



Comparative cost analysis for bore hole and bark streak tapping methods in resin production from *Pinus brutia*

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Abstract This study assesses the economic and technical feasibility of two resin extraction methods, Bore Hole Tapping (BH) and Bark Streak Tapping (BS), applied to *Pinus brutia* in the Korudağ Forest, Türkiye. Resin production from 758 trees was analyzed over six months to compare setup costs, operational expenses, labor costs, and yields. Additionally, a feasibility study involving 2500 trees was conducted to evaluate market, technical, and financial aspects. Results show that both methods incur high production costs, making resin production economically unviable under current market conditions. The BH method is particularly unfeasible due to significant initial investments and high operating costs. In contrast, the BS method, with lower costs, approaches viability at historically higher resin prices. Sensitivity analyses

suggest that the BS method could become feasible with a significant rise in market prices. However, resin production from *Pinus brutia* remains economically unfeasible at present.

Keywords *Pinus brutia* · Resin production · Economic feasibility · Bore hole tapping · Bark streak tapping

Introduction

Given the crucial role of non-timber forest products in providing sustainable livelihoods (Delgado et al. 2023; Pandey et al. 2016), resin production similarly stands out as a significant economic activity contributing to rural communities (Lemenih et al. 2003). Species of the genus *Pinus* are renowned for their resin production, an economically significant activity in many parts of the world (Rodrigues-Corrêa et al. 2012). Resin tapping not only contributes to forest management but also provides a stable source of income for local communities, particularly in rural Mediterranean areas. This practice is especially important for pine species like *Pinus pinaster* Ait. in the Iberian Peninsula and France, *Pinus brutia* in Türkiye (Caglayan et al. 2024), and both *Pinus brutia* and *Pinus halepensis* in Greece (Papadopoulos 2013; Zevgolisi et al. 2022). The extracted resin is used in the production of high-value goods, including

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adhesives, varnishes, and pharmaceuticals (da Silva Rodrigues-Corrêa et al. 2013).

Despite its economic significance and potential to enhance local economies, resin production continues to receive less attention than improvements in wood quality and quantity, which remain higher societal priorities (Soliño et al. 2020). Unlike timber, resin production has not yet garnered sufficient investment or policy support, limiting its development within the forestry sector. This disparity is evident in the lower levels of funding, research, and institutional backing directed toward resin extraction (Soliño et al. 2020). Consequently, the full economic and sustainable development potential of resin tapping remains underutilized. Additionally, global assessments like the Global Forest Resources Assessments (GFRA) often report resin production inconsistently and incompletely, which undermines the accurate representation of its true economic potential and impedes effective policy and management decisions (Shackleton et al. 2024). In Spain, the economic value of resin is not fully reflected in current accounting and reporting systems, leading to gaps in official statistics (Campos et al. 2021). Similarly, in Türkiye, France, Italy, and many other countries, resin's value is inadequately assessed, resulting in deficiencies in economic reporting and policy development (Masi-ero et al. 2016). This underestimation is not limited to resin alone but extends to other Non-Wood Forest Products (NWFPs) in Europe, where collection rates and values are often underestimated due to the lack of comprehensive data (Lovrić et al. 2020).

Pinus brutia, commonly known as Turkish red pine, is a notable source of resin despite its moderate yield (Satil et al. 2011). The resin of *Pinus brutia* is particularly valued for its quality and diverse applications, making it an important resource for industrial uses and a contributor to local economies through sustainable income generation (Petrakis et al. 2007; Satil et al. 2011). Traditionally carried out in Mediterranean regions where this species is abundant, resin production from *Pinus brutia* involves extracting resin from tree trunks using various methods, each with unique advantages and drawbacks (Petrakis et al. 2007). Resin, a viscous substance exuded by trees, has been utilized for centuries in manufacturing, medicinal uses, fragrance and flavoring, and art and craft (López and Shanley 2004). Its economic importance lies in its role in supporting rural

economies and contributing to the livelihoods of forest-dependent communities (Fikir et al. 2016). Furthermore, resin tapping provides a sustainable source of income without necessitating the felling of trees, thus promoting forest conservation and a renewable resource-based economy.

Evaluating different resin production methods is crucial for optimizing both yield and economic viability. Different tapping methods can significantly impact the overall cost, efficiency, and sustainability of resin production (López-Álvarez et al. 2023b, 2023a; Rodríguez-García et al. 2016). By thoroughly analyzing the costs and benefits associated with each method, forest managers and industry stakeholders can make informed decisions that enhance productivity while ensuring the long-term health of the forest ecosystem. For instance, the Bore Hole Tapping (BH) method demonstrated higher resin yield compared to the traditional drill method in *Chir pine* (Meena and Akash 2023), while Rodríguez-García et al. (2016) showed that upward tapping methods produced higher resin output in *Pinus pinaster*. Similarly, Freitas et al. (2023) emphasized that different system variations yielded varying amounts of resin, highlighting the critical role of tapping techniques and their configurations. Empirical results indicate that the inclusion of resin benefit results in lengthening optimal rotation age and that resin benefit has a greater effect on rotation age when discount rates are low (Wang et al. 2006). This highlights the economic significance of resin production in extending forest rotation periods, influencing both long-term management strategies and profitability. Understanding these financial implications helps in identifying the most cost-effective approach, contributing to better resource management and overall economic sustainability.

Resin tapping contributes not only to economic development but also to the ecological sustainability of forests by promoting tree health and resilience. Research indicates that properly managed resin extraction, can enhance radial growth without compromising the tree's ability to respond to affecting trees' climate sensitivity, as observed in Scots pine (van der Maaten et al. 2017). Similarly, in *Pinus tabulaeformis*, resin tapping caused minimal impacts on tree growth and carbon reserves, with no significant changes in adaptability to environmental conditions (Zeng et al. 2021a). These findings highlight the importance of sustainable tapping

practices in preserving tree vitality and ensuring long-term productivity (Génova et al. 2014).

In recent years, the growing demand for natural and sustainable products has increased, leading to a renewed interest in biobased resin due to its eco-friendliness, biodegradability, and non-toxicity compared to synthetic alternatives (Andrew and Dhakal 2022; Phiri et al. 2023). This trend highlights the need for efficient and sustainable resin production methods. As consumers and industries shift towards more sustainable practices, the role of biobased resin in the market is expected to grow, necessitating the refinement of extraction techniques to maximize yield and minimize environmental impact.

