resinae

december **2024**

"(...) It is necessary to create conditions to increase the value of forest products and by-products."
Nuno Canada

The Potential of Rosin for the Bioeconomy as a Natural and Renewable Raw Material
Firmino Rocha

Biopolymers and Resins: Sustainable Innovation in Adhesive Formulation
KEMI - Pine Rosins

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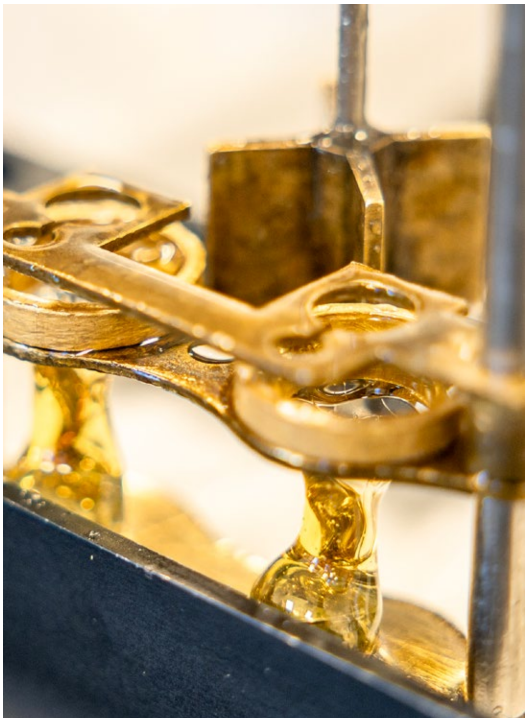

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Address
Quinta de Prados, Campus da UTAD
5001-801 Vila Real, Portugal

Contacts
geral@rn21.pt

Print Run
750 copies

Frequency
Biannual

ISSN
2975-9595

The RN21 Integrated Project - Innovation in the Natural Resin Sector for the Reinforcement of the National Bioeconomy, is co-financed by the Environmental Fund through Component 12 - Promotion of Sustainable Bioeconomy (Investment TC-C12-i01 - Sustainable Bioeconomy No. 02 / C12-i01 / 202), European funds allocated to Portugal by the Recovery and Resilience Plan (PRR), under the European Union's (EU) Recovery and Resilience Mechanism (MRR), framed within the Next Generation EU, for the period from 2021 to 2026.

Bioeconomia FUNDO AMBIENTAL PRR Plano de Recuperação e Resiliência REPÚBLICA PORTUGUESA Financiado pela União Europeia NextGenerationEU

EDITORIAL

In the fourth edition of Resinae magazine, we explore the Natural Resin sector's ongoing commitment to the Bioeconomy, focused on innovation and optimization across its value chain. At a time when environmental issues and sustainable development are key priorities, Natural Resin emerges as a vital resource for a greener economy, contributing to the ecological transition of Portugal and Europe.

Natural Resin represents one of the few sectors that combines responsible forestry practices with the supply of natural, biobased, and multifunctional raw materials. Resin is essential in various industries – from pharmaceuticals to cosmetics, automotive to paints and varnishes, among many others. This versatile nature of Natural Resin drives global demand and positions it as a sustainable alternative to fossil-based derivatives. Optimizing the value chain is therefore crucial to ensuring that Portugal increases its production and transformation potential for maritime pine resin, aligned with sustainability commitments.

The sector's growth and value enhancement depend on a value chain that acknowledges each stage: from sustainable resin tapping to innovative treatment and transformation, all the way to the market. Implementing practices that promote natural regeneration and efficient management of maritime pine stands is essential to secure the continuous availability of this biological product. This value chain also extends to the development of new applications that support the circular economy, with biopolymers and a growing range of products and markets.

Supporting certification and establishing quality standards also strengthens the competitiveness of Portuguese resin, boosting market confidence and enabling entry into new sectors that value product traceability and sustainability. In this context, the RN21 Consortium plays an essential role investing in research, technological development, and applied innovation.

Carlos Fonseca
CTO CoLAB ForestWISE

This edition of Resinae highlights advancements, challenges, and strategies for a more competitive, sustainable, and highly valued Natural Resin. The commitment to Bioeconomy is not merely an ideal but a reality in progress, positioning the sector as a key ally in environmental preservation, the green economy, improving the living conditions of those connected to the pine forest, and enhancing the value of Rural Communities.

“THE SECOND TRANSFORMATION OF TURPENTINE SUPPORTS THE DEVELOPMENT OF BIOECONOMY, THROUGH THE SUSTAINABLE USE OF BIOLOGICAL RESOURCES, MATERIALS, AND PRODUCTS.”

Pedro Gil is the Executive Administrator of Gum Rosin, where he works in product research and development. With a background in chemistry, he is involved in implementing industrial processes and manufacturing systems within the pine resin sector.

GUM Rosin – Project managment and R&D, S.A is a start-up founded in 2021, located in Cantanhede, and operating within the chemical manufacturing sector. Gum Rosin's activity is focused on the production, research, and development of terpene resins. Its project within the scope of RN21 involves the construction of a production facility by the end of 2025, with aim to start the production and commercialization of terpene resins in 2026.

What are the main products manufactured by Gum Rosin, and what are their most common applications?

Gum Rosin's activity is focused on the production, research, and development of terpene resins. The current focus is on using monomers derived from pine resin, such as alpha-pinene and beta-pinene, which come from the fractional distillation of turpentine.

Sustainability is a growing concern in the industry. What practices has Gum Rosin adopted to ensure sustainable production?

Sustainability is a crucial issue in the activities of Gum Rosin, making it imperative to adopt practices that ensure long-term sustainability. Gum Rosin aligns with the sector's best practices, including:

1. Energy Efficiency:
- Seek renewable energies and replace fossil fuels with renewable sources.
- Process optimization: Implement technologies and processes that reduce energy consumption.
- Monitoring: Implement systems to monitor energy use and consumption, identifying waste and improving efficiency.

2. Reduced Emissions:
- CO_2 emissions control: Reduce greenhouse gas emissions by adopting cleaner technologies.
- Replace non-renewable products: Introduce renewable products to the market as substitutes for equivalent fossil-based products.

3. Waste Management:
- Circular economy: Implement waste management models that encourage reuse in the production process.
- Recycling: Promote the recycling of materials and the reuse of resources, minimizing landfill waste.

4. Responsible Use of Natural Resources:
- Sustainable water management: Reduce water usage and implement systems for water treatment and reuse. Monitoring: Implement systems to monitor water usage and consumption to identify waste and improve efficiency.

5. Development of Sustainable Products:
- Material innovation: Seek sustainable alternatives such as naturally derived polymers (polyterpene resins), ensuring an improved ecological footprint.

6. Encouraging Innovation:
- R&D in green technologies: Invest in research and development of technological solutions that can reduce environmental impact and optimize resources.
- Partnerships and collaborations: Collaborate with other companies to develop new technologies and more sustainable practices.

How does Gum Rosin contribute to the Integrated RN21 Project?

Gum Rosin enhances the RN21 Consortium's reach by extending the field of activity for natural resins derived from pine trees through tapping. While Portugal has a strong tradition in resin tapping and turpentine production, the transformation of turpentine has never achieved significant commercial scale. Gum Rosin's project within RN21 aims to change this by adding value to turpentine through the production of terpene resins derived from it. Gum Rosin's activity will be based on synergies between existing companies in the natural resin market, producing an innovative product in Portugal and contributing to the sector's competitiveness.

How can the second transformation of turpentine contribute to a more sustainable value chain and bioeconomy?

The transformation of turpentine into higher value-added products promotes reduced environmental impact compared to equivalent petroleum-derived products. This includes reducing greenhouse gas emissions and lower energy consumption.
Turpentine-derived products tend to be more biodegradable than their petrochemical counterparts, helping reduce pollution and protect ecosystems and biodiversity.
The second transformation of turpentine supports the development of Bioeconomy, through the sustainable use of biological resources, materials, and products. Using resins and resin derivatives from sustainably managed forests strengthens rural economies, creating economic opportunities in forestry, agriculture, and the green chemical industry.

Biopolymer production is an emerging and crucial area for sustainability. What are the main applications of the biopolymers under development by Gum Rosin within RN21?

Polyterpene resins have excellent adhesive and tack properties, and they are widely used in various sectors such as adhesives, paints, coatings, sealants, rubber, and chewing gum.

What are the environmental advantages of the biopolymers developed by Gum Rosin compared to conventional plastics?

Biopolymers, particularly polyterpene resins, offer several environmental advantages compared to conventional plastics, which are derived from fossil fuels and non-renewable sources. These advantages include replacing fossil-based products, contributing to biodegradability, reducing environmental impact, decreasing toxicity for human health, and fostering the bioeconomy.

With the increasing demand for natural and sustainable products, how will Gum Rosin respond to future market needs?

The growing demand for natural and sustainable products is driving a greater market demand for biopolymers, positioning Gum Rosin as a key player in filling this current market gap.

What are Gum Rosin's expectations regarding the results of the Integrated Project RN21, and how can they impact the company and the industry as a whole?

