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Effect of resin tapping system and collection period on resin production and growth traits in 12-year-old Pinuselliottii var. elliottii

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Abstract:Resin tapping is an activity designed to extract resin from trees, especially species of the genus *Pinus*. Current systems of tapping and collecting resin are well known, but further study is needed to make these systems more efficient and profitable for producers. Therefore, this work aimed to evaluate the effect of five resin tapping systems during five different collection periods on the production and growth of resin trees for a population of *Pinuselliottii* var. *elliottii* planted in Itapetininga, SP. Resining affects tree growth, especially in diameter. Results showed that system 4, with eight panels on each plant and four on each side, presented the highest average production of resin per tree, while system 1, with 2 panels on each plant and 1 on each side, presented the lowest average resin production per tree. It was concluded that resin production is dependent on the system employed, time of collection, and their interactions.
Keywords:Pine, Resin, Non-Timber Forest Product.

Introduction

Pine trees produce wood for various purposes. Furthermore, they also produce resin, a non-timber forest product with high added value in the market. Resin is a major source of terpenes. The liquid fraction is turpentine, and the solid fraction is called rosin. Both are sources of raw material for the chemical industry (Lima et al., 2016). After processing, resin is composed of 80% rosin and approximately 20% turpentine (Salvador et al., 2020).The first studies on resin exudation in species of *Pinu*s spp. focused on tree survival against beetle attack. Overall, trees killed by beetles have smaller resin ducts than those of surviving trees, and these same trees continued to have larger resin ducts after the beetle outbreak. By increasing the volume of resin flow, larger resin ducts probably reduced the likelihood of successful beetle colonization on surviving trees substantially by providing sticky physical barriers, sealing beetle entry wounds, and releasing toxic compounds (Erbilgin et al., 2017, 2019; Mason et al., 2019).

Resin production in Brazil has experienced increased growth over the years, especially in the last five years. Between 2017 and 2018, more than 185 thousand tons of resin were produced. Particularly, after 2011, the natural resins sector grew by 103% (Schmid, 2019). This scenario made Brazil the second largest producer in the world, behind only China (Neves et al., 2006; Schmid, 2019). Much of the resin produced is exported, and most of the product is destined for Portugal, Vietnam, and China (Schmid, 2019).The largest producer of gum resin in Brazil is the State of São Paulo, followed by Rio Grande do Sul and Paraná. Together, they are responsible for approximately 80% of the national production of pine gum-resin (Júnior, 2018). Of the total resin production in Brazil, 60% is extracted from *P. elliottii* var. *elliottii* in subtropical regions, and 30% is from *P. caribaea* var. *hondurensis* in tropical regions (Aguiar et al., 2012). Currently, the activity has expanded to other states, such as Minas Gerais, Mato Grosso do Sul and southwestern regions of the state of São Paulo (Brazilian Association of Resin Producers - Associação de Resinadores do Brasil-ARESB, 2019). Intraspecific variation should be considered when predicting how pine populations will face the increased biotic risk associated with global change, *e.g.*, increase in Earth average temperature (Benito-Garzón and Fernández-Manjarrés, 2015).

The main method of extracting resin from trees in Brazil is from striations. This is carried out by cutting from the tree bark to the cambium, not reaching the wood, from which exudation occurs. The resin that becomes available is stored in a collection container fixed under the tree (Candaten et al., 2021). Resin tapping in *Pinus* spp. forests dates to the Egyptian civilization (Garrido et al., 1998).

Resin extraction by the Brazilian system reached an experimental peak in the early 1970s with translation of the “Manual: Modern Resin Tapping Methods” (“Manual: Métodos de ModernaResinagem”) used in the USA. It was written by Ralph W. Clements from Lake City Research Center, Florida with translation and adaptation by GurgelFilho in 1970. Being Clements' manual, adapted and standardized for use in Brazil by Garrido et al. (1998), being a current reference in the cultivation of *Pinus* and resining.