This study focuses on two primary methods of resin extraction from *Pinus brutia*: Bore Hole Tapping (BH) and Bark Streak Tapping (BS). The BH method involves mechanically drilling holes into the tree trunk, while the BS method relies on manually creating streaks in the bark. Conducted in the Korudağ Forest, Edirne, Türkiye, this study evaluates the economic and technical feasibility of these two methods. Over a period from April to October 2023, comprehensive data on initial setup costs, recurring operational expenses, labor costs, and resin yields were collected from 758 trees subjected to both methods. Additionally, a larger-scale feasibility study involving 2500 trees provided a robust analysis of market, technical, and financial factors influencing resin production.

The primary objective of this research is to compare the BH and BS methods to determine which is more cost-effective and efficient under current market conditions. By examining the economic viability, potential market opportunities, and technical requirements of each method, valuable insights for forestry management and resin production stakeholders can be provided. The findings of this study will contribute to optimizing resin extraction practices and support sustainable forest management strategies in Türkiye and beyond. This study aims to achieve the following objectives based on preliminary observations and existing literature:

- Compare the initial and operational costs of the BS method with the BH method to determine which is more cost-effective under current market conditions.

- Assess whether the BH method is economically feasible, considering its higher initial investment and operational expenses, even during periods of historically high resin prices.
- Evaluate the potential economic viability of the BS method if market prices for natural pine resin increase significantly by using sensitivity analyses.

By achieving these objectives, this study aims to provide valuable insights into the economic sustainability of resin production from *Pinus brutia* and contribute to informed decision-making in forestry management.

Materials and methods

This section outlines the materials and methodologies employed in our study to compare the BH and BS methods for resin extraction from *Pinus brutia* in the Korudağ Forest, Edirne, Türkiye.

Bore hole tapping (BH) method

The BH Method involves mechanically boring holes into the tree trunk to facilitate the flow of resin. The BH process consists of the following steps:

1. Tree Preparation: Clear the bark around the drill site to expose the cambium layer using a peeling tool.
2. Drilling the Hole: Drill a hole at a predetermined height and angle to optimize resin flow.
3. Acid Application: Apply acid inside the drilled hole to stimulate resin production.
4. Inserting the Plastic Pipe: Insert a plastic tube into the hole to channel the resin into an attached plastic bag using cable tie.
5. Collection Setup: Place barrel to store resins from plastic bag.
6. Closing Operations: Treat and seal the holes at the end of the season to prevent damage and remove all equipment.

The bark streak tapping (BS) method

The BS Method is another traditional approach for extracting resin, particularly suited for use with *Pinus*

brutia. This method involves less mechanical intervention compared to BH and focuses on manually creating streaks or cuts in the bark to facilitate resin flow. The process is as follows:

1. **Tree Preparation:** Begin by using a peeling tool to carefully remove sections of bark, exposing the cambium layer beneath where the resin flows.
2. **Creating Streaks:** Employ a wound opening tool to make vertical streaks in the exposed cambium. These streaks are designed to maximize resin exudation.
3. **Acid Application:** Apply acid strategically above the streaks to enhance resin production.
4. **Applying Plastic Bags:** Secure plastic bags around the streaked areas using a staple gun. This ensures that all resin exuded is efficiently collected.
5. **Collection Setup:** Transfer the resin collected in plastic bags into barrels for storage and further processing.

Data collection methodology

For our cost analysis of resin production using both the BH and BS methods, we conducted a comprehensive study from April 2023 to October 2023. This study was carried out in the Korudağ Forest, located in Edirne, Türkiye, providing a robust setting for assessing these methods under typical forest conditions.

The study included a total of 758 trees, with 369 trees subjected to the BH method (Caglayan et al. 2025) and 389 trees to the BS method (Caglayan et al. 2024). This provided a balanced and comparative assessment of both methods. The data collection spanned six months (from May to October 2022), allowing for the observation of seasonal variations in resin yield and associated costs. Resin collection in this study was conducted biweekly for both the BH and BS methods to ensure consistent tracking of resin yield. For the BH method, angled holes were drilled into the trunk of *Pinus brutia* every 15 days, with acid paste applied to stimulate resin flow. The resin was directed through plastic pipes into securely attached collection bags (Caglayan et al. 2025). In the BS method, 3 cm wide streaks were created on the bark every 15 days, and acid paste was similarly applied to enhance resin flow. Resin

was collected in plastic bags and weighed biweekly to monitor production (Caglayan et al. 2024).

The average resin yield per tree per season was significantly higher for the BS method (610 g) compared to the BH method (210 g), underscoring the superior efficiency of the BS approach. Temperature emerged as a key factor influencing resin yield, with the BS method exhibiting a stronger relationship ($R^2=0.7713$, $p<0.001$) (Caglayan et al. 2024) compared to the BH method ($R^2=0.4429$, $p<0.001$) (Caglayan et al. 2025). Environmental factors, particularly precipitation and temperature, play a crucial role in resin production, affecting both methods. Previous studies indicate that seasonal variations, especially during warmer months, are associated with increased resin yields. Additionally, tree characteristics, such as diameter at breast height, contribute to yield differences between the two methods (Caglayan et al. 2024, 2025). Since the impact of these factors on resin yield has been extensively analyzed in previous research, this paper primarily focuses on the economic analysis of the methods.

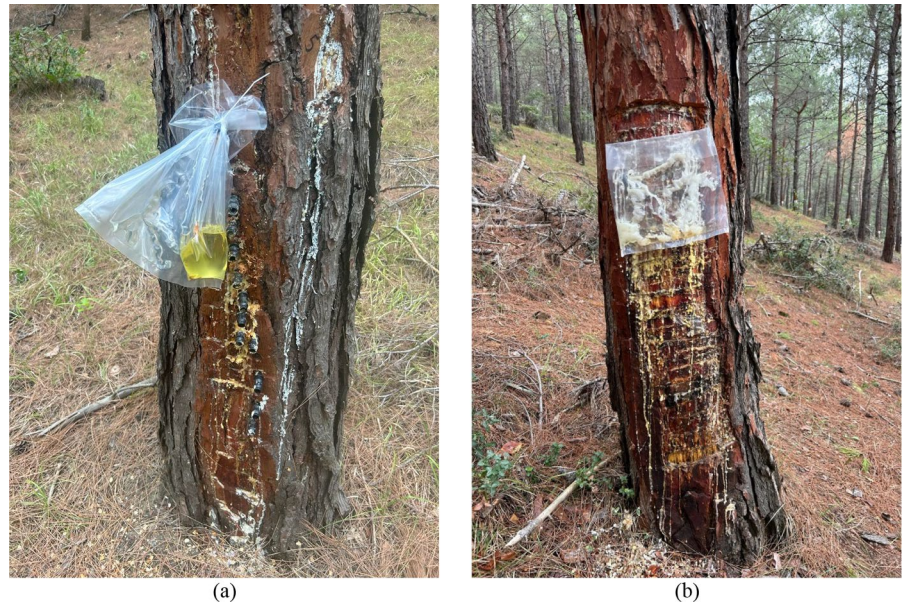
As illustrated in Fig. 1, the BH method (Fig. 1a) involves mechanically drilling holes into the tree trunk to facilitate resin flow. In contrast, the BS method (Fig. 1b) relies on manually creating streaks in the bark to promote resin exudation. These methods were chosen for their distinct approaches to resin extraction, providing a comprehensive comparison of their efficiency and cost-effectiveness under the same environmental conditions.