The Integrated Project RN21 has enabled collaboration between companies in the same sector, generating synergies, innovation, and business expansion in the pine chemicals industry. This collaboration has fostered innovation, increased competitiveness, and created new business opportunities. This new paradigm in the bioeconomy sector has allowed a company focused on innovation and sustainability, such as Gum Rosin, to establish itself in the market, enriching the value chain of this sector.

Pedro Gil
Executive Administrator of Gum Rosin

Turpentine-derived products tend to be more biodegradable than their petrochemical counterparts, helping reduce pollution and protect ecosystems and biodiversity.

NUNO CANADA | INTERVIEW

“(...) IT IS NECESSARY TO CREATE CONDITIONS TO INCREASE THE VALUE OF FOREST PRODUCTS AND BY-PRODUCTS.”

Nuno Canada is the President of the Board of Directors of the National Institute for Agricultural and Veterinary Research (INIAV) since 2013 and a Member of the Board of Directors of the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) in Paris since 2013. He is also Associate Professor at the Abel Salazar Biomedical Sciences Institute of the University of Porto since 1999.

INIAV plays a crucial role in agricultural and veterinary research in Portugal. What are INIAV's main research areas in the forestry sector?

INIAV has a wide range of activities, although it is primarily focused on agriculture, food, forestry and biodiversity, and territorial development, particularly in rural areas.

In the forestry sector, it engages in activities across the entire value chain, particularly in areas such as the environment and natural resources, forest production, industry, and related sectors. Forest health, genetic improvement, and the introduction of new tools and solutions into the value chain are also key concerns for our research teams.

We emphasize an integrated, systemic approach, aiming to connect forestry to the territory, to mixed systems of livestock, forestry, and agriculture, including dimensions such as beekeeping, wild resources, and the promotion of biodiversity.

How is INIAV contributing to the development of the forestry sector, particularly in the area of natural resin?

INIAV has been involved in various studies and trials for resin production from living trees, typically maritime pine, but also, to a lesser extent, stone pine, depending on various production factors, such as the timing and duration of the resin tapping season and the use of different chemical stimulants for resin extraction. Several attempts have also been made to mechanize resin extraction, which is traditionally done using very rudimentary methods, aiming to reduce the high labor costs associated with resin tapping operations.

It's worth noting INIAV's participation in the most important European research projects on this topic, which we'll discuss further on. This involvement highlights INIAV's interest and capacity for intervention in this area.

What is INIAV's role in the RN21 Integrated Project?

Organized resin production in Portugal began in the 19th century in the Leiria National Forest and later expanded to maritime pine stands and communal lands in the Central and Northern regions of the country. In the 1930s, the National Resin Board was established, which later merged into the Forest Products Institute (IPF) in the 1970s. At that time, Portugal was the third-largest producer of resin worldwide. With Portugal's entry into the European Economic Community (EEC), the National Resin Board was dissolved, transferring the IPF's technical and laboratory expertise to INIA, now the National Institute of Agrarian and Veterinary Research (INIAV), strengthening the know-how of its National Forest

Nuno Canada
Chairman of the Board of Directors of INIAV

In the forestry sector, INIAV activities span the entire value chain, particularly in the areas of environment and natural resources, forest production, industry, and related fields. Forest health, genetic improvement, and the introduction of new tools and solutions within the value chain are key concerns for our research teams.

Station (EFN). Portugal's entry into the EEC, now the EU, triggered various factors contributing to the decline of this sector, particularly competition from lower-priced resins from other regions (China and Brazil), making it difficult for Portugal to compete on cost. However, the primary and secondary processing industries adapted to the new landscape, allowing them to remain internationally recognized and competitive.

This Project (RN21), supported by the RN21 Consortium - Innovation in the Natural Resin Sector to Strengthen the National Bioeconomy, brings together the entire sector, promoting research and innovation to increase the value of national Natural Resin as a "bio" product. INIAV contributes its accumulated expertise to this sector through its participation in RN21 Pillar I - "Promoting the production of national Natural Resin" - with a special focus on the maritime pine genetic improvement program for resin production, benchmarking other resin-producing pines, and R&D&I in resin tapping techniques and collection containers, all of which are essential to the upstream success of this sector.

In this Project, INIAV is responsible for the project "Genetic improvement program for maritime pine specifically for resin production," which is part of Pillar I, "Strengthening the productive capacity of pine forests," Measure M1.

INIAV also collaborates on two other consortium projects: "I1M2: Benchmarking other resin-producing Pinus species" within Pillar I, Measure M2, led by ISA, and "I2.M2: R&D in resin tapping techniques and collection containers" within Pillar I Initiative 2, "Increasing resin productivity," Measure M2, led by UTAD.

How can genetic improvement increase natural resin production?

The genetic improvement program developed by INIAV to boost resin production potential focuses on the genetic selection of trees with superior resin yields. The program's main goals are: 1) identifying genetically superior trees through an innovative method called massal genotypic selection; 2) establishing three clonal orchards to produce genetically improved maritime pine (*Pinus pinaster* Ait.) reproductive material (seeds and scions) specifically for resin production; 3) creating an SNP (Single-nucleotide polymorphism) platform for marker-assisted selection to enhance resin production.

What is the potential of genetic improvement for Portugal's maritime pine forests?

Recent genetic trials, led by INIAV under the PDR2020 Program Operation 7.8.5, indicated significant variability with strong genetic control. Through the PDR2020-785-063762 project, "Maritime pine (Pinus pinaster Aiton): conservation and improvement of genetic resources," two clonal resin extraction trials were established using grafted trees aged between 40 and 45 years. Resin production of each clone was monitored over two years. The results showed high values for broad-sense heritability (H^2) for resin production, ranging between 0.72 and 0.88. This strong genetic component, along with the detection of genetic variability, creates the necessary and sufficient conditions for the success of a genetic improvement program targeting this trait.

How does INIAV collaborate with other research institutions and industry to strengthen the resilience of Portuguese forests and improve resin production?

INIAV has participated in several international European projects with research institutions from various countries (primarily Spain and France) to revive the resin sector in Europe, which currently has a significant deficit in resin products.
Several primary processing industries, as well as more recently resin derivatives and resin tapper associations, have been active partners in these projects, as it is impossible to develop or maintain the sector at meaningful activity levels without their involvement. Examples include projects aimed at modernizing resin extraction and collection techniques and technologies, such as the Eureka Eurogem project, and more recently, the Interreg Sudoe - SUSTFOREST PLUS Project, which took an integrated approach to the entire resin value chain, identifying bottlenecks and proposing innovative solutions. The results are available on the project's website.

In addition to the economic value it generates, resin tapping ensures a stronger human presence in forests than any other productive activity, particularly during the period when forests are most vulnerable to fires. Resin tappers serve as agents of prevention, early detection, and first response to forest fires. Preparing forest stands for resin extraction also involves creating forest paths where none exist and reducing fuel material in the understory, allowing access to the trees.

How does INIAV plan to continue contributing to the national bioeconomy and the sustainability of the forestry sector?

INIAV shares the principle of reducing dependency on petroleum-derived products and aligns itself with the commitment of the European Chemical Industry to prioritize the development of stable sources of forest-based raw materials, preferably sourced within Europe.
In this regard, its involvement in RN21 is grounded in contributing to the objectives of the Recovery and Resilience Plan (PRR), specifically Component C12 – Sustainable Bioeconomy, and in coordination with other components, notably C8 – Forests and C5 – Capitalization and Business Innovation, which is one of the guiding principles of the Consortium.
This principle is based on a set of objectives aimed at supporting the national bioeconomy and sustainability of the forestry sector by enhancing economic resilience and promoting a sustainable bioeconomy. INIAV supports and will continue to support forestry sector companies in diversifying their portfolio of bio-based, high-added-value products and in potentially improving and modernizing production processes through the incorporation of new technologies, promotion of decarbonization, and adoption of Circular Economy principles.

Consequently, INIAV is committed to contributing to carbon neutrality and making Portuguese forests more productive and resilient, thereby enhancing their carbon sink capacity through improved plant material that increases the production of high-quality forest products. Furthermore, achieving this requires not overlooking the territorial cohesion of the sector's business fabric by boosting the competitiveness of companies, creating qualified employment, and strengthening science and technology connections through R&D&I activities in partnerships with companies in the sector.

What are the main challenges in the transition to a sustainable bioeconomy?

In the transition to a sustainable bioeconomy, it is necessary to create conditions to increase the value of forest products and by-products, enabling a wider range of market applications. This goal also involves promoting modernization, innovation, and enhancement of the existing knowledge within the National Scientific and Technological System (SCTN), of which INIAV is a part, across all forestry value chains. We must not forget the United Nations Sustainable Development Goals (SDGs) for 2030, as the transition to a more sustainable economy should respond to these goals. Offering numerous opportunities to revitalize more traditional sectors of the Portuguese economy, grounded in the use of renewable natural resources. Moreover, various strategic documents already recognize the importance of forests and their value chains for a low-carbon, resilient economy, leveraging R&D&I with companies in this sector. The goal is to create high-value-added forest products and services that generate income for forest owners, contribute to job creation, and support local businesses.