Later, with the evolution of the resin system, this activity consisted of cutting the bark and wood with the objective of exposing the resin canals and allowing the resin to flow. These incisions, cuts or striations were repeated weekly to unclog the resin canals closed by crystallization (Marcelino, 2004). As this process is very labor-intensive, several chemical products were tested to maintain resin flow without having to make such frequent cuts. To meet commercial forestry needs, the resin system has been improved and is comprised of six steps. In the first step, after surveying all trees in the plantation, those with DBH above 10 cm are chosen. The trunk is then cleaned for a smooth surface, and a mustache-incision is made for later fixation. In the fourth step, the collection container is placed. These are typically plastic bags fixed by wires that require constant monitoring in the first days of resin exudation to avoid leaks. The striation step involves incision through a striator iron up to the region of the vascular cambium and resin canals. Finally, an acidic paste is applied through a tube or laboratory wash bottle with the purpose of breaking the layers of cellulosic walls of the resin canals, thereby increasing the exudation of the resin canals (Ferreira, 2001).

The resin system adds significant value to the culture of *Pinus* spp. However, the resin extraction process significantly affects tree growth in height and diameter. According to experiments carried out in Brazil and in other countries, it is estimated that the resin tapping system can cause a decline of around 25% in annual tree growth, but when the resin tapping system is stopped, trees continue to grow normally (Garrido et al., 1998). Therefore, it is necessary to evaluate different resin extraction methodologies, aiming to affect the dendrometric characteristics of the tree as little as possible since height and diameter strongly influence the volume of wood (m^3) (Lousada et al., 2009).

As previously reported, we have seen that the resin tapping system consists of successively removing the bark from the stem of the trees, thus opening a rectangular panel. Stretch marks on the stem are performed every fifteen days, followed by placement of a stimulant which maintains the flow of resin into a container below the panel. This procedure is repeated periodically until the plan for forest management is completed. Based on the number of trees to be rosined and forest availability over a short period of time (2 or 3 years), it is possible, through a program of adaptive forest management, to maximize the use of these trees and minimize possible losses in productivity and wood quality at the end of resin tapping system exploration.

In order to improve the resin tapping system, while protecting tree growth, we aimed to determine the effect of five resin tapping systems during different collection periods on resin production and the growth of trees from *Pinuselliottii*var. *elliottii*.

Materials and Methods

Planting area and experimental design

The study was carried out in a commercial stand of*Pinuselliottii* var. *elliottii* established with seedlings from a first-generation clonal orchard, which was selected for resin production. It was set up in the municipality of Itapetininga (Figures 1-2), São Paulo State (23°42′S, 47°57′W, elevation 600-700m). The climatic type isCfa with hot and dry winters. Average annual temperature is between 0.2°C and 37.5°C with frost. The average temperature of the hottest month is 23.3°C (January), and the average temperature of the coldest month is 15.3°C (June). The region presents soft, wavy relief and extensive floodplains characterized by Red yellow Podzolic and hydromorphic soils that are acidic with high aluminum concentration (Santos et al., 2018).

The seedlings were planted in a spacing level of 3 m x 2 m. The resin tapping system was evaluated in two harvests (one per year) at 12 years old. For each treatment, five different resin extraction systems were installed in 50 trees and another 50 trees as a control, totaling 300 trees from the plantation in six parallel lines. Tree panels were stripped at intervals of approximately fifteen days, and a chemical stimulant in a past formulation, composed of 12% sulfuric acid, as well as rice bran, organic aggregates and water, was applied.

Resin production from each panel was collected and weighed separately during five collection periods. Diameter at breast height at 1.30 from the ground (DBH) and total height of all resin trees and control trees were measured at the beginning and at the end of study in order to determine the development of forest growth in each condition. Resin tapping systems are presented in the schematic illustration (Figure 3).