During this period, we systematically recorded all relevant data, including initial setup costs, recurring operational expenses, labor costs, and resin yields. By maintaining detailed records, we ensured that our analysis would accurately reflect the economic feasibility and efficiency of each resin production method under real-world conditions. The study's duration allowed us to capture variations in resin production due to seasonal changes, providing a comprehensive understanding of each method's performance throughout the year.

Feasibility study of resin production from *Pinus brutia*

The *Pinus brutia* species, extensively cultivated and rapidly expanding across Türkiye, holds

Fig. 1 Methods of resin extraction from *Pinus brutia*: **a** BH Method, which involves mechanically drilling holes into the tree trunk to facilitate resin flow, and **b** BS Method, which relies on manually creating streaks in the bark to promote resin exudation



considerable potential for resin production. Natural pine resin offers several advantages over synthetic resin, including its eco-friendliness, biodegradability, and non-toxicity. Unlike synthetic resin, which often contains harmful chemicals, natural pine resin is a renewable resource that does not contribute to environmental pollution. Market research highlights a growing consumer preference for natural and sustainable products, driving demand for natural pine resin. Furthermore, its unique properties—such as superior adhesive strength and resistance to weathering—make it highly desirable in various industries, including cosmetics, pharmaceuticals, and adhesives.

This increasing demand presents significant market opportunities for natural pine resin producers. However, potential alone does not ensure economic feasibility. For an initiative to attract entrepreneurs, it must be economically viable; otherwise, despite its social and environmental benefits or perceived high potential, it may fail to gain traction.

As of October 2023, the price of raw natural pine resin is approximately \$600 per ton. However, prices have shown considerable instability. Interviews with producers revealed that while higher prices were achievable in previous years, current selling prices fall below expectations, leading many producers to withhold sales to avoid losses. Economic difficulties have partially reduced demand for natural products in the short term, but this trend is expected to reverse

as economic conditions stabilize and consumer preferences shift back toward sustainability and eco-friendliness.

Expert opinions suggest that natural resin will likely appreciate in value over the long term, aligning with global sustainability goals. Consequently, this study emphasizes the importance of conducting both present value analyses under current conditions and break-even analyses to identify the price ranges necessary to justify investment. These analyses are crucial for making informed decisions amidst dynamic market conditions and evolving sustainability objectives.

In this study, we conducted an economic analysis based on results obtained from 758 trees in the study area, scaling the findings to a scenario involving 2,500 trees within the same region. Field observations revealed that a single worker can manage approximately 500 trees per day during an 8-h work shift, performing tasks such as making incisions, attaching collection bags, and applying acid. This estimate is derived from systematic field measurements taken biweekly over a 6-month period (Caglayan et al. 2024, 2025). With a team of five skilled workers, the total number of trees that can be feasibly processed in a single production day is 2500. This scaling is based on actual operational capacity observed in the field, providing a realistic framework for assessing economic feasibility under practical working conditions.

Additionally, a detailed technical analysis was performed to identify the labor and equipment requirements for resin extraction using the BH and BS methods over a five-year period. The analysis meticulously calculated labor and equipment needs, as well as associated costs, based on a pilot study involving 2500 trees. Costs are categorized into fixed costs incurred at the start of the five-year period, seasonal costs recurring annually, and operational costs arising during production months. Some costs are calculated per tree, while others are calculated per worker. These costs are based on October 2023 values and were primarily incurred in Turkish lira (TL). For an international audience, they have been converted to US dollars using an exchange rate of 1 USD = 32 TL.

The comprehensive assessment provides insights into the labor, equipment, and financial investment required for sustainable resin production. By integrating technical and economic analyses, this study offers a holistic perspective on the feasibility of large-scale natural pine resin production, ensuring alignment with market opportunities and sustainability objectives.

Bore hole tapping (BH) method

The bore hole method involves significant initial investments in equipment, such as drills and generators, which are reflected in the high fixed costs. The costs of this method are detailed in Table 1.

Initial investment cost Before production begins, several critical items and costs need to be addressed to ensure operational readiness. These include drilling equipment, transportation, barrels, funnels, and the area rent, all of which are one-time or initial investments. Drilling equipment consists of drills, batteries and a generator. Drill and Battery are essential for creating boreholes, each drill and its battery cost \$375. For 5 workers, this amounts to $5 \times 375 = \$1875$. Additional costs for drill bits and chucks are incurred annually, further elevating the overhead. The generator, essential for charging the drill battery, costs \$390.63. This is a one-time cost necessary for the borehole method's operation at the start of the project. Generator cable is necessary for connecting the generator, and it costs \$35.94. This cost is also a one-time investment at the beginning of the project. To transport materials to the site, a one-time cost of \$156 is needed. It covers moving all

materials to the study area. This cost is spread over 5 years to align with the project's timeline. Barrels are used to store the collected resin. Each barrel can store the resin collected from 100 trees and is priced at \$11.56. Given the project plans to collect resin from 2,500 trees, the total number of barrels required is: $2500/100 = 25$. Therefore, the cost for barrels over 5 years is: $25 \times 11.56 = \$289$. This cost is amortized once at the beginning of the planning period. The rent payment to OGM is \$0.0078 per tree. For 2500 trees over 5 years, the total rent is $2500 \times 0.0078 = \$19.5$. Funnels, used for adding acids to the plastic tube, costs \$2.66 per unit. This expense is considered part of the initial setup and is amortized over the 5-year period. Fuel Cans are used to transfer gasoline to the generator, and it costs \$6.25. This is included in the initial costs to ensure operational readiness. Hammers are used to hammer pipes into trees, each cost \$5.16. For 5 workers, the total is: $5 \times 5.16 = \$25.8$. Peeling Tools are necessary for removing bark, each tool costs \$15.62. For 5 workers: $5 \times 15.62 = \$78.1$.