"The genetic improvement program defined by INIAV to help increase the production potential of Natural Resin will focus on the genetic selection of superior trees for resin yield."

FIRMINO ROCHA | OPINION

THE POTENTIAL OF ROSIN FOR THE BIOECONOMY AS A NATURAL AND RENEWABLE RAW MATERIAL

The transition to a more sustainable economy based on renewable natural resources is a growing global priority. The bioeconomy, which relies on short-cycle biological, renewable resources to replace fossil-based materials and fuels, has gained significant attention. In this context, rosin, a Natural Resin extracted from commercially planted forests for resin production, emerges as a promising raw material whose economic and environmental benefits remain underexplored.

Rosin, also known as colophony, has been used for centuries in the production of base raw materials for industries such as varnishes, adhesives, paints, cosmetics, pharmaceuticals, food products, rubber, paper, construction, and other technical applications. However, in recent years, its versatility as a renewable raw material has gained new prominence due to the increasing demand for sustainable alternatives to fossil-based products.

Rosin is extracted from the exudation of pines from the Pinus genus, such as the maritime pine (*Pinus pinaster* Ait.), *Pinus elliottii* Engelm., *Pinus Massoniana* Lamb., and *Pinus Caribaea* Morelet, among many other species abundant worldwide. Traditionally, Portugal is in a favorable position to produce high-quality rosin. In addition to its use in the varnish, paint, and adhesive industries, this natural compound has been studied to produce biodegradable polymers, aiming to replace conventional fossil-based polymers and even to create biofuels. Its ability to be transformed and adapted for different purposes without the negative environmental impacts associated with petrochemical materials is one of its key advantages.

Planting and maintaining pine forests for rosin production can be done sustainably, allowing for continuous tree regeneration while contributing to carbon sequestration. Unlike fossil-based products,

rosin does not add more carbon to the cycle; on the contrary, it has a negative carbon footprint, helping to mitigate climate change.
Moreover, resin extraction can coexist with other forest management practices, such as timber or paper production and livestock farming, creating a circular bioeconomy where the forest's value is maximized sustainably. This cycle of renewability not only promotes forest protection but also generates new jobs and economic opportunities in rural areas, which are often affected by depopulation.

Despite rosin's great potential, there are still challenges to its large-scale implementation in the bioeconomy. One of the main obstacles is competition from cheaper fossil-based products, which continue to dominate the market due to their mass production and low cost. However, as environmental awareness grows and global regulations push for greener solutions, rosin could become an economically viable alternative, especially if there is investment in technological innovation and governmental incentives to support its use.

Firmino Rocha
Administrator of KEMI - Pine Rosins

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"Rosin's ability to be transformed and adapted for different purposes without the negative environmental impacts associated with petrochemical materials is one of its key advantages."


© CoLAB ForestWISE

Furthermore, the rosin industry can benefit from ongoing research into new applications and more efficient extraction processes. The development of techniques that improve the quality of the product and its use in new sectors, such as cosmetics or biomaterials, can enhance its competitiveness in the global market.
Rosin represents an excellent example of how nature offers renewable and sustainable solutions to the challenges of the modern economy. With the growth of the bioeconomy and the demand for alternatives to fossil-based products, rosin can play a central role in creating a greener, more circular, and sustainable economy. However, a firm commitment is needed from governments, industry, and academia to invest in research, technology, and policies that encourage the use of this natural raw material, placing rosin at the heart of the bioeconomic revolution.
Portugal, with its vast pine forests and long tradition in resin extraction, is in a privileged position to lead this movement. The remaining question is: Are we ready to harness all the potential that rosin has to offer?

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DUARTE MARQUES | OPINION

ARE THERE FOREST MANAGEMENT MODELS THAT TAKE ADVANTAGE OF RESIN TAPPING TO ENHANCE THE VALUE OF PINE FORESTS IN PORTUGAL?

Maritime pine (*Pinus pinaster* Ait.) is a native species with a significant presence in the landscape, deeply embedded in our history and part of Portugal's natural heritage. However, this alone is not enough to ensure its importance and continuity in the future!

The inadequate management and lack of appreciation for maritime pine stands are the main reasons for their severe degradation and disappearance, primarily due to wildfires. It is essential to value maritime pine and its entire sector, which can only be achieved through active forest management of these stands. However, this requires adequate resource allocation. In addition to public funding programs, which still need significant improvements in terms of allocation, predictability, approval, and timely payments, we must also focus on the sustainable exploitation of resources. We believe that resin plays a crucial role in the economic, social, and environmental sustainability of this species in Portugal.

Let’s take a look:

(1) In Portugal, there are areas with pine stands large enough to implement sustainable management actions, with trees already at diameters suitable for resin tapping, as well as the production of other non-wood forest products. These areas currently see little to no management actions beyond timber exploitation, but the owners or managers are open to the introduction of new models of value creation, protection, and management.

(2) It is widely known that timber production from maritime pine only yields returns in the medium to long term, requiring investments with deferred returns. Conversely, the exploitation of non-wood forest products, such as resin, provides short-term income, creating financial flows that motivate and facilitate investment. In areas where resin tapping has been in place for several years, there are numerous examples where resin generates annual revenues that can vary between €150 and €400/ha/year. Therefore, resin tapping can significantly contribute to increasing the value of forest areas and funding management activities.

Duarte Marques
President of Aguiarfloresta

(3) Additionally, there are still resin tapping companies interested in investing in this activity and in linking and complementing their work with other actions that enhance profitability and protect the areas where they operate. These companies, mainly due to a lack of skilled labor (resin tappers), also seek greater stability in their teams, not limited to just the resin tapping season, and are increasingly willing to contribute to the management of these areas.

(4) There are still residents in villages where the primary occupation of the surrounding land is forestry, mainly maritime pine, who are unemployed and whose chances of employment are low, often requiring relocation. Resin tapping creates one job position per 20 to 50 hectares (on average) of pine forest, making it the forestry activity most dependent on and intensive in labor.

(5) Technological advancements related to resin extraction are beginning to be implemented, and their adoption will have a disruptive effect on the value of resin tapping and, consequently, on the value of pine forests. The transition to closed extraction systems, using a closed bag or pot, will enable mechanization in certain phases of the process, eliminating previously unproductive steps. This transition also increases the value of the extracted raw material by preserving volatile components and producing a final product without impurities, factors highly valued by the primary processing industry.

(6) There are some support programs for the resin sector, including the RN21 Integrated Project – Innovation in the Natural Resin Sector to Strengthen the National Bioeconomy – which must be effectively implemented to modernize and boost this sector.

This unique opportunity for the Natural Resin sector cannot be missed!

Given this reality, we have few options left on the path forward!

We need to collaborate with stakeholders—including forest owners and managers, forestry and resin tapping companies, forest producers' organizations, local communities, and other genuinely interested entities—to develop and implement integrated value creation models for pine forests focused on resin tapping. These models should blend the management and utilization of timber resources with the sustainable harvesting of non-wood forest products, especially resin. Resin tapping is a labor-intensive activity that offers ongoing opportunities and generates short- to medium-term economic returns. Additionally, we should explore other products and services for owners, managers, and local communities. This approach could be the last opportunity to enhance the value of maritime pine stands, ensuring their active management, creating jobs, and promoting rural development.

Such models of integrated value creation for pine forests with a focus on resin tapping certainly promote the value and diversification of forest resources and the sustainability of active management. They reduce the minimum management unit size necessary to make forestry activities viable by diversifying and increasing income sources. Most importantly, they reduce the exposure of pine forests to fire risk, replacing non-productive investments in protection with increased efficiency in forest management and exploitation.

To improve the viability of this type of integrated model, it is important to allocate or contract silviculture, fuel management, and other resource exploitation activities to resin tapping businesses and their teams. This would offer the opportunity to employ these human resources permanently, eliminating the seasonality of employment and progressively turning them into full-time forest workers.

The development of these forest activities and the associated job creation also improves the perception of the forest’s importance and its protection by local communities and entities.

Resin tapping and the exploitation of other non-wood forest products, through payments for tree leases, resin tappers' wages, and product sales, contribute to increased financial flows at the local and regional levels. The development of these forest activities and the associated job creation also improves the perception of the forest's importance and its protection by local communities and entities.

Resin tappers and other forestry workers, with their knowledge of these areas, equipped with appropriate materials, tools, and training, and properly integrated into municipal wildfire management systems, can clearly contribute to preventive actions, fire surveillance, and detection – as part of their productive activities – and assist in first-response firefighting and post-fire surveillance.

Resin tapping can no longer be carried out as an isolated activity without integration into the value creation of other forest products, forest management, or the protection of pine stands. This leads to seasonal employment interruptions and the underutilization of the presence and knowledge of resin tappers.

