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SHORT COMMUNICATION

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Timing of resin-tapping operations in maritime pine forests in Northern Spain

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Abstract

Aim of study: To optimize the timing of resin-tapping activities for maximizing the economic efficiency of resin tapping in Atlantic maritime pine forests.

Area of study: Northern Spain.

Materials and methods: We conducted three small experiments in a mature maritime pine forest aimed to test: i) the impact of groove frequency on resin production, ii) the effect of previous grooves as a driver of temporal patterns of resin production along the seasons and iii) the impact of previous tapping on resin production in the following campaign.

Main results: The resin produced decreased as groove frequency decreased, but the reduction was low. Considering that the number of trees that a worker can tap increases with more spaced grooves, higher tapping efficiency can be achieved with monthly grooves. Previous tapping increased resin yield during the following campaign but resin production was not affected by the previous grooves during the current tapping campaign.

Research highlights: Responses to wounding seem to require time to be effective and temporal patterns of resin production appear to be driven by weather conditions alone.

Keywords: resin yield; *Pinus pinaster*; seasonality; induced responses; wounding.

Authors' contributions: RT, ML, and RZ conceived the idea, designed the experiments and provided the founding. RT performed the field work and processed the datasheets. ML and RZ carried out the statistical analyses. All authors contributed to the writing through successive revisions of the text.

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Introduction

Resin tapping of pine forests does not only provide valuable economic complements (Susaeta *et al.*, 2014), but also high-value and broad-scale ecosystems services (*e.g.* fire prevention and surveillance (Solino *et al.*, 2018), promotion of rural employment and retention of local populations (Justes & Solino, 2018), recreation and people welfare (Heinze *et al.*, 2021), substitution of petroleum derivatives by renewable bioproducts in the industrial sector (Rodrigues-Correa *et al.*, 2012)).

Given the multiple direct and indirect benefits, resin tapping activities should be seen as a key tool to rekindle many pine plantations of southern Europe with low timber profitability and high risk of wildfires. However, the cost efficiency of resin tapping is low and often below the economic minimum for field workers (Justes & Solino, 2018). In addition, the high volatility of resin price in the markets, strongly linked to that of petroleum, adds great uncertainty to the sustainability of resin tapping (Heinze *et al.*, 2021). This has resulted in drastic swings of the surface tapped and the number of resin workers in European pine forests during the last decades (Ortuño Perez *et al.*, 2013).

Two main lines of research are nowadays aiming to overcome these drawbacks through the quantification of ecosystem services searching for compensatory measures (Solino *et al.*, 2018) or the optimization of management operations for maximizing the efficiency of working operations (*e.g.* groove mechanization (Rodríguez-García *et al.*, 2016), development of new chemical stimulants (Michavila Puente-Villegas *et al.*, 2021), genetic improvement (Vázquez-González *et al.*, 2021).

In the present study, we focus on two factors that can strongly determine the efficiency of resin tapping operations but have received comparatively less attention: the tapping frequency and the variation of resin production throughout the season. In Spain, resin tapping has been traditionally concentrated in the Central Plateau on mature maritime pine forests growing on sandy and poor soils under Mediterranean climates with dry and hot summer seasons. Conventional resin tapping is performed by doing fortnightly grooves and applying a sulfuric-acid-based stimulant paste (Rodríguez-García *et al.*, 2016). To our knowledge, this periodicity has little experimental support despite directly determining the number of trees that a worker can process within a campaign. With more spaced grooves, a single worker could tap significantly more trees with the same effort, maximizing, thus, the profitability of the labor.

Another important point that deserves attention is when and where a pine forest could be tapped. Nowadays, resin tapping is being incorporated in timber-oriented maritime pine forests growing under Atlantic climates with much more humid and fresh summer seasons, and there are some doubts about whether the tapping period should be adjusted for this new climatic scenario (Zas *et al.*, 2020a). Previous investigations have shown pronounced seasonal patterns of resin production in these Atlantic areas, with a peak in summer (Zas *et al.*, 2020a) associated to the increase of mean temperature and water deficit (Zas *et al.*, 2020b). However, seasonal patterns of resin production are not only determined by weather variation, but also they can be largely influenced by the induced responses of pines to previous and successive wounding (Hood & Sala, 2015; Rodríguez-García *et al.*, 2014). To avoid confounding these two sources of variation, different starting points (within the season) of resin tapping should be compared (Zas *et al.*, 2020a).