Seasonal investment cost Seasonal investment costs include several key components essential for the operations. Field preparation incurs significant labor costs, calculated at \$46.87 per day. Given that the preparation activities, such as drilling and bark removal, require five worker-days, the total labor cost amounts to \$234.35. Another recurring expense is the battery replacement for the generator, which ensures efficient operation. The annual replacement cost is \$36.87, beginning in the second season and repeating at the start of each subsequent season. Additionally, tools like drill bits and drill chucks are necessary, costing \$8.9 and \$7.81, respectively. Lastly, plastic tubes used for applying acid to trees cost \$0.7813 each. For five workers, the total expense for tubes is calculated as $5 \times 0.78 = \$3.90$.

Monthly production cost The monthly production cost comprises components related to consumables, labor, and operational expenses. Consumables include sulfuric acid, cable ties, plastic pipes, and plastic bags, which are essential for the resin extraction process but contribute to the overall operational cost. The sulfuric acid is applied six times per season, costing \$0.024 per tree, resulting in a total expense of \$60 for 2,500 trees. Cable ties and plastic pipes, used per tree, cost \$0.01 and \$0.03 respectively, amounting to a combined cost of \$100 for all trees. Plastic bags, used twice monthly to collect resin, cost \$0.023 per tree, leading to a monthly

Table 1 Cost analysis for BH method in resin production

No	For	Description	Product	Unit	Quality/life	Price (\$)	Usage quantity	Unit price (per tree/\$)	Period
1	Fixed	A drill is used for the bore hole method and it used to charge the drill battery	Generator	1 unit		390.63	5 years		Initial Investment Cost: Once at the beginning of the planning period
2	Fixed	Generator cable	Generator cable	1 unit		35.94	5 years		
3	Fixed	Used to transfer gasoline to the generator	Fuel can	1 unit		6.25	5 years		
4	Fixed	Used for storing collected resins. Resin collected from 100 trees fills a barrel	Barrel	60 L		11.56	5 years		
5	Fixed	Covers transportation of all materials to the study area	Transportation	one-time		156	5 years		
6	Fixed	Funnel for adding acids to plastic tube	funnel	Each		2.66	5 years		
7	Fixed	Rental payment was made to OGM for \$0.0078 per tree	Rent	Each		0.0078	5 years		
8	Per worker	It includes the cost of the drill (\$264) + a battery (\$111) to be used in the bore hole method	Drill and Battery	1 unit		375	5 years		
9	Per worker	to hammer the pipes into the tree	Hammer	1 unit		5.16	5 years		
10	Per worker	used for removing bark	peeling tool	1 unit		15.62	5 years		
11	Fixed	Batteries are purchased for the generator once a year	Battery			36.87	Annual		Once per season
12	Per worker	Used to apply acid on trees	Plastic tube	1 unit		0.78	Annual	0.78	
13	Per worker	16 mm drill bit	Drill bit	1 unit		8.9	Annual		
14	Per worker	Drill chuck	Drill chuck	1 unit		7.81	Annual		
15	Per worker	Labor cost for bark removal over 5 days by 2 workers	Labor	per day		46.87			

Table 1 (continued)

No	For	Description	Product	Unit	Quality/life	Price (\$)	Usage quantity	Unit price (per tree/\$)	Period
16	Per tree	Sulfuric Acid If acid is applied to 250 trees with 1 kg of acid: $1/250 = 0.004$ kg to 1 tree. Acid is required for this. $0.004 \times 3 = \$0.012$	Sulfuric Acid	1 kg	0.004	3	2 times	$(0.012 \times 2 = 0.024)$	Two times per month
17	Per tree	Unit price for a 1 kg bag is \$2.07 with 180 units, costing \$0.0115 per unit	Plastic bag	1 kg	180	2.07	2 times	$(0.0115 \times 2 = 0.023)$	
18	Per tree	If 1 cable tie is used for each tree: $0.5/100 = \$0.005$	Cable tie	1 pack (100 unit)	100	0.5	2	$(0.005 \times 2 = 0.01)$	
19	Per tree	16 mm plastic pipe	Plastic pipe	1 unit		0.015	2	$(0.015 \times 2 = 0.03)$	
20	Per worker	covers 1 months of labor (2 workers—4 times land per month, 4 times daily wage for 2 workers)	Labor	per day		46.87			
21	Per tree	When working with a single battery, 2.5 L of gasoline is consumed per battery. And one battery drills 250 trees	Gasoline	1 battery 1 tree	0.01	1.25	2	$(0.0125 \times 2 = 0.025)$	Once in two months on May, July, September in each year

expense of \$57.5. Labor costs represent another significant portion, with workers paid \$46.87 per day. For five workers working twice a month, the labor expense totals \$468.7 monthly. Additionally, gasoline used to operate the drill battery costs \$0.025 per tree per month, adding up to \$62.5 for 2,500 trees. Together, these costs form the comprehensive monthly production expense.

Revenues It is observed that using Bark hole method, 210 g of resin can be produced from a tree in a season. With 2500 trees the production amount can be calculated as 0.525 tones per season. Since the price of raw natural pine resin is approximately \$600 per ton, seasonal revenue can be calculated as $0.525 \times 600 = \$315$. The produced resin is sold at the end of the season at once.

Bark streak tapping (BS) method

The bark streak method involves fewer mechanical tools but requires a similar level of manual labor as the bore hole method (Table 2).

Initial investment cost Before production begins, several critical items and costs need to be addressed to ensure operational readiness such as tools, transportation, barrels, funnels, and rent. Tools, including wound-opening and peeling tools, cost \$15.62 each. For five workers, this totals \$156.2. Transportation involves a one-time expense of \$156.25 to deliver materials to the site, spread over five years. Barrels for resin storage are priced at \$11.56 each, with 25 barrels required for 2,500 trees, resulting in a cost of \$289, amortized once at the start. Funnels cost \$2.66 each, while the rent payment to OGM, calculated at \$0.0078 per tree for 2,500 trees over five years, totals \$19.5.