Implementing models of integrated value creation for pine forests, focusing on resin tapping in combination with the exploitation of other non-wood forest products, can reduce by half the area of pine forest necessary to ensure financial sustainability compared to relying solely on timber production. The integration and coordination of various activities can maximize stable, long-term job creation, supply sustainable raw materials to the market, contribute to the value and protection of forests and territories, and significantly aid in Portugal's environmental commitments.

Resin tapping can no longer be carried out as an isolated activity without integration into the value creation of other forest products, forest management, or the protection of pine stands. This leads to seasonal employment interruptions and the underutilization of the presence and knowledge of resin tappers.

Don't believe it's possible or viable to implement this model?
Yes, it is possible!
Want to see how?
Come visit us in Tresminas, where this model has been implemented since 2012, employing 8 people permanently and actively managing 200 hectares of pine forest.
We look forward to seeing you!

INSTITUTO SUPERIOR DE AGRONOMIA

HOW MUCH RESIN DO THE PINE SPECIES EXISTING IN MAINLAND PORTUGAL PRODUCE? THE IMPORTANCE OF A NETWORK OF PERMANENT PLOTS

Maritime pine (*Pinus pinaster* Ait.) is the resinous species that occupies the largest forested area in mainland Portugal, with a higher concentration in the northern and central regions. Its primary use is for timber, but in the past, particularly in specific geographic regions, resin extraction was a complementary activity that provided an annual income for landowners. In the 1970s, Portugal was one of the largest producers of resin in the world, with 170,000 tons annually. After a less favorable period for the Natural Resin sector, due to factors such as competition from countries like China and Brazil, conditions have now been created for the revival of this activity. Today, the demand for replacing fossil fuels with bio-based alternatives is a societal requirement and presents an opportunity for the development of new products, including those derived from Natural Resin.

Understanding the potential of national Natural Resin production is crucial for the primary processing industry to develop strategies that reduce dependence on production from other countries. Climate projections for Portugal foresee increases in temperature, reduced precipitation, and changes in the annual rainfall pattern, as well as an increase in the occurrence of extreme events such as heatwaves and storms. One consequence will be the shifting of the locations of forest species in Portugal, generally leading to a reduction in their range. Since national Natural Resin production is largely focused on maritime pine, it is justified to quantify the resin yield of other *Pinus* species present in the country.

Although all species of the *Pinus* genus have the capacity to exude resin, only a few are commercially tapped for this product. In the Iberian Peninsula, there are records of resin production for species such as *Pinus pinaster* Ait. (maritime pine), *P. pinea* L. (stone pine), *P. halepensis* Miller (Aleppo pine), *P. sylvestris* L. (Scots pine), *P. nigra* J.F. Arnold (black pine), and *P. radiata* D.Don (radiata pine). Therefore, as part of the RN21 Integrated Project, a network of permanent resin tapping plots was established to assess the suitability of this practice for *Pinus* species present in mainland Portugal. The species were selected based on their ecological optimums, specific characteristics, and the area they currently occupy in the national territory (Figure 1).

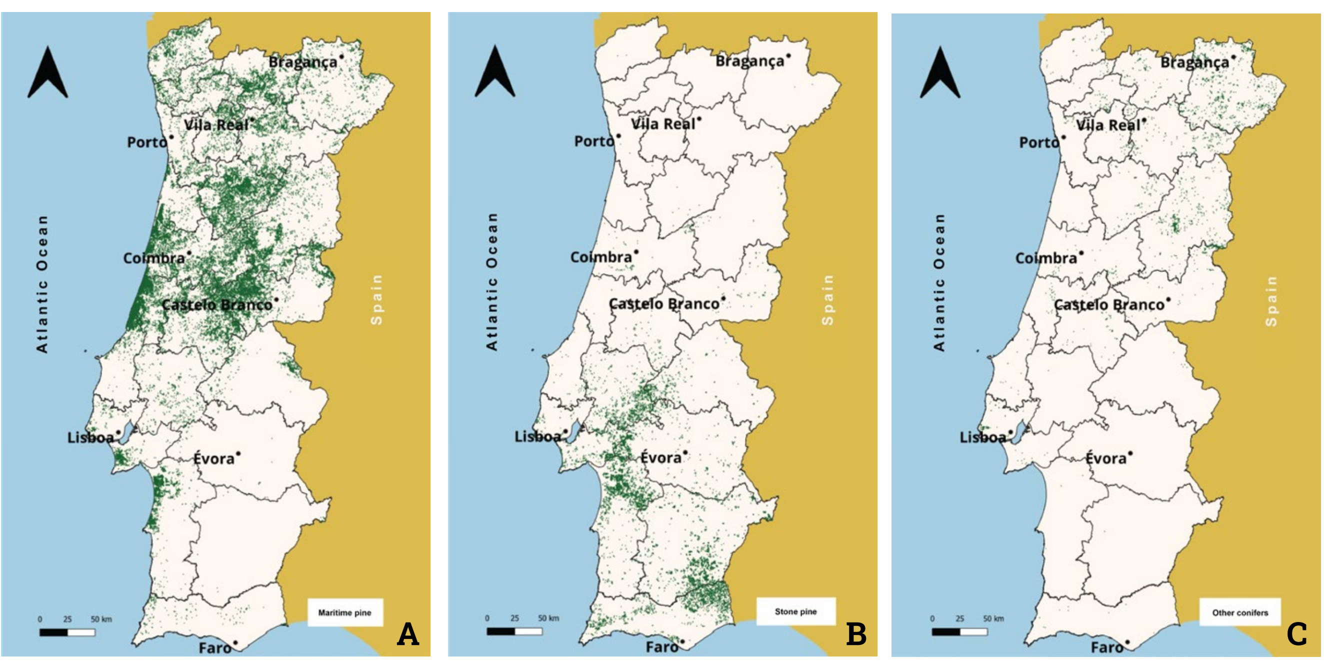

Figure 1 – Identification and location of *Pinus* species in the plots of the 6th National Forest Inventory (IFN6) (ICNF); A – maritime pine; B – Stone pine; C – Other conifers.

The permanent plots were established at the beginning of the resin tapping campaigns in 2023 and 2024, in stands that met the following conditions (Figures 2, 3, and 4): pure stands of the selected species (maritime pine, Stone pine, Aleppo pine, Scots pine, black pine, and radiata pine), stands to be tapped for the first time using the life resin tapping method, tree diameter complying with legislation (Decree Law No. 181/2015, August 18), good accessibility, and easy movement within the stands. A protocol for plot installation and resin tapping was also defined. To ensure that production was not influenced by the number of wounds per tree — which depends on tree diameter — it was decided to make a single incision per tree, on the south-facing side, with the number of renewals dependent on the start and end dates of the campaigns, which varied with location and resin tapping worker. The average renewal period was 21 days. Resin tapping was conducted using an open bag stapled to the tree and traditional paste. Before resin tapping installation, all tree variables — diameter at 1.30 m height, total height, and height of the canopy base — were measured to characterize the plots (Table 1). Each tree was sequentially numbered with aluminum tags attached at the base of the tree.

As shown in Table 1 (N and N>20), all stands had trees with diameters below 20 cm, which did not allow for resin tapping on these trees. Resin production was weighted at midway and at the end of the campaigns using a digital dynamometer. Resin production was recorded at the tree level, and the values presented in Table 1 are the sum of the two weighings, after deducting the bag weights.

Figure 5 shows the resin production for the plots installed during the 2023 campaign and the first weighing of the 2024 campaign in those same plots, as the 2024 campaign has not yet concluded.

2023 Campaign

- Municipality of Vila Pouca de Aguiar, parish of Tresminas, Common land of Covas, maritime pine;
- Municipality of Vila Pouca de Aguiar, parish of Bornes de Aguiar, Common land of Pinhal de Baixo, black pine;
- Municipality of Vila Pouca de Aguiar, parish of Tresminas, Common land of Aldeia de Revel, Scots pine;
- Municipality of Oleiros, parish of Isna, Village of Isna, maritime pine;
- Municipality of Moura, parish of Amareleja, private property, stone pine.

2024 Campaign

- Municipality of Alcobaça, parish of Pataias, private property, maritime pine;
- Municipality of Arcos de Valdevez, parish of Soajo, Common land of Soajo, maritime pine;
- Municipality of Vila Nova de Cerveira, parish of Covas, Common land of Covas, maritime pine;
- Municipality of Alenquer, parish of Ota, Forest Perimeter of the Serra de Ota, Aleppo pine;
- Municipality of Oleiros, parish of Oleiros-Amieira, private property, radiata pine.