Here, we conducted three small experiments aimed to i) quantify the influence of groove periodicity on resin yield and ii) determine the influence of previous grooves (within the same campaign and across campaigns) on resin yield along the tapping period. The experiments were conducted on a mature maritime pine forest located close to the Atlantic coast of northwestern Spain.

Material and Methods

The study was conducted in a naturally-regenerated mature maritime pine (*Pinus pinaster* Ait.) forest located in Campo Lameiro, Galicia (NW Spain, 42.5566°N, 8.54392°W). The stand has a tree density of 652.5 ± 43.4 trees ha^{-1} (mean ± s.e.) and a basal area at breast height of 36.4 ± 2.2 m^2 ha^{-1}. Trees were around 25 years-old, 16.5 ± 0.29 m tall and 26.5 ± 0.8 cm in diameter at breast height (dbh) at the time of experimental setup. Climate in the area is humid and mild, with 13.4 °C of mean annual temperature, around 1600 and 150 mm of annual and summer (July-September) precipitation, respectively, and low temperature oscillation between the mild winters and the fresh summers (average climate obtained from www.meteogalicia.gal for the period 2007-2020). Three independent experiments were conducted between June 2019 and October 2020.

Experiment 1 was designed to test the effect of three different tapping frequencies (weekly, biweekly and monthly grooves) on resin yield. Twenty-four neighboring trees were selected within the stand and randomly assigned to one of the three frequencies. Starting on February 5, 2020 all the experimental trees were resin tapped following the conventional method commonly used in central Spain (Rodríguez-García *et al.*, 2016) but varying the frequency of the grooves. In all cases, 12-cm wide and 3-cm high striped wounds ("grooves") were periodically made on the southern side of the trunk moving upwards. Mechanical wounds were enhanced by applying a strip of stimulant paste in the upper-inside border of the practiced wound. The paste used is that commonly used for resin tapping in Spain and is based on sulfuric acid (see details in Zas *et al.*, 2020a). A total of 8, 16 and 30 grooves were practiced on monthly, biweekly and weekly frequencies, respectively, with all treatments ending at the same moment (October 10, 2020). In all cases, wounding was started at 25 cm from the ground and ended at around 50, 75 and 115 cm for monthly, biweekly and weekly frequencies, respectively. For all treatments, resin flow was collected in pre-weighed 2-L pots every two weeks (*i.e.* just before the biweekly grooves were applied) and the amount of resin determined gravimetrically (0.1 g).

In Experiment 2 we tested whether previously tapped trees on the preceding campaign produce more resin than previously untapped trees. To this end, 16 trees conventionally-tapped during spring-summer of 2018 and 16 nearby untapped trees were selected. All these trees were tapped following conventional procedures applying biweekly grooves (same details as before) during a whole year (June 2019 – June 2020). The resin flow exuded after each groove was determined every two weeks.

Experiment 3 was established to test whether previous wounds influenced the resin produced along the resin campaign or, alternatively, immediate resin flow is only dependent on tree phenology and weather conditions. Thirty two previously un-tapped trees were selected and randomly assigned to each of four treatments corresponding to four different dates of initiation of resin-tapping (10 June 2019, 5 February 2020, 2 April 2020 and 2 June

2020). In all cases, trees were tapped since each initial date, applying biweekly grooves and the same procedure described before. Resin flow produced after each groove was collected and weighted every two weeks during the common tapping period for all treatments (2 June 2020 to 10 October 2020; 8 grooves in total).