Seasonal investment cost It includes field preparation, consumables, and equipment like plastic tubes and staple machines. Field preparation costs \$234.35 for labor. Plastic tubes cost \$0.78 annually per worker, amounting to \$3.9 for five workers. Staple machines, essential for securing bags, cost \$13.28 annually per worker, totaling \$66.4. Additionally, plastic bags used

Table 2 Cost analysis for BS method in resin production

No.	For	Description	Product	Unit	Quality/ life	Price (\$)	Usage quantity	Unit price (per tree/\$)	Period
1	Fixed	Used for storing collected resins. Resin collected from 100 trees fills a barrel	Barrel	60 L		11.56	5 year		Initial Investment Cost: Once at the beginning of the planning period
2	Fixed	Covers transportation of all materials to the study area	Transportation	Each		156.25	5 year		
3	Fixed	Funnel for adding acids to plastic tube	Funnel	Each		2.66	5 year		
4	Fixed	Rental payment was made to OGM for \$0.0078 per tree	Rent	Each		0.0078	5 year		
5	Per worker	Used to open wounds on trees	Wound opening tool	Each	5	15.62	5 year		
6	Per worker	Used for removing bark	Peeling tool	Each	5	15.62	5 year		
7	Per tree	Unit price for a 1 kg bag is \$2.07 with 180 units, costing \$0.0115 per unit	Plastic bag	1 kg	180	2.07	1 times	(0.0115*2=0.023)	Once per season
8	Per worker	Used to apply acid on trees	Plastic tube	1 unit		0.78	annual	0.78	
9	Per worker	If the total staples needed are 1500 bags and expire: $13.28/1500=0.0088$ \$, staple machine cost per bag. Let a staple season be used	Staple machine	1 Ad	1500	13.28	annual	13.28	
10	Per worker	Labor cost for bark removal over 5 days by 2 workers	Labor	per day		46.87			
11	Per tree	Sulfuric Acid If acid is applied to 250 trees with 1 kg of acid: $1/250=0.004$ kg to 1 tree. Acid is required for this. $0.004*3=\$0.012$	Sulfuric Acid	1 kg	0.004	3	2 times	(0.012*2=0.024)	Two times per month
12	Per worker	covers 1 months of labor (2 workers—4 times land per month, 4 times daily wage for 2 workers)	Labor	per day		46.87			
13	Per tree	If 20 staples are used per bag, and one pack contains 5000 staples with a pack price of \$1	Staples	1 packet	5000	1	2 times	0.0002	

once per tree per season cost \$0.0115 each, amounting to \$28.75 for 2,500 trees.

Monthly production cost The monthly production cost includes sulfuric acid, staples, and labor. Sulfuric acid, applied at a cost of \$0.024 per tree per season, totals \$60 for 2,500 trees. Staples, used at 20 per bag with a unit cost of \$0.0002, cost \$10 for all trees. Labor expenses are significant, with a monthly cost of \$234.35 for five workers.

Revenues Using the BS method, 610 g of resin can be harvested per tree per season. For 2,500 trees, the total production is 1.525 tons per season. At a price of \$600 per ton, the seasonal revenue is calculated as $1.525 \times 600 = \$915$, with the resin sold at the end of the season in bulk.

Comparison of cost breakdown

Table 3 presents a detailed comparison of the cost breakdown between the BH and BS methods for resin extraction. This comparison highlights the key cost

items, the associated expenses for each method, and a brief description of their necessity in the process.

Feasibility analysis

The net cash flows for the BH and BS methods, as detailed in the previous sections, are summarized in Table 4.

As shown in the Table 4 and Fig. 2, under current conditions, neither method is able to cover the production costs. In addition to requiring an additional initial investment cost, the seasonal revenue generated by the borehole method does not even cover one month's production cost. Although the BS method has lower initial investment and operating costs, it is also evident that the production costs cannot be covered with the current prices. When examining the resin prices of previous years, it is observed that there have been significant fluctuations. There have been periods when the price per ton of resin exceeded \$2000. Therefore, sensitivity analysis is conducted

Table 3 Cost breakdown table: BH versus BS

Cost item	BH method (\$)	BS method (\$)	Description
<i>Initial investment</i>			
Drilling equipment (drill & battery)	1875	–	Essential for drilling in the BH method
Generator	390.63	–	Needed to power drilling equipment in BH method
Transportation	156.25	156.25	Required to transport materials for both methods
Barrels (resin Storage)	289	289	Used to store resin collected from both methods
Acid pouring funnel	2.66	2.66	Used to apply acid in both methods
Rent (OGM)	19.50	19.50	Rent paid to OGM for forest use, applicable to both methods
Wound opening tool	–	156.2	Essential for creating streaks in BS method
Peeling tool	78.10	78.1	Required for tree preparation in both methods
<i>Seasonal investment costs</i>			
Field preparation (labor)	234.35	234.35	Labor required for preparing the field in both methods
Generator battery replacement	36.87	–	Annual cost to maintain generator functionality in BH method
Drill bit and chuck	16.71	–	Necessary for maintaining drilling equipment in BH method
Plastic tube	3.90	3.90	Used in both methods to channel resin
Staple machine	–	66.4	Required for securing plastic bags in BS method
Plastic bag	57.50	28.75	Used to collect resin in both methods, more costly in BH method
<i>Monthly production costs</i>			
Sulfuric acid	60	60	Used in both methods to stimulate resin flow
Cable ties and plastic pipe	100	10	Used to secure and channel resin, more costly in BH method
Labor cost (5 workers/month)	468.70	468.70	Monthly labor costs for both methods
Gasoline	62.50	–	Fuel for generator used in BH method
Staples	–	10	Required to secure bags in BS method

Table 4 Net cash flows generated from processing 2500 trees (in \$)

	BS Method	BH Method
April 2024	−957.01	−3133.84
May 2024–October 2024	−301.85	−748.70
October 2024	915.00	315.00
April 2025	−304.65	−291.83
May 2025–October 2025	−301.85	−748.70
October 2025	915.00	315.00
April 2026	−304.65	−291.83
May 2026–October 2026	−301.85	−748.70
October 2026	915.00	315.00
April 2027	−304.65	−571.83
May 2027–October 2027	−301.85	−748.70
October 2027	915.00	315.00
April 2028	−304.65	−571.83
May 2028–October 2028	−301.85	−748.70
October 2028	915.00	315.00

to analyze the sensitivity of the currently unfeasible methods of obtaining resin from *Pinus brutia* trees for several parameters.

When the current interest rate is calculated as 5% per year, and considering that the market value of resin per kilogram is \$0.6, both methods do not yield profitability, resulting in a negative net present value.