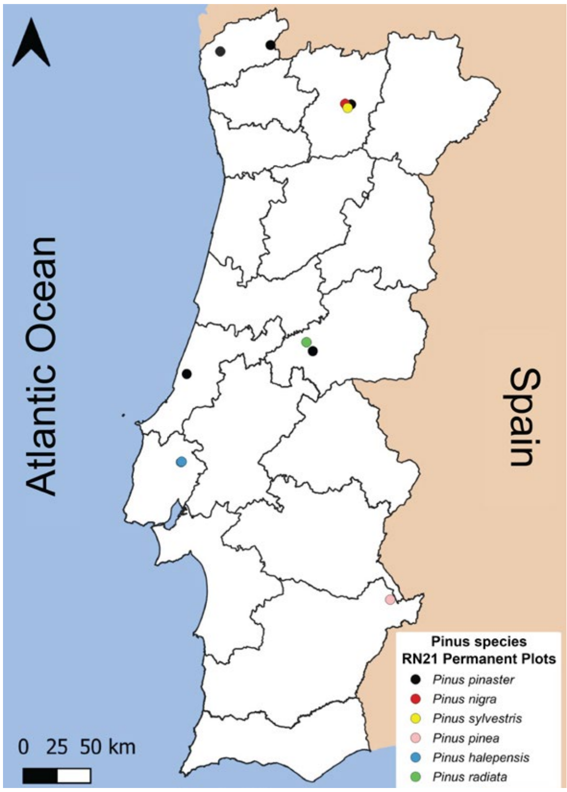

Figure 2 – Location of permanent plots established in the 2023 and 2024 campaigns, forming the resin tapping plot network.

Figure 3 – 2023 Campaign: plots in Vila Pouca de Aguiar – maritime pine, black pine, and Scots pine.

Figure 4 – 2024 Campaign: plots in Oleiros and Ota – radiata pine and Aleppo pine.

Table 1 – Characterization of permanent resin tapping plots that make up the plot network established under the RN21 Integrated Project, at the time of installation.

VPA, Vila Pouca de Aguiar; AV, Arcos de Valdevez; VNC, Vila Nova de Cerveira; Pb, Maritime pine (*Pinus pinaster*); Pl, black pine (*Pinus nigra*); Ps, Scots pine (*Pinus sylvestris*); Pm, Stone pine (*Pinus pinea*); Pa, Aleppo pine (*Pinus halepensis*); Pi, Radiata pine (*Pinus radiata*); hdom, dominant height; N, number of trees per hectare; N>20, number of trees with a diameter greater than 20 cm per hectare; G, basal area; dg, quadratic mean diameter.

Plot	Name	Area (m^2)	Year of Instalation	hdom (m)	N (ha^{-1})	N>20 (ha^{-1})	G (m^2/ha)	dg (cm)
1	VPA-Pb	1089	2023	13.1	882	496	33.2	21.5
2	VPA-Pl	987	2023	25.7	952	750	62.1	28.8
3	VPA-Ps	1190	2023	18.0	454	345	27.4	27.7
4	Oleiros-Pb	1190	2023	17.6	689	487	40.2	27.3
5	Amareleja-Pm	1728	2023	6.9	324	220	9.7	19.6
6	Alcobaça-Pb	745	2024	14.1	537	510	41.2	31.3
7	AV-Pb	852	2024	15.1	610	-	47.0	31.3
8	VNC-Pb	601	2024	14.3	1632	566	51.8	20.1
9	Alenquer-Pa	1125	2024	13.2	356	213	14.3	22.7
10	Alenquer-Pa	1004	2024	15.6	309	259	16.6	26.2
11	Oleiros-Pi	917	2024	23.6	600	480	29.7	25.1

The resin production values obtained across different plots and species are not directly comparable since resin yield depends on various factors. These include the edaphoclimatic characteristics of the plot locations, weather conditions during the campaign period, the number of renewals per tree, the paste used by different resin tappers, the density of the stands (number of trees/ha), and the characteristics of the trees (notably diameter and canopy depth).

The installation of all plots for the 2023 campaign (Table 1) occurred in May, and the resin tapping was dismantled in November, with 7 renewals conducted in all plots. The average resin production in the 2023 campaign for the plots in Vila Pouca de Aguiar was similar for maritime pine (1.117 kg) and Scots pine (1.100 kg), both of which were higher than the production for black pine (0.511 kg). It should be noted that these values refer to a single incision per tree, regardless of the tree's size. This pattern was confirmed during the first weighing in the middle of the 2024 campaign. In the maritime pine plot located in Oleiros, compared to that in Vila Pouca de Aguiar, a higher resin production was recorded in 2023 (1.406 kg), which was also observed in 2024.

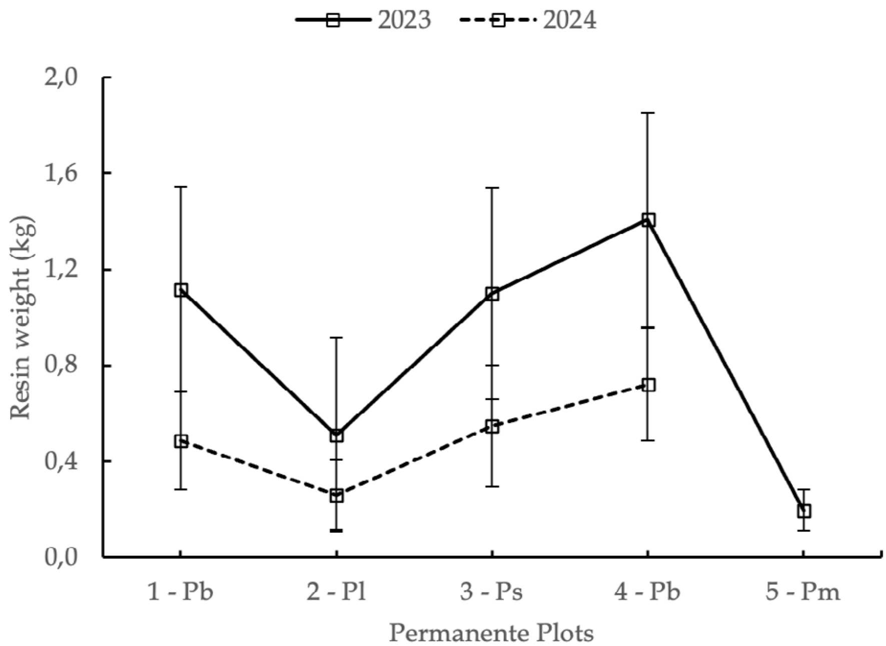

Figure 5 – Resin weight (mean ± standard deviation) in plots installed in 2023, at the end of the 2023 campaign and mid-way through the 2024 campaign. The production corresponds to one incision per tree, regardless of tree size. Pb – Maritime pine (*Pinus pinaster*), Pl – Corsican pine (*Pinus nigra*), Ps – Scots pine (*Pinus sylvestris*), Pm – Stone pine (*Pinus pinea*).

Resin production in the stone pine plot was significantly lower (0.195 kg). This plot had many trees with a diameter below the minimum required for resin tapping (20 cm), as shown in Table 1. The resin tapping was done by the landowner, who was tapping for the first time due to the difficulty of finding resin tappers in that region. Unfortunately, the landowner stopped tapping in the 2024 campaign, so no production values are available for that year. In this network of plots, the lack of data for stone pine is not due to an absence of areas or stands offered by landowners but rather due to the challenge of finding resin tappers in those geographic areas. However, it would be important to analyze the impact of resin tapping on cone production in this species.

The results obtained highlight the importance of having a network of resin tapping plots for various species of the *Pinus* genus in mainland Portugal. The plots installed as part of the RN21 Integrated Project are the seed of this network, which should be expanded so that we can have greater variation in locations and stands for each species. This would allow the development of equations that could estimate resin production by species and support management decisions aimed at exploiting this important non-timber forest resource within the context of the bioeconomy.

Paula Soares,[a] Juan Carrabs,[a]
[a]Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa

KEMI - PINE ROSINS

BIOPOLYMERS AND RESINS: SUSTAINABLE INNOVATION IN ADHESIVE FORMULATION

Growing environmental concerns and the need for more sustainable alternatives to conventional polymers have driven research and development of biopolymers capable of replacing fossil-based polymers.

Synthetic polymers derived from fossil sources, such as EVA, EBA, SIS, and SBS, have been widely used across various industries due to their durability and versatility. However, these polymers pose environmental challenges, including reliance on non-renewable resources, pollution, and plastic waste accumulation. In this context, biopolymers derived from renewable sources like plants, algae, and bacteria have emerged as a promising alternative.

The production of biopolymers can reduce dependence on non-renewable resources, contributing to a low-carbon economy, as these materials generally have a lower carbon footprint compared to conventional polymers. Some examples of biopolymers under investigation include PLA (polylactic acid), PHA (polyhydroxyalkanoates), and regenerated cellulose. These polymers have shown good performance in applications that traditionally relied on fossil-based polymers, such as packaging and disposable products. Among the possible applications for biopolymers, the adhesive market stands out as an area of great interest. Adhesives play a crucial role in a wide variety of industries, from construction to automotive. Currently, adhesives are produced using fossil-based materials. However, with increasing environmental awareness, stricter regulations, and the imminent depletion of oil resources along with the associated volatility of oil prices, it has become timely to seek sustainable alternatives [1]. This presents an opportunity in the adhesive market to replace fossil-based products with natural or bio-based materials, such as biopolymers. Using biopolymers in adhesive formulation offers several advantages. One of the key benefits is the reduction of toxicity in the final product when compared to synthetic adhesives, which is beneficial for both workers and consumers. Additionally, biopolymers can be engineered to have adhesive properties equivalent to or even superior to those of conventional polymers, making them suitable for a wide range of applications.