System 0: control group (without resin extraction) (Figure 3a). System 1: A panel about 40 cm high by 17 cm wide was installed on each face of 50 plants in the plot, and resin tapping was carried out, repeating in the second harvest. With a total of 45 splines, 23 on the first panel and 22 on the second panel, system 1 was installed from 50 cm to 1m on the left side with a panel for each year of extraction (Figure 3b). System 2: Two panels were installed, one on each side of the plant about 40 cm high and 17 cm wide each. This was replicated in 50 plants in the plot to promote resin tapping, repeating in the second harvest in sequence. With a total of 45 splines, 23 on the first panel and 22 on the second panel, system 2 was installed from 50 cm to 1 m high on both sides of the tree, repeating installation of the panels in the first and second year for resin extraction (Figure 3c). System 3: Two panels were installed on the same face of the plant, one at the base and the other one meter above the first, both measuring approximately 40 cm in height by 17 cm in width, repeating the two panels in sequence, totaling four panels on the same face. Panels were installed from 50 cm to 2 m high on the right side of the tree with the extraction panel in the first and second year (Figure 3d). System 4: Two panels were installed on the same face of the plant, one at the base and the other one meter above the first, repeating the same procedure on the opposite face of plant, measuring approximately 40 cm high by 17 cm wide for each of four panels.

Repeating in sequence during the second harvest, four panels were installed totaling eight panels in each plant, four on each of the two sides, from 50 cm to 2 meters high on both sides of the tree. The extraction panel in the first year is shown in blue and in orange for the second year (Figure 3e). System 5: Four panels were installed on the same side of plant, one at the base, the second at 50 cm from the first, the third at 100 cm from the first, and the fourth at 150 cm from the first, repeating the same procedure on the opposite side of plant in the second harvest, all panels measuring approximately 40 cm high by 17 cm wide. During the first harvest, four panels were installed on the first side, and during the second harvest, four panels were installed on the second side (Figure 3f).

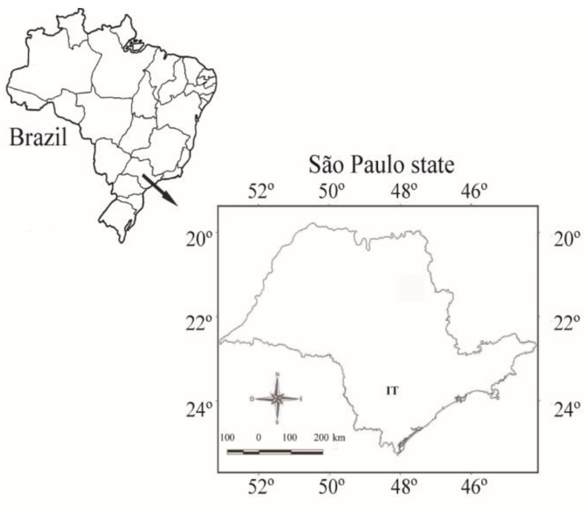

Figure 1. Location in municipality of Itapetininga (IT) in São Paulo State, Brazil.

Figure 2. Overview of *Pinuselliottii* var. *elliottii* plantation used in the municipality of Itapetininga, São Paulo State.