Sensitivity analysis

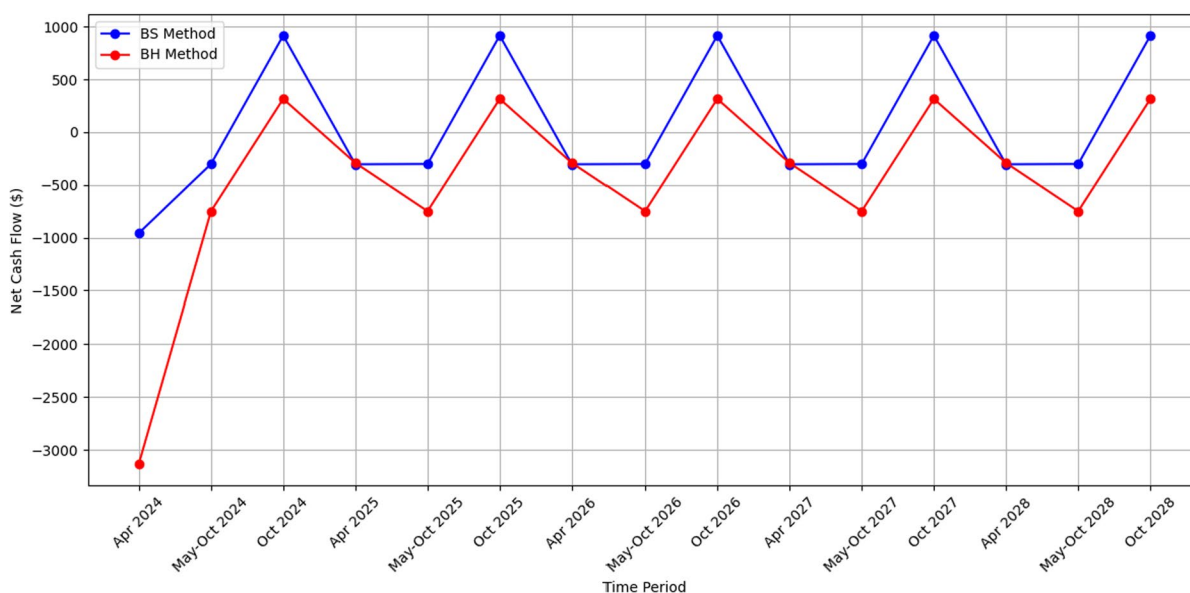
This section examines the sensitivity of the investment decision on several parameters such as prices, production amount, and labor costs.

Sensitivity on prices

For 2500 trees, the breakeven point of the resin prices that makes the investment feasible for BS method is calculated as \$1775 per tone and for BH as \$10,710 per tone. It is obvious that BH method cannot be used in the production process since the breakeven price is calculated to be an impossibly high value (Fig. 4a, 4b). However, since \$1843 has been a price experienced in previous years, if the price of resin increases, production using the BS method could become a feasible investment. When the inflation-free interest rate is assumed to be 0, the BS method becomes feasible at a price of \$1686, and the BH method at a price of \$10,481 (Fig. 3).

Sensitivity on trees used in production

It has been determined that changes in the number of trees used in production do not cause a significant change in the price break-even point. In the analysis conducted for 25,000 trees, the break-even price

**Fig. 2** *Pinus brutia* resin production for 2500 trees: cash flows for BH and BS methods

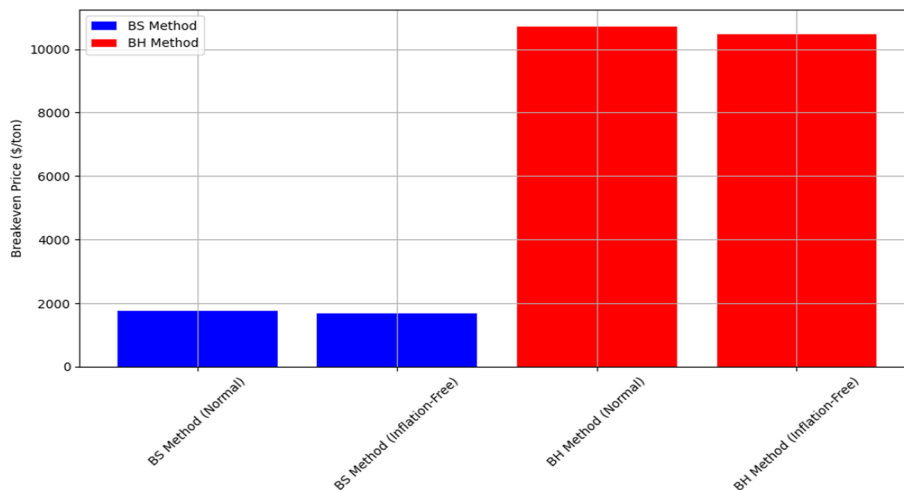


Fig. 3 Breakeven price comparison for BS and BH methods

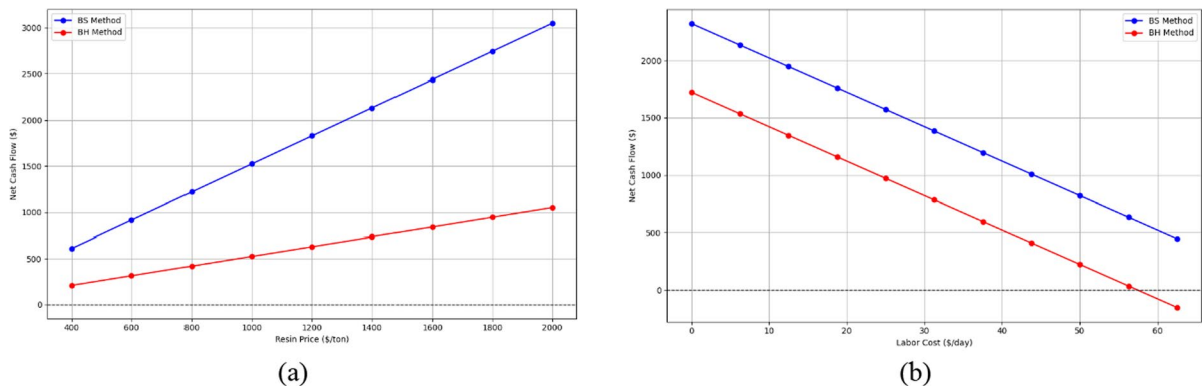


Fig. 4 Market price sensitivity analysis (a) and labor cost sensitivity analysis for resin production (b)

was calculated to be \$1747 for the BS method and \$10,282 for the BH method.