There are various types of adhesives, and the global hot melt adhesive market was valued at USD 7.37 billion in 2020. It is expected to experience a compound annual growth rate (CAGR) of 4.8% from 2021 to 2028, drawing significant attention to this segment of the adhesive market [2].

Hot Melt Adhesives consist of a combination of polymer (approximately 33%), resin (approximately 33%), wax (approximately 32%), and antioxidant (approximately 1%). In the adhesive formulation, the polymer is responsible for viscosity, rheology, cohesion strength, flexibility, and adhesive strength [3].

The increasing demand in the packaging market, particularly for sealing general consumer boxes (such as food packaging, parcels, etc.), combined with the characteristics of hot melt adhesives, is driving the growth of this segment. Hot melt adhesives offer excellent adhesion properties for a wide range of materials and surfaces, such as fabric, paper, ceramics, metal, cardboard, and plastics.

Various types of polymers can be used in adhesive formulations, each offering distinct properties that influence the performance and final application. Among the existing polymers, polyamides and polyesters stand out due to their unique combination of properties, such as high mechanical strength, good adhesion to various materials, and long-lasting durability.

Polyamides

Polyamides are crystalline polymers typically produced by the condensation of a dicarboxylic acid and a diamine, or they can be polymerized from a monomer that contains both an amine and a carboxylic acid group in its structure (e.g., caprolactam) [4, 5]. During polyamide formation, the carboxylic acid group (-COOH) reacts with the amine group (-NH_2), releasing water molecules as the polymerization reaction proceeds, as shown in Figure 1.

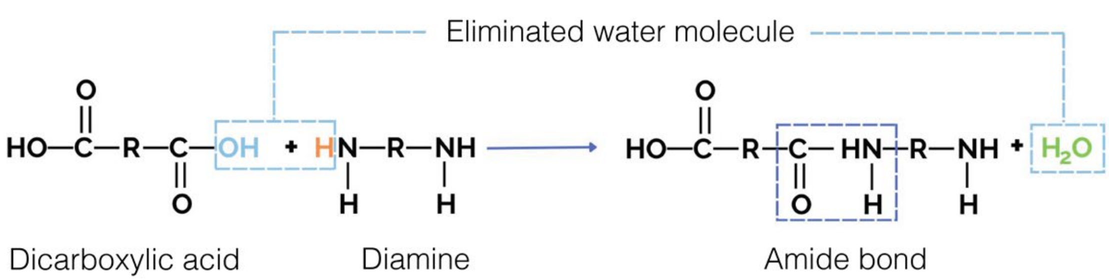

Figure 1 - Generic reaction of polyamide formation.

Polyamides exhibit several highly desirable properties, one of which is their ability to melt and be shaped into various forms, enabling the continuous production of fine filaments [6]. Additionally, polyamides demonstrate excellent mechanical strength, good flexibility, resistance to high temperatures, and strong adhesion to a wide range of substrates, making them ideal for formulating hot melt adhesives.

Traditionally, the monomers used in polyamide formulations are derived from non-renewable fossil-based sources, but new pathways for synthesizing diacids and diamines from biomass are currently being developed [7].

Efforts to produce bio-based polyamides have predominantly resulted in hybrid polyamides, where diacid monomers are derived from renewable biomass, while diamines are still fossil-based [8]. Most bio-based polyamides currently exhibit inferior physicochemical and mechanical properties compared to their fossil-based counterparts, underscoring the need for further research to develop bio-based polyamides that offer both desirable properties and a competitive cost. Depending on the monomers used and the length of the carbon chains in the diacid and diamine, the resulting polyamide will have distinct properties, making it essential to balance the monomers chosen with the intended application, such as in hot melt adhesive formulations.

Polyesters

Polyesters, on the other hand, are synthesized through a reaction between a diacid and a diol. Similar to polyamides, the synthesis of polyesters occurs via a condensation reaction between the carboxyl group (-COOH) and the alcohol group (-OH), releasing water molecules as the polymerization progresses, forming ester bonds (-COO-) in the polymer chain (Figure 2).

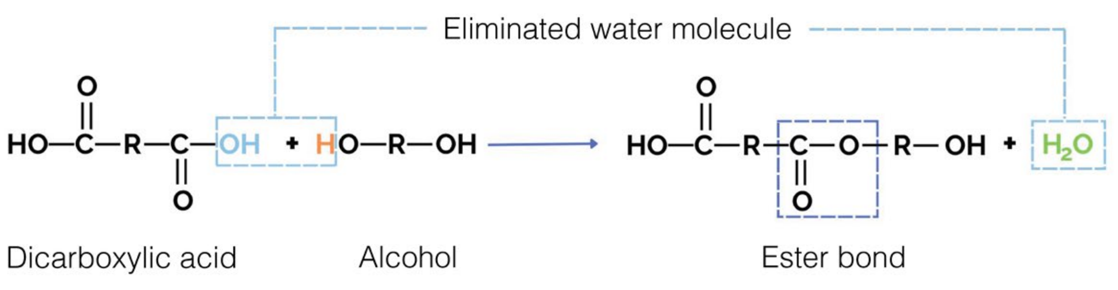

Figure 2 - Generic reaction of polyester formation

These polymers can be produced from both natural sources (such as lactic acid in the case of polylactate) and petrochemical sources (such as polyethylene terephthalate, or PET). The diversity of possible structures within this class of polymers allows for the creation of materials with diverse physical and chemical properties. The investigation of naturally-derived polyesters is critical for the development of new adhesives, as these polymers offer excellent characteristics for such applications, including good flexibility, resistance to aging, and adhesion to various surfaces.

Polyamides and polyesters play key roles in hot melt adhesive formulations, each with specific characteristics that make them suitable for different industrial applications. Polyamides are preferred in scenarios requiring high thermal and chemical resistance, while polyesters are widely used for their affordability and strong adhesion to various surfaces. The choice between polyamides and polyesters depends on the specific requirements of the application, such as temperature, flexibility, chemical resistance, and cost.

Figure 3 - Solid polyamide at room temperature, with a softening point of 89°C without tackifier.

Thus, the research and development of biopolymers like polyamides and polyesters are crucial for creating more sustainable and effective hot melt adhesives. Renewable-source polyamides and polyesters provide an alternative to fossil-based polymers, helping reduce carbon footprints and environmental impact, while offering excellent adhesive properties such as strength and flexibility.

At KEMI-Pine Rosins, under the RN21 Integrated Project, various formulations of both polyamides and polyesters have been developed, combining bio-based monomers with different characteristics. These studies have resulted in over 60 bio-based polyamide and polyester formulations (Figures 3 and 4), each with distinct properties.

The resulting polyamides and polyesters are evaluated individually and in combination with pine rosin resins, demonstrating compatibility between the two products. This compatibility allows them to be used as hot melt adhesives for different types of substrates or under various processing conditions, while maintaining their adhesive properties.

Figure 4 - Semi-solid polyamide at room temperature, with a softening pint of 67°C without tackifier.

Diana Branco,[a]
[a]KEMI - Pine Rosins

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SECONDARY PROCESSING OF TURPENTINE: PRODUCTION OF A VALUE-ADDED NATURAL RESIN

The base chemicals derived from the pine resin are rosin and turpentine. In Portugal, the use and manufacture of rosin derivatives is widely implemented. However, the development and commercialization of turpentine derivatives has consistently been lacking in the national market. Gum Rosin – Project management and R&D, S.A. aims to explore this gap in the national market by developing products derived from turpentine, particularly polyterpene resins, produced from α-pinene, β-pinene, and limonene, the terpenes that are present in turpentine in higher quantities.

Terpene resin is an organic compound obtained from natural sources such as wood and citrus fruits. These are low molecular weight hydrocarbon polymers, obtained by the cationic polymerization of terpenes. Their composition makes them excellent tackifying materials. They are also a renewable, biodegradable, and non-toxic raw materials, making them a potential substitute for petroleum-derived resins, which are fossil-based and non-renewable products. Due to their excellent adhesive and tack properties, terpene resins are widely used in various sectors, such as adhesives, paints, coatings, sealants, rubber, and chewing gum. The polyterpene resin market is witnessing significant growth due to the increasing demand for eco-friendly and sustainable products in various sectors.

Applications

Paints and Coatings
Characterized by their resistance to water, chemicals, and UV exposure, they offer strong adhesion and durability. Demand has grown due to their low volatile organic compound (VOC) emissions and biodegradable properties.

Plastic and Rubber Processing
Used to enhance flexibility, strength, and adhesion, these materials are eco-friendly, biodegradable, and have low VOC emissions. They are useful in automotive applications, construction, and tire manufacturing.

Cellulose and Paper
Used to improve the strength and appearance of paper products, these materials create a strong bond between cellulose fibers, enhancing paper durability and providing a smooth, glossy finish

Leather Processing
Used as binders to enhance the strength and appearance of leather products with a glossy finish. Their strong adhesion and durability make them ideal for products exposed to wear and moisture.