In all experiments, immediate resin flow exuded every ca. 14 days was analyzed with a repeated measures mixed model in which the treatments (groove frequency (three levels: every 1, 2 and 4 weeks), previous tapping (two levels: tapped, untapped) and date of initiation (four levels: Jun19, Feb20, Apr20, Jun20) for experiments 1, 2 and 3, respectively) acted as fixed across-subject factors and the time and the time × treatment interaction as repeated measures within each subject (the individual trees). In addition, total resin yield across the tapping campaign (or the common period in experiment 3) was analyzed with a one-way ANOVA. Dependent variables were log-transformed (log(x+1)) if needed to achieve normality assumptions. Heterogeneous residual variances across treatments were allowed if they significantly improved the likelihood of the models.

Results and Discussion

Tapping frequency

Periodicity of grooves significantly affected total resin production after a whole tapping campaign ($F_{2,21}$ = 3.98, p = 0.034). The more frequent the grooves the more resin was produced, although differences were only significant between monthly grooves and the other two tapping intervals (weekly and biweekly) (Fig. 1).

Despite the significantly lower resin production of monthly grooves, relative resin production efficiency was around 40% higher for monthly grooves than for the conventional biweekly grooves (Fig. 1). In other words, the reduction in resin production with more spaced grooves was largely compensated by the fact that a greater number of trees could be processed if the interventions are less frequent. This result is of remarkable applied relevance as, given the current prices of resin in the market and the economic needs of field workers, the profitability of resin tapping activities in Spain is strongly compromised by the effectiveness of the daily labors (Justes and Solino, 2018). In addition, more spaced grooves imply lower number of traumatic wounds along a resin campaign on a given tree, and thus reduced impact on the trees (*e.g.* growth, wood quality, protection from fire damage, etc) (Génova *et al.*, 2013; van der Maaten *et al.*, 2017), or increased number of years that a tree can be tapped. The final profitability of lower groove frequencies (*e.g.* 4 weeks) must be, however, carefully estimated, as increasing the number of working trees implies some extra field works (*e.g.* initial preparation of the trees by smoothing the bark), increased movements of the workers within the stands, and the need of more materials (pots, sheets).

We are not aware of previous published studies exploring the resin production efficiency of different frequency tapping interventions. Judging from the literature (*e.g.* Heinze *et al.*, 2021; Yi *et al.*, 2021), groove frequency largely varies (ca. from every 2 days to every 3 weeks) depending on the species, the climate, the stimulant paste used and, probably, the manpower costs. Results presented here contrast with previous experimental findings in Spanish maritime pine forests, showing that resin flow decreased exponentially with time since wounding, with most of the resin flow occurring during the first week post wounding (Zas *et al.*, 2020a). However, those results were obtained through micro-tapping procedures and we cannot discard that resin flow in conventional tapping is maintained through longer periods because of reduced crystallization and higher fluidity of the resin produced on larger wounds.

Across- and within-years induction

Trees subjected to resin-tapping in the previous year produced more resin than trees newly tapped, although the differences were only marginally significant ($F_{1,30}$ = 3.1, p = 0.087, Fig. 2a). A previous campaign of conventional resin tapping increased 41% the resin yield in the following campaign (Fig. 2a). A closer look to the

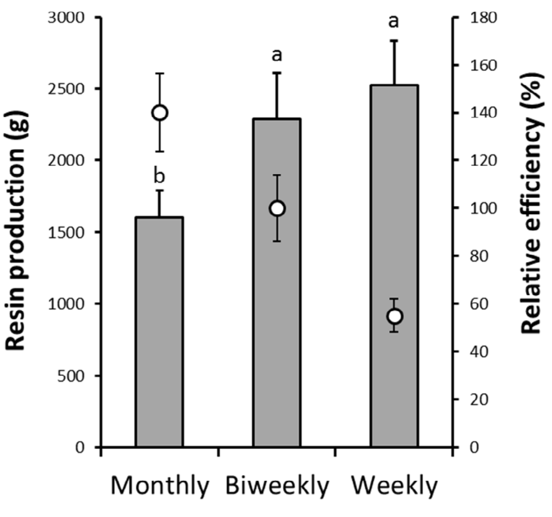

Figure 1. Resin production (mean ±standard error, gray bars) after a whole tapping campaign (February to October 2020) as a function of the periodicity of the grooves (weekly, biweekly and monthly). The relative efficiency (%) in terms of final yield per worker for each periodicity in relation to the conventional biweekly operations is also shown (circles, right axis). Relative efficiency was estimated assuming that the number of trees that a worker can process with monthly and weekly grooves is 2 and 0.5 times greater than that processed with biweekly grooves, respectively.