Sensitivity on labor costs

Even if the daily labor cost is zero at current prices, the BH method is still not feasible (Fig. 4b). However, the BS method becomes feasible at current prices if the daily labor cost decreases to \$7.69. This, however, would require a reduction in labor costs of over 80%.

In conclusion, due to the unfeasibility of prices covering the costs, it has been determined that resin production from the *Pinus brutia* tree species is not suitable under current conditions. These productions may become viable when prices reach the breakeven

points. Cost studies obtained from the pilot study indicate that the BS method is significantly superior to the BH method in terms of costs and the amount of product obtained from a tree. However, this investment is still not feasible under current conditions.

To calculate the breakeven point (BEP) for resin production methods, the raw oleoresin price must reach \$2.80 per kg for the BS method and \$11.33 per kg for the BH method to cover production costs and become economically viable.

As a result of the sensitivity analyses, the following findings were obtained:

- Under current resin prices, both methods are economically unfeasible.

- Resin production becomes feasible if the price reaches at least \$1,775 for the BS method and \$10,710 for the BH method.
- The number of trees used in production does not significantly impact the results.
- Labor costs constitute the primary cost driver in production. For the BS method to become feasible, labor costs would need to be reduced by 80%.

Discussion

The results of this study provide important insights into the economic feasibility and operational efficiency of two resin extraction methods—BH and BS—from *Pinus brutia* in the Korudağ Forest, Edirne, Türkiye. By examining the resin yield, cost analysis, and financial feasibility of each method, we can better understand their potential applications and limitations in the context of sustainable forestry practices.

The economic feasibility of resin tapping methods relies heavily on resin yield, operational costs, and the long-term sustainability of the chosen approach. Our study revealed that the BS method produced a significantly higher resin yield (610 g per tree per season) compared to the BH method (210 g per tree per season), making it a more economically viable option. This difference in yield not only reduces the per-unit production cost but also maximizes labor efficiency, as observed in field operations where one worker manages up to 500 trees per day, enabling a team of five workers to handle 2500 trees daily. Similarly, resin production methods have been shown to directly influence yield and economic feasibility, as demonstrated by the BH method in Chir pine, which produced higher resin output compared to the traditional rill method, while also reducing mechanical damage (Meena and Akash 2023). Variations in tapping systems can further impact resin output, with more intensive systems yielding greater production (Freitas et al. 2023). Additionally, tapping methods that promote higher resin canal frequency, such as upward tapping in *Pinus pinaster*, have been found to enhance resin yield (Rodríguez-García et al. 2016). Together, these findings highlight the critical role of method selection in optimizing resin yield, improving economic feasibility, and ensuring sustainable forestry practices.

The economic advantage of the BS method is further highlighted by its lower operational costs. The BH method, while requiring specialized tools, causes greater mechanical damage to the tree, potentially reducing wood quality and increasing maintenance costs over time. Papadopoulos, (2013) demonstrated that even with the BS method, resin tapping in Aleppo pine led to a 14.1% reduction in tree-ring width, a 6% decrease in latewood proportion, and caused wood deformations and discoloration. Interestingly, Meena and Akash, (2023) reported that the BH method in Chir pine caused less mechanical damage compared to traditional rill methods, suggesting that the extent of mechanical impact may vary depending on the species and tapping context. However, this observation remains open to further discussion, as the differences in tree physiology, tapping intensity, and environmental conditions could influence the extent of damage caused by the BH method. These findings suggest that more invasive methods like BH, which involve deeper incisions and greater mechanical damage under certain conditions, could exacerbate such effects.

Environmental factors also play a significant role in the cost-effectiveness of resin production. Temperature and precipitation were identified as key predictors of resin yield for both methods. The BS method demonstrated a stronger dependency on these factors, with temperature explaining 77.13% of the variation in resin yield (Caglayan et al. 2024). Génova et al. (2014) highlighted that resin tapping in *Pinus pinaster*, despite causing long-term growth suppression, did not alter the overall growth-climate relationships. This suggests that resin-tapped trees remain valuable for understanding climatic influences on growth patterns. Similarly, resin tapping in Scots pine stimulated radial growth at breast height without affecting the trees' sensitivity to climatic conditions, even after several years of tapping (van der Maaten et al. 2017). In *Pinus tabulaeformis*, resin tapping caused minor changes in tree ring growth and slightly reduced carbon reserves, but it did not affect the trees' response to temperature and humidity (Zeng et al. 2021a). As observed in Caglayan et al. (2024), resin yields were highest during the warmer months, highlighting the importance of aligning tapping schedules with optimal environmental conditions to enhance operational profitability. Efficient scheduling during these

high-yield months can further enhance operational profitability while maintaining the ecological resilience of tapped trees.

The duration and intensity of tapping significantly impact economic outcomes by influencing resin yield and long-term tree health. Chen et al. (2015) found that resin tapping in older Masson pine trees (> 65 years) reduced growth, while younger trees (< 65 years) compensated more effectively. Similarly, Du et al. (2021) reported that moderate-intensity tapping in slash pine caused localized changes in carbohydrate reserves without significantly affecting wood growth, suggesting that careful management of tapping intensity can minimize economic losses. Long-term tapping, as observed in *Pinus pinaster* (30 years; Génova et al. 2014) and Scots pine (6 years; Magnuszewski and Tomusiak 2013), often suppresses growth, highlighting the need to balance resin yield with sustainability through strategic management.

Labor efficiency is a critical determinant of economic feasibility. In both methods, our assumption of 2500 trees managed daily by a team of five workers provides a realistic operational scale. However, the BS method's higher per-tree yield reduces the cost per kilogram of resin produced, making it the superior choice for large-scale operations. These findings are consistent with Williams et al. (2017), who reported no significant impacts on growth in young Masson pine trees subjected to short-term tapping, reinforcing the economic benefits of targeting younger, fast-growing stands. While the BS method clearly outperforms the BH method in terms of yield and cost-efficiency, its reduced mechanical damage, as highlighted by Zevgolis et al. (2022), helps preserve the long-term productivity of resin-tapped forests. These advantages make the BS method a promising option for balancing short-term profitability with long-term forest health.

The study's findings have significant implications for sustainable forestry practices. The BS method, with its higher resin yield and lower costs, presents a more sustainable and economically viable option for resin extraction from *Pinus brutia*. This method's lower environmental impact and reduced need for mechanical equipment align well with sustainable forestry objectives, promoting the conservation of forest resources while supporting local economies. Resin production alone has been shown to be profitable (Sandim et al. 2022); however, whether the combined

production of wood and resin is economically viable remains debatable, as resin extraction, while valuable, imposes physiological stress on trees, affecting growth rates, crown size, and diameter (Yousefi et al. 2020). Studies also suggest that mechanical damage from resin tapping may concentrate growth on the living parts of the tree (van der Maaten et al. 2017). It was concluded that the combined production is not economically advantageous (Sandim et al. 2022) due to the reduction in tree diameter during resin tapping (Zeng et al. 2021b). Thus, balanced management practices are crucial to sustain tree health and maximize both resin and wood yields. Wang et al. (2006) further emphasize that while the inclusion of resin benefits can extend the optimal rotation age, this advantage diminishes as site productivity increases, suggesting that the economic viability of combined wood and resin production may be more limited in highly productive sites.

The cost analysis revealed significant differences in the initial and recurring costs associated with each method. The BH method requires a substantial initial investment in equipment such as drills and generators, resulting in high fixed costs. In contrast, the BS method involves lower initial costs due to the minimal mechanical intervention required. Additionally, the recurring costs for consumables and labor are lower for the BS method, making it a more economically viable option in terms of operational expenses. However, despite these cost differences, it is essential to consider whether resin production is completed without damaging the commercial value of the tree wood for a sustainable economy. The Bark streak method causes damage to the bark and cambium, but has no adverse effect on the commercial value of the tree. In contrast, the Bore-hole method causes damage to the wood, which can negatively impact its commercial value.

However, on the current market conditions, both methods are infeasible. The BH Tapping method, despite its high initial investment, does not generate sufficient revenue to cover the monthly production costs, leading to a consistently negative cash flow. The BS method, while performing better financially, still results in a negative net present value due to the current low price of resin. The breakeven analysis indicates that the price for resin needs to reach \$1,775 per ton for the BS method to be feasible, a price point that has been observed historically but is

not guaranteed. In contrast, the BH Tapping method requires an unrealistically high breakeven price of \$10,710 per ton, rendering it impractical under current economic conditions.

The sensitivity analysis underscores the critical impact of prices on the feasibility of these methods. The BS method shows potential for profitability if resin prices increase to historical highs. Additionally, while changes in the number of trees used in production did not significantly affect the feasibility, reductions in labor costs could enhance the feasibility of the BS method. However, achieving the necessary labor cost reductions would require substantial changes to current wage structures, which may not be practical.

It is important to note that the resin yield measurements may contain intrinsic variability due to factors such as slight differences in tree physiology, and tapping skill among workers. While the study included 758 trees and extrapolated to a scenario of 2500 trees, larger sample sizes or multi-year data could further reduce uncertainties. Additionally, any variations in labor productivity, fluctuations in daily wage rates, or unexpected changes in tool performance (e.g., drill durability) were not fully captured in this study. Future research could incorporate these uncertainties into a more robust risk or stochastic analysis framework to enhance the reliability of the conclusions.

Based on the findings of this study, several recommendations can be made to improve the economic and environmental feasibility of resin tapping practices. First, efforts should focus on market development to stabilize and expand the demand for natural pine resin, potentially supported by policies promoting the benefits of natural products. Additionally, exploring cost reduction strategies, particularly in labor and consumables, could significantly enhance the financial viability of resin extraction methods. Technological advancements that combine the efficiency of mechanical methods with the gentleness of manual approaches, such as BS tapping, could further optimize yields while minimizing operational costs. Lastly, adopting sustainable resin extraction practices, like the BS method, is essential to ensure the long-term health and productivity of forest ecosystems, aligning resin production with broader sustainability objectives.

From a policy perspective, supporting resin production through incentives or subsidies could help

offset initial setup and operational costs, especially for small-scale producers. Additionally, developing quality standards and traceability systems for natural pine resin may bolster market confidence, potentially stabilizing prices. Integrating resin tapping into broader forest management plans, such as agroforestry or multiple-use forestry schemes, could enhance local livelihoods while maintaining ecological sustainability. Collaboration with local cooperatives, government bodies, and private investors might foster innovations in tapping technology and stimulate the development of value-added resin products.

Conclusion

This study provides a comprehensive analysis of the BH Tapping and BS methods for resin extraction from *Pinus brutia* in the Korudağ Forest, Edirne, Türkiye. The key findings highlight significant differences in resin yield, cost structure, and financial feasibility between the two methods. The BS method demonstrated a substantially higher resin yield per tree compared to the BH method (610 g vs. 210 g per tree per season), showcasing its superior efficiency in resin extraction. Additionally, the BS method incurred lower initial investment and operational costs, making it a more economically attractive option under certain conditions. However, the financial feasibility analysis revealed that under current prices for resin, neither method is economically viable. The BH method, with its high initial and recurring costs, requires an unrealistically high breakeven price, making it impractical. On the other hand, the BS method, while more cost-effective, still falls short of covering production costs unless prices for resin rise significantly to historical highs. The sensitivity analysis further emphasized the critical role of prices in determining the feasibility of these methods. It also highlighted the potential for the BS method to become viable with modest increases in resin prices and reductions in labor costs.

Efforts should be directed towards stabilizing and developing the market for natural pine resin, including policy interventions and promoting the advantages of natural resin over synthetic alternatives. Research into cost reduction strategies, particularly focusing on labor and consumables, could enhance the economic viability of resin extraction. Innovations in extraction technologies that blend the efficiency of

mechanical methods with the sustainability of manual techniques could improve yields and reduce costs. Emphasizing sustainable extraction methods like BS aligns with long-term forestry management goals and supports environmental conservation.

In conclusion, while the current economic conditions do not favor the immediate feasibility of resin production using either method, the BS method holds potential for future viability. Continuous market monitoring, cost optimization, and technological advancements are essential to realizing the full potential of resin extraction from *Pinus brutia*, contributing to sustainable forestry and economic development in the region.

Author contributions İC: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing—Original Draft, Writing—Review & Editing, Visualization, Project administration. ÖK: Formal analysis, Investigation, Data curation, Writing—Review & Editing. İÜS: Validation, Data curation, Supervision, Writing—Review & Editing.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request. No datasets were generated or analysed during the current study.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: İC reports financial support from The Scientific and Technological Research Council of Türkiye. Other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare no competing interests.

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After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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