Adhesives and Sealants
Used as binding agents with low volatility and high solubility, providing excellent adhesion to wood, paper, and plastic. Sealants offer moisture protection, commonly applied as coatings on furniture and flooring.

Chewing Gum
Used as a natural binding agent and flavor enhancer, helping keep the gum intact, reducing excessive stickiness, and extending shelf life with antibacterial properties. It's an alternative to synthetic ingredients.

The market for polyterpene resins is being driven by the rising demand for eco-friendly and sustainable raw materials across various industries, such as adhesives and coatings. The growing focus on reducing carbon footprints and promoting bio-based products is also fueling the growth of this market. However, factors such as fluctuations in the prices and availability of raw materials, as well as competition from synthetic resins, can act as constraints to the market's growth. Nevertheless, increased consumer awareness regarding the environmental impact of synthetic chemicals is also contributing to the growing popularity of polyterpene resins.

It is estimated that the terpene resin market will grow at a CAGR (Compound Annual Growth Rate) of 7.9%, from an estimated value of USD 991.1 million in 2022 to USD 1.45 billion in 2027. Demand for terpene resins from the pulp and paper, and paints and coatings sectors is expected to expand significantly between 2022 and 2027.

With continuous research and development efforts to improve the properties of polyterpene resins, the market is expected to follow an upward trajectory in the coming years.

Polyterpene resins stand out for being naturally derived, with low molecular weight, a high softening point (due to their cyclic and polycyclic structures in the polymer chain), and better thermal stability, compatibility, and solubility. Commercially available resins have softening points ranging between 80°C and 130°C.

The softening point and molecular weight of polyterpene resins are key characteristics for their primary use (adhesion). Their adhesive behavior results from the relationship between softening point and molecular weight. Compared to rosin-based natural resins, polyterpene resins have a higher softening point with lower molecular weights, making them suitable for more specific and demanding market sectors. Polyterpene resins also tend to exhibit better oxidation stability compared to rosin-based resins.

In summary, the advantages/disadvantages of polyterpene resins can be outlined as follows:

Characteristics	Advantages / Disadvantages	Target market
High softening points	Sustainability	Used in paints, varnishes, and paper coatings
Low molecular weights	Biodegradable (can be decomposed by bacteria and fungi)	Suitable for the healthcare industry (unlike petroleum-based resins)
Soluble in various chemical solvents	Antibacterial, antifungal, and antiviral properties	Food industry, such as chewing gum (unlike petroleum-based resins)
Colorless or transparent	Antioxidant and anti-inflammatory	Ideal for adhesives and sealants
Inert to acids, alkalis, and solvents	Higher cost	Leather processing
Good adhesive properties	Available in smaller quantities	Applicable in plastic and rubber processing
Resistant to heat and moisture	More complex processing	

The main terpene resins available on the market are prepared from the following monoterpenes: α-pinene, β-pinene, and limonene. These terpenes consist of two isoprene units, with the following generalized molecular formula $(C_5H_8)2n$, where n is the number of units. Figure 1 presents the molecular structure of the aforementioned monoterpenes, α-pinene, β-pinene, and limonene.

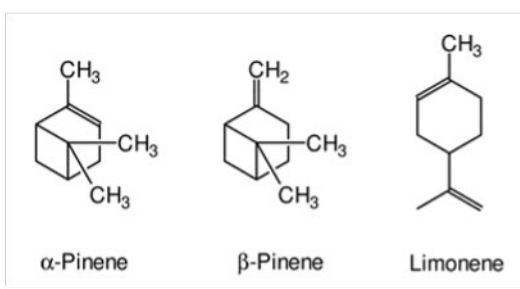


Figure 1 - Chemical structure of α-pinene, β-pinene, and d-limonene.

α-pinene, β-pinene, and limonene can be obtained by fractional distillation of turpentine. Limonene can also be sourced from other plant origins, such as citrus fruits, where it is found in higher concentrations.

The synthesis of polyterpene resins involves cationic polymerization of the monomer with the aid of a catalyst, which forms a complex H^+G^- that attacks the double bond of the terpene, initiating chain polymerization.

Polyterpene Resins Based on α-pinene

α-pinene does not have an exocyclic double bond, so compared to β-pinene, the conditions for the polymerization reaction are more demanding. The rate-limiting step in α-pinene polymerization is propagation, due to the spatial arrangement of atoms (stereochemical hindrance).

There are two potential structures in an α-pinene-based polyterpene resin. The most abundant unit makes up 2/3 of the total, where the bond is made via the β carbon and contains an olefinic group. The following figure shows the two possible mechanisms for obtaining polyterpene resin from α-pinene.

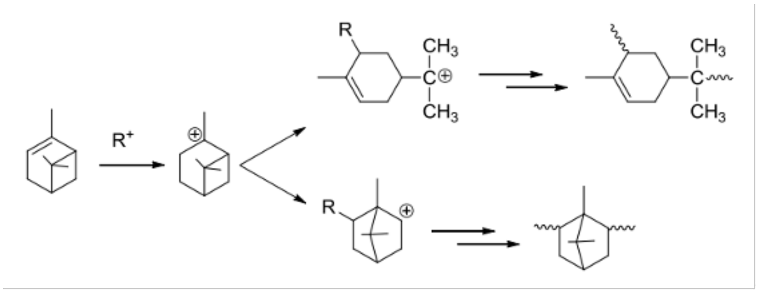


Figure 2 - Possible polymerization mechanisms of α-pinene to obtain politerpene resins.

Polyterpene Resins Based on β-pinene

The polymerization of β-pinene occurs through its exocyclic methylene group, which is attacked, and the formed carbocation rearranges to attack the next monomer, initiating the propagation process.

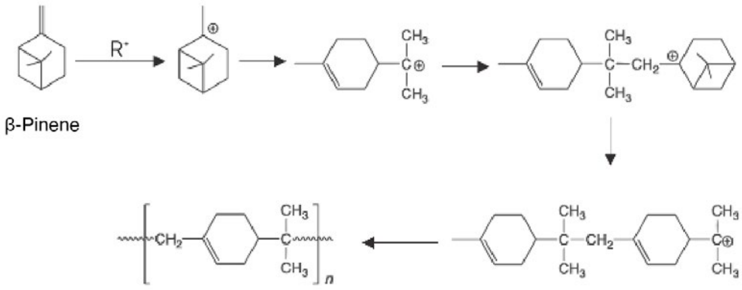
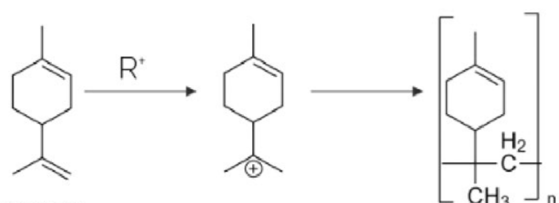


Figure 3 - Polymerization mechanism of β-pinene to obtain politerpene resins.

Polyterpene Resins Based on Limonene

The initiation of limonene is quite similar to that of β-pinene, as it also has an exocyclic double bond. The polymerization reaction begins with this bond. Propagation proceeds with the carbocation attacking the exocyclic double bond of the next monomer. Figure 4 presents the described mechanism.



Limonene

Figure 4 - Polymerization mechanism of limonene to obtain politerpene resins.

Terpene resins, derived from natural sources, have great potential in a market that increasingly values sustainable products, making them attractive to industries seeking alternatives to petroleum-based derivatives. With the growing demand for eco-friendly solutions that promote the bioeconomy, the future of terpene resins looks promising, especially with advances in extraction and processing technologies evolving to make these resins more competitive and accessible.

Carolina Malaquias,[a] Emanuel Silva,[a] Pedro Gil,[a]
[a]Gum Rosin

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UNIVERSIDADE DE AVEIRO

STIMULANT PASTES FOR PINE RESIN PRODUCTION: RESEARCH AND FUTURE PERSPECTIVES

Resin, or oleoresin, is a viscous, translucent natural liquid primarily composed of diterpenic acids, also known as resinic acids. Resin can be obtained from a wide range of tree species, particularly gymnosperms of the *Pinus* genus (Pine), such as *Pinus pinaster* Ait., *Pinus radiata*, *Pinus elliottii* Engelm, *Pinus massoniana* Lamb., *Pinus caribaea* Morelet, among others [1]. In Portugal, the most common pine species are *P. pinaster* (maritime pine), which is mainly used for resin tapping, and *P. pinea* (stone pine), primarily cultivated for pine nut production. The main resin-producing regions in Portugal include the Central Coastal area (Leiria and Coimbra districts) and the Northern Interior (Viseu and Vila Real districts) [1].
Oleoresin consists of a volatile fraction, called turpentine or spirits of turpentine, which accounts for approximately 20% of the resin composition, and a non-volatile fraction, known as rosin, pitch, or colophony, which makes up about 80% [2, 3, 4].
Turpentine is composed of a mixture of terpenes, with isoprene (2-methyl-1,4-butadiene) serving as the basic carbon skeleton unit, namely monoterpenes (C10), sesquiterpenes (C15), and diterpenes (C20), among others. The main components of turpentine are the monoterpenes α-pinene (45-97%) and β-pinene (0.5-28%), along with smaller amounts of other monoterpenes, such as limonene, Δ3-carene, camphene, and tricyclene, as well as sesquiterpenes. On the other hand, rosin primarily consists of diterpenic acids (90-95%), with the general formula $C_{19}H_{29}COOH$. The most common resinic acids in rosin include abietic, neoabietic, palustric, dehydroabietic, and pimaric acids (Figure 1) [2, 3].
Resin obtained from trees of the *Pinus* genus is a non-wood forest product, a renewable raw material for various industrial sectors, including the production of insecticides, cleaning products, disinfectants, perfumes, and fragrances. Rosin is used in the production of derivatives for surface coatings, chewing gum, paints, adhesives, and pharmaceuticals [3, 5]. Therefore, the development of new resin extraction techniques (tapping) that promote increased production in an optimized, safe, and environmentally friendly manner is becoming increasingly important. One of the initiatives aimed at achieving these goals is the development of new stimulant pastes [3].