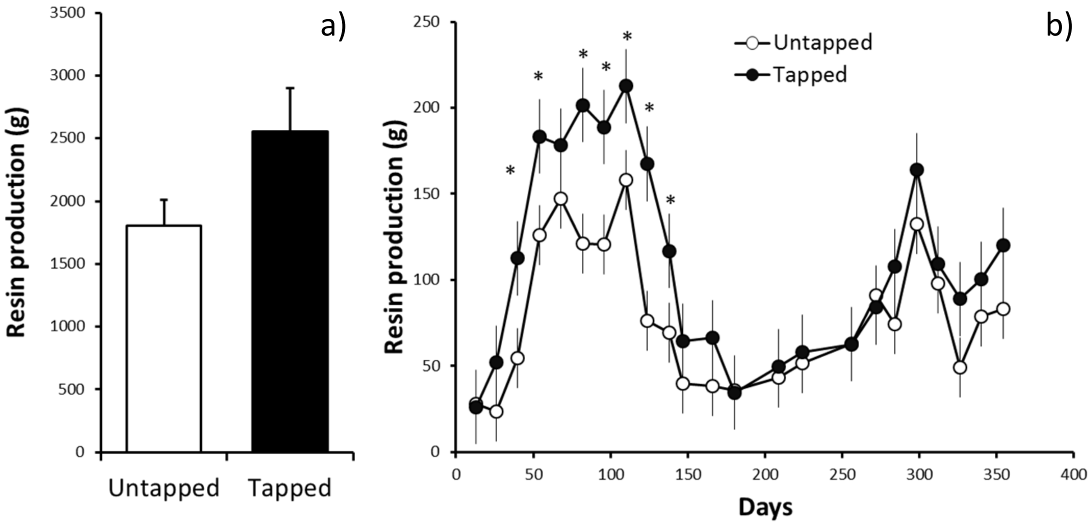

Figure 2. a) Accumulated resin production from June 2019 to June 2020 in previously tapped and untapped trees. Differences between both groups were marginally significant ($F_{1,30}$ = 3.1, p = 0.087). b) Immediate resin production (mean ± standard error) after each biweekly groove in previously-tapped and newly-tapped trees during the assessed period (June 2019-June 2020). Note that significant differences (denoted with an asterisk) between both groups occurred only between the 3rd and the 10th groove and disappeared thereafter. The previous-tapping × time interaction was significant ($F_{22,660}$ =1.6, p = 0.036).

temporal patterns indicated that the effect of previous tapping significantly interacted with time, with significant differences in immediate resin flow after each groove between previously tapped and untapped trees occurring only during the first half of the assessed period, and tending to dilute thereafter (Fig. 2b). This result is consistent with previous findings (de Oliveira Junkes *et al.,* 2019; Neis *et al.*, 2018), and is likely due to the production of traumatic resin ducts as a response to wounding (Rodríguez-García *et al*., 2014).

Despite the observed effects of previous tapping on resin production in the following campaign, both accumulated resin production at the end of the tapping campaign ($F_{3,27}$ = 0.47, p = 0.707, Fig. 3b), and temporal patterns of immediate resin flow after each groove ($F_{21,196}$ = 0.15, p = 0.999, Fig. 3a) were not significantly influenced by the moment when trees began to be tapped within the current campaign. Pine responses to biotic or mechanical damage include both increased resin production and flow from existing resin ducts (Moreira *et al.*, 2012), and the differentiation of new traumatic resin ducts (Vázquez-González *et al.*, 2020). Based on these responses, we expected that resin production would be dependent on the number of previous wounds practiced on the tree, but this pattern was only observed at the very beginning of the experimental period (April 2020, day 15) when resin flow was significantly lower in those trees with no previous wounds in relation to trees subjected to previous periodical wounds (Fig. 3a). However, these differences quickly disappeared, and even switched at the end of the experimental period, with trees tapped for the shortest period (7 grooves since April 2020) producing significantly more resin than those previously tapped for the longest period (31 grooves since June 2019) (Fig. 3a). This pattern is consistent with a rapid but timid induction of resin production in preexisting resin ducts after the first wounds, with the boost of resin production quickly exhausting the resin accumulated in the resin duct web. On the contrary, responses to wounds involving differentiation of traumatic resin ducts would require more time to be produced (Hood and Sala, 2015; Moreira *et al.*, 2015), and their effects will be seen only in the following tapping campaign (Rodríguez-García *et al.*, 2016). Within a single campaign, temporal patterns of resin flow seem to be more dependent on other factors (*e.g.* weather conditions, Rodríguez-García *et al.*, 2015; Zas *et al.*, 2020b) than to previous recent wounds. An increase in resin production in successive resin campaigns should be, however, expected.

Practical recommendations

Three practical recommendations can be derived from the results presented here. First, the tapping frequency should be revised as reducing the frequency of interventions may result in increased production efficiency. These results should be, however, confirmed with further research, as the power of the experiment presented here is limited (one single site, one single campaign). Second, as temporal patterns of resin production are weakly influenced by previous recent wounds, and are mainly dependent on temperature and water deficit (Rodríguez-García *et al.*, 2015; Zas *et al.*, 2020b), the resin tapping period should be adjusted according only to the local climatic conditions avoiding cold and wet periods during the

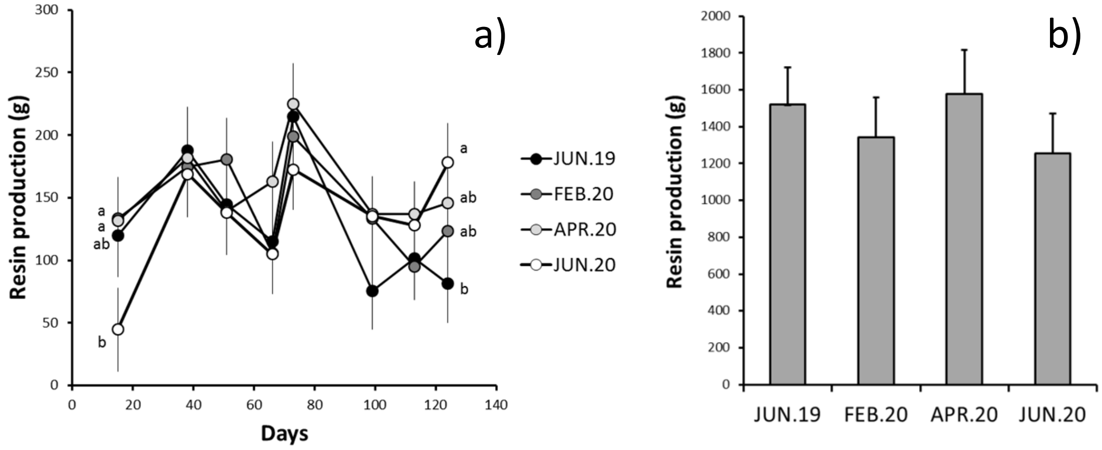

Figure 3. a) Immediate resin production (mean ± standard error) after each biweekly groove as a function of the starting point of the resin tapping operations (June 2019, February 2020, April 2020 and June 2020). Only the common assessment period (June 2020 – October 2020) is shown. Significant differences ($p < 0.05$) between treatments were only observed for the starting (day 15) and ending dates (day 124). For each of these dates, different letters denote significant differences between treatments. b) Accumulated resin production from June 2020 to October 2020 as a function of the starting point of the resin tapping operations. No significant differences ($F_{3,27} = 0.47$, $p > 0.05$) were observed.

tapping period. Third, pine responses to resin tapping take time to be effective and may influence resin production in successive tapping campaigns. Previous quantifications of resin yield potential based on newly-tapped trees (*e.g.* Zas *et al.*, 2020a) may be thus underestimated.

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