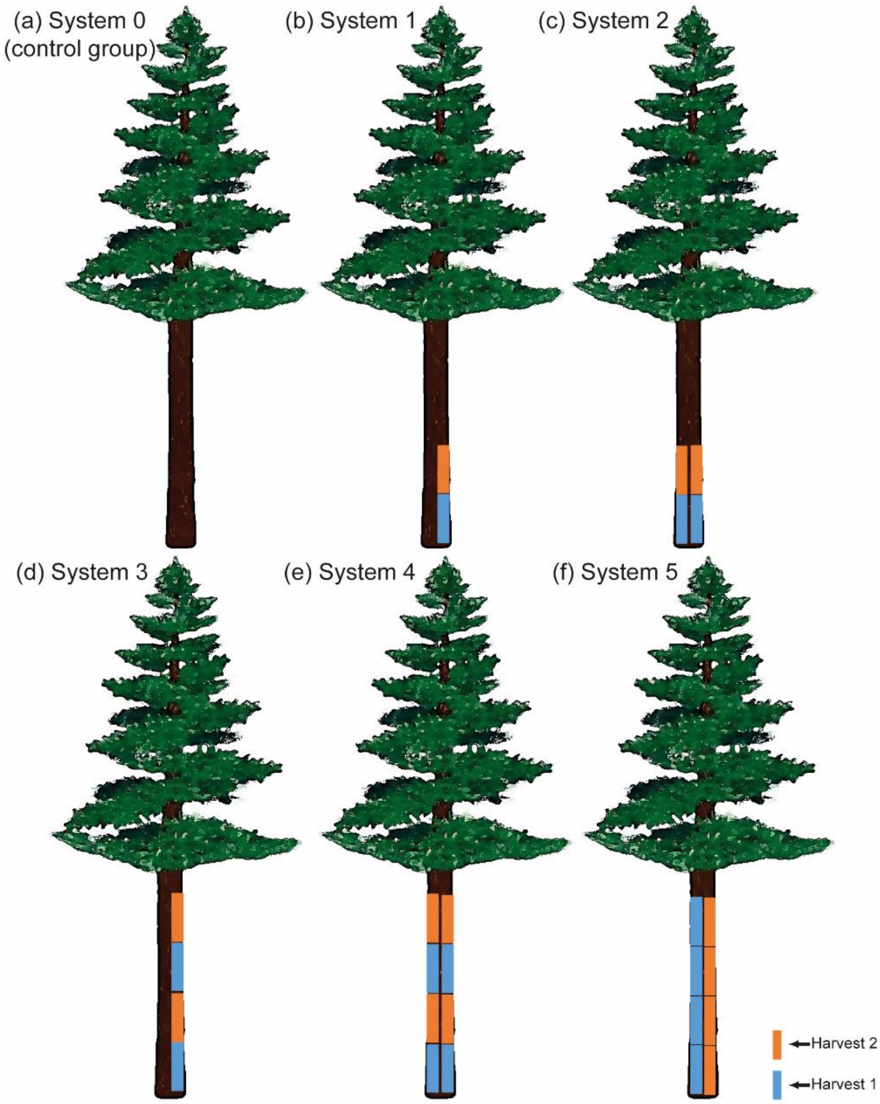

Figure 3. Schematic illustration of control group and five resin tapping systems in two harvests at 12-year-old *Pinuselliottii* var. *elliottii* in the municipality of Itapetininga, São Paulo State.

Statistical analyses

Data analyses were carried out in two stages. In the first stage, we analyzed increment in diameter and height of the trees, comparing increment in trees before and after resin tapping. To do this, we used a completely randomized design. In the second stage, we analyzed the comparison of resin tapping systems with the collection period, and to do this, a 5 x 5 factorial design was adopted (5 resin tapping systems x 5 collection periods) in randomized block. Data analyses were performed using SAS ® software for Windows (SAS Institute, Inc. 1999).

Results and Discussion

Significant differences between resin extraction systems were observed at the 1% level (Table 1). We verified that only the increase in diameter and tree height of *P. elliottii* var. *elliottii* was influenced by the resin tapping systems (Figure 4).

According to analysis of variance, we can report a significant interaction between resin tapping systems and factors affecting collection period, as shown in Tables 2 and 3, where, after splitting out the interaction, we found all interactions between resin tapping system x collection periods to be significant. For example, we found resin production to be dependent on both resin tapping system and collection period (Table 4). When combining resin tapping system and collection period, the highest average resin production per tree occurred with system 4 and period 4, whereas the lowest average occurred when combining system 1 and period 2.

Table 1. Summary of analysis of variance for mean diameter increment (MDI) and mean height increment (MHI) in *Pinuselliotti* var. *elliottii* trees

		MS	
Cause ofvariation	DF	MDI (cm)	MHI (m)
Systems	5	49.0526**	1.6390 n.s.
Residual	294		
Mean		1.2206	1.5450
SD		1.6290	0.7563

MS = Mean square, DF = Degrees of freedom and SD = standard deviation.

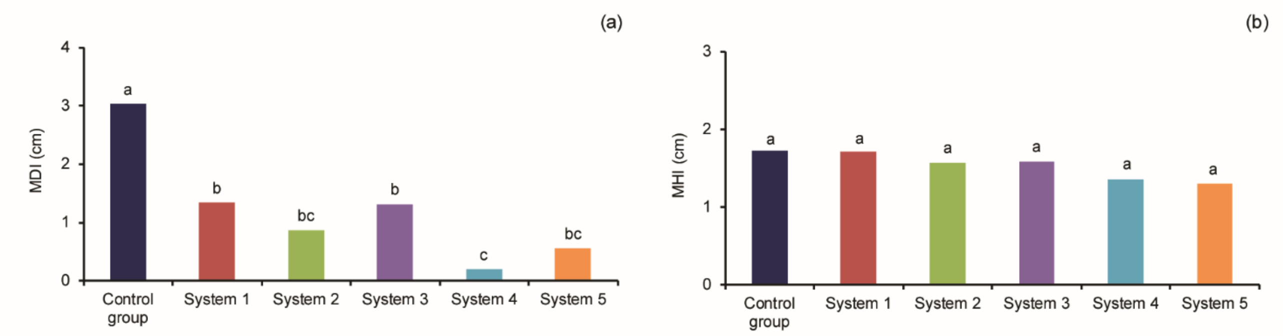

Figure 4. Mean diameter increment (MDI) (a) and mean height increment (MHI) (b) as a function of resin tapping systems and collection periods at 12-year-old *Pinuselliottii* var. *elliottii* in the municipality of Itapetininga, São Paulo State.

Table 2. Summary of variance analysis for resin production from resin tapping system and collection periods in *Pinuselliottii* var. *elliottii* trees

		MS
Cause ofvariation	DF	Resinproduction (kg)
Systems (S)	4	223.51**
Collections (C)	4	128.19**
(S) x (C)	16	11.68**
Residual	1225	
Mean		2.83
CV		29.25

MS = Mean square, DF = Degrees of freedom, CV= Experimental coefficient of variation.

Resin tapping system 4 had the highest average resin production, as characterized by eight panels in each plant from 50 cm to 2 m high from the base of the tree, four on each of the two sides. The lowest average was obtained in resin tapping system 1, which was composed of 2 panels on each tree installed from 50 cm to 1 meter from the base of the tree, one on each side. System 4 presented the highest average resin production, and collection systems 2 and 5 were the least productive.

The resin process that presented the highest average production per tree was system 4, which was characterized by eight panels in each plant, four on each of the two sides, and the lowest average was obtained in system 1, which was composed of 2 panels on each floor with 1 on each of two sides. Collection 4 showed the highest average resin production, and collections 2 and 5 were the least productive.

The highest resin production, when considering the two harvests, was observed in tapping system 4, while the lowest resin production was observed in tapping system 1. The highest production per tree was also reported in tapping system 4 and the lowest in tapping system 1. Tapping system 1 presented the highest production per panel and system 5 the lowest (Table 4).The different collection periods significantly influenced resin production (Table 3). A significant interaction was also observed between resin systems and the time of collection, demonstrating a relationship between these two factors.

Table 4. Summary of interaction split analyses: resin tapping system versus collection periods at 12-year-old *Pinuselliottii* var. *elliottii* in the municipality of Itapetininga, São Paulo State. MS = Mean square, DF = Degrees of freedom

Systems	DF	MS	F	Pr> F
1	4	10.408701	15.17	<.0001
2	4	37.634096	54.84	<.0001
3	4	18.743007	27.31	<.0001
4	4	80.423017	117.19	<.0001
5	4	27.616671	40.24	<.0001

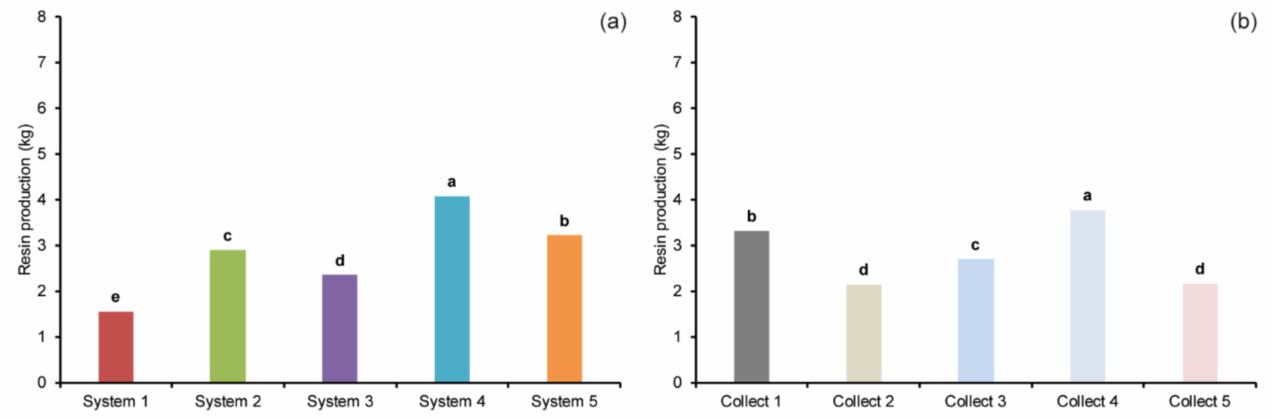

Figure 5. Resin production of tapping system (a) and collection period (b) at 12-year-old *Pinuselliottii* var. *elliottii* in the municipality of Itapetininga, São Paulo State.

Table 5. Total resin production values as a function of resin tapping system at 12-year-old *Pinuselliottii* var. *elliottii* in the municipality of Itapetininga, São Paulo State

Tapping system	Total production (kg)	Production per tree (kg)	Production per panel / year (kg)
1	392	7.84	3.92
2	727	14.53	3.63
3	590	11.81	2.95
4	1.024	20.47	2.56
5	807	16.14	2.02

We reported that no trees from any tapping system presented significant difference in height, including the control group (Figure 4b). The experiment was established with seeds from a clonal orchard with seminal and non-clonal seedlings. Therefore, the genetic variation existing in the seedlings may have also influenced the dendrometric characteristics of the trees, such as height (Deng et al., 2021).

However, other authors who studied two areas of *P. elliottii* var. *elliottii* where resin was exploited confirmed a reduction in growth characters from the beginning of the resin process (Garrido et al., 1998). They reported that the height of trees without resin tapping grew more than resinous trees. On the other hand, Yuan et al. (2013) observed a decrease in tree height and diameter in *P. elliottii* var. *elliottii* resinous trees at eight years of age, consequently causing a 10.65% reduction in volume compared to non-resinous trees. However, the resin process was economically viable, despite having a negative effect on tree growth (Lima et al., 2021). In the resining process, we must also consider that there is a loss of wood volume by the resining technique. However, in a work plan, such a loss, can be easily compensated by anticipation of income due to resin sale (Marcelino, 2014).

Yuan et al. (2013), when analyzing the influence of the diameter class on the production of resin from *P. elliottii* at 8 years of age, found that the panels placed in the upper portions tend to exude and produce more resin than the panels for extraction closer to the base. The results of the present study show the same effect since most systems, except 1 and 2 closes to the base of trees, had resin extraction heights equal to 50 cm to 1 m of height with panels on both sides of the tree. It is concluded that these extraction systems negatively affect resin production and are, therefore, not economically viable systems for resin exploitation for *Pinuselliottii* var. *elliottii*.

By splitting out the interaction between tapping system and collection period, it was found that all process interactions x collection systems were significant, confirming the relationship between resin systems and resin collection periods (Table 3). Temperature and water deficit are the main factors affecting resin production (Zas et al., 2020). High daily average temperatures during the day and high minimum temperatures for approximately one week before sampling positively influenced resin flow (Zas et al., 2020). Water deficit that accumulated during the previous week was also positively correlated with resin flow. Resin flow normally tends to increase toward the end of the growing season when growth is reduced, and the differentiation of resin ducts increases (Zas et al., 2020). Climatic factors also influenced resin production for the species of *Pinuspinaster* (Genoa et al., 2013). Therefore, the effect of climate should not be discounted in research related to resin production. Thus, surveys should be carried out at least in the two main seasons of the year in tropical regions. The genetic effects must also be considered since resin production has high genetic control, *i.e*., strongly conveys the parents' characteristics.

Celedon and Bohlmann (2019) evaluated the influence of soil and climatic factors on resin production in Brazil, observing that rainfall and relative humidity also affect resin yield. Higher resin yields were observed with increasing temperature associated with lower precipitation and relative humidity. In general, resin yield decreases during the transition period from spring to winter (Demko and Machava, 2022).

Other determinants of resin yield are species, their origin, and the quality of seeds or propagules (Neves et al., 2001). Resin production per tree is a characteristic that has high individual heritability (h2i) values between 0.65-0.77 (Garrido et al., 1999). Equally important are the physiological state of the mother plants of resin-tapped trees and age, starting in southeastern São Paulo state at 8 years old for resin extraction of *P. elliottii*, as well as spacing between trees and tree size, mainly diameters of stem and crown. Several authors recommend harvesting only trees with a DBH greater than 16 cm. Resin yield also depends on the operating system. Strip width and length, panel height and width, and chemicals applied to stimulate resin flow can directly affect productivity. These are factors that can be controlled with proper training of field workers (GurgelFilho and Garrido 1977).

The highest production of resin tapping systems for the two harvests was observed in system 4 and the lowest in system 1 (Table 4). The higher production of system 4 can be attributed to the greater number of panels used, 8 in total. In this system, the panels were installed interspersed on each face of the tree, alternating in arrangement with each new panel installed. This resulted in a longer period before placing a new panel in the same sequence on the face of the tree. System 4 differs from system 5, which also has 8 panels in total, but in this case, the 4 panels of each crop were placed on the same face in sequence, which resulted in a loss of production for each new panel installed. Also, the highest production per tree was found in system 4 and the lowest in system 1 (Table 4). System 1 presented the highest production per panel and system 5 the lowest. System 5 was composed of four panels on the same side of the plant, repeating the same procedure on the opposite side.

In addition to the technical analysis of the resin systems, an economic analysis of the process is recommended. With market demand for constant growth, the increase in the price paid per ton of resin in recent years encourages the sector to study the application of technologies to improve quality and increase resin production (Candaten et al., 2021).

Conclusions

Resin tapping system influenced the growth in diameter, but not the height of trees. The increase in diameter is more sensitive to the effect of resin tapping than the height of the trees.

System 4 had the highest average yield per tree than the other systems. System 1 presented the lowest average production per resin tree.

Collection period 4 presented the highest average production, and collection periods 2 and 5 had the lowest average production of resin per tree.

The effect of climate should be considered in research related to resin production. The collections must be carried out at least in the two main seasons of the year in tropical regions. The genetic effect must also be considered since resin production has high genetic control, *i.e*., strongly conveys the parents' characteristics.

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