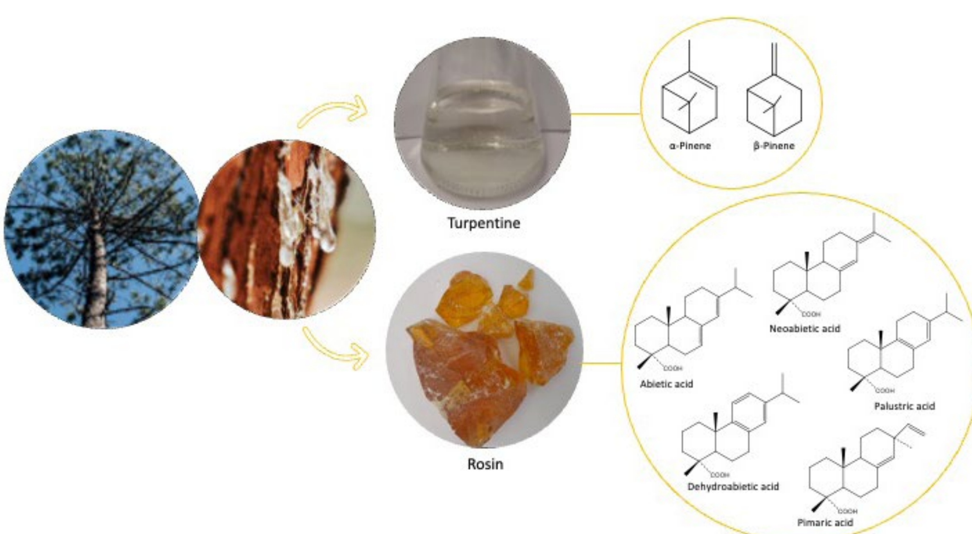

Figure 1 - Main products obtain from pine resin transformation and their respective main components.

Currently, resin tapping involves several steps (Figure 2). First, the "descarrasque" is performed, which involves removing the bark of the pine tree in the area where the incision will be made. Next, an incision is made, from which the resin will be collected using traditional cups or plastic bags. To maximize resin production, a stimulant agent is applied, typically sulfuric acid (H_2SO_4), with the aim of increasing and prolonging resin production. To further enhance production, additional incisions, known as renewal incisions, are made just above the previous one, generally at intervals of 15 to 21 days [6].

This technical article aims to provide a brief review of the different types of stimulants currently available and their modes of action, as well as possible substitutes. This review is particularly important, as no comprehensive reviews on the various stimulants and their comparative results have been published to date.

Figure 2 - Main stages of resin tapping

Stimulant Pastes Used in Natural Resin Production

In general, conifers produce resin in the living epithelial cells surrounding the resin ducts (Figure 3). The secretion of resin occurs as a physiological response to external stimuli or injury. In pines, resin is produced and stored under pressure within a complex three-dimensional network of resin ducts (Figure 3).

When the resin ducts are exposed to an injury, whether from physical damage or caused by pests or diseases, the accumulated resin is directed to the exposed injury site, forming a protective layer of crystallized resin over the wound, sealing it and allowing the tree to defend itself against the inflicted damage. After the crystallization of the resin over the injury, the flow of resin to the injured area is interrupted [7,8].

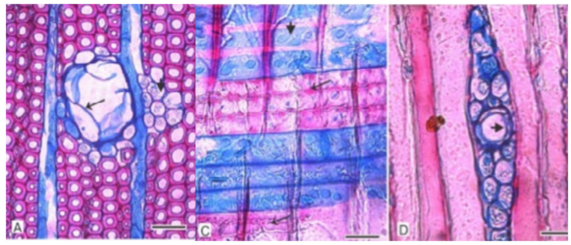

Figure 3 - Resin ducts of *P. elliotti* xylem in cross section (A), radial section (C) and tangential section (D). Scale bar 50 µm. Adapted from Siegloch & Marchiori [8].

The resin industry exploits this physiological response of the tree to increase resin production by using stimulant pastes. These stimulant pastes help keep the resin ducts open and facilitate the exudation of resin. The most commonly used stimulant paste is based on sulfuric acid. This paste increases resin exudation by preventing its crystallization and inhibiting the formation of tyloses. Additionally, sulfuric acid slows the crystallization of resin, facilitating its flow and subsequent collection. Studies have shown that the use of sulfuric acid paste increases resin production by 70%, demonstrating the importance of using stimulant pastes in resin tapping [9]. However, sulfuric acid is a strong acid that can cause damage to the trees, raise safety concerns for users, and can have a negative environmental impact. To address these limitations, other safer alternatives have been studied as stimulants, ideally having equal or greater impact on resin production. Some examples include stimulants composed of organic acids, phytohormones, herbicides, metallic ions, or yeast extracts, or mixtures of these [10–12].

Organic Acids

Among the organic acids used as stimulants, benzoic acid and citric acid stand out (Figure 4). These acids act similarly to sulfuric acid but are weaker acids, making them less aggressive on the resin ducts and less likely to cause damage to the trees [12]. Furthermore, these organic acids are generally considered safer for the environment and for handlers. They are biodegradable and less corrosive, which reduces the risk of soil and water contamination and protects the workers involved in the resin tapping process [12,13].
However, due to their lower acidity, particularly compared to sulfuric acid, their effectiveness in stimulating resin production is lower [12]. For example, Lukmandaru et al. [12] showed that citric acid paste combined with ethylene, in unspecified quantities, is ineffective in inducing resin production compared to the paste composed of sulfuric acid [12].

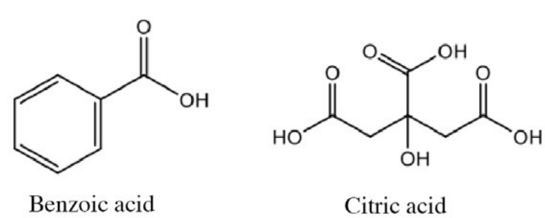

Figure 4 - Chemical structure of the main organic acids studied as resin tapping stimulants [13].

Phytohormones and Synthetic Analogues

Phytohormones are compounds found in plants that regulate various biological functions, such as physiological processes and development. Synthetic analogues have been developed to act similarly to phytohormones and induce physiological responses in plants [14]. Therefore, these compounds can be studied in the formulation of stimulant pastes. Among them, 2-chloroethylphosphonic acid (Figure 5), also known as CEPA or Ethephon, stands out for stimulating the creation of new resin ducts and consequently increasing resin production. Furthermore, 2-chloroethylphosphonic acid is a precursor to the biosynthesis of ethylene, a plant hormone associated with growth and development, as well as defense responses. Its production in the tree can trigger increased resin production as a defensive response [9].

Messer studied resin production with the application of CEPA and observed a 110% increase in production compared to the control (without stimulant paste) [15].

In a study conducted by Neis et al., the application of CEPA was compared to a paste based on benzoic acid containing 20% sulfuric acid [11]. In the first year of resin tapping, resin production was 5.1 kg/tree/year higher using CEPA compared to the productivity obtained with the benzoic acid paste. However, in the second year, the results obtained with the different pastes were similar, which may be due to the greater development of the resin ducts.

Also notable in this group are methyl jasmonate and salicylic acid (Figure 6). Methyl jasmonate is a phytohormone that regulates plant development processes, fruit ripening, and responses to biotic and abiotic stressors to which trees are exposed. This compound also promotes increased biosynthesis of mono and diterpenes, thereby stimulating the activation and formation of resin ducts. Junkes et al. compared resin production using methyl jasmonate to the control (water and glycerol), finding that in young trees (1 year old), resin production was 2.4 times higher [16].

Salicylic acid is a phytohormone that acts as a resistance inducer against pathogens and biotic and abiotic stress, which can lead to resin production and exudation [10]. For instance, a study by Rodrigues et al. showed that a salicylic acid stimulant paste (10 or 100 mM) containing CEPA moderately increased resin production compared to the control (20% H_2SