate, 4% adhesive spreader and water) contributed to a higher average resin production per tree.

Resin tapping in a closed system can be a good alternative for producers to better control the production system. New studies must be carried out to improve the resin production system with new pastes, and thus reduce the price, making this product more competitive in the market.

In the same study site, there are other tests to be evaluated in the future by our team. Additionally, we suggest that other types of stimulating pastes and concentrations should be tested in *Pinus elliottii* var. *elliottii*., or other species that produce resin. Thus, it is possible to evaluate the improvement in resin production and processes, which will contribute to decision of owners and companies in the resin sector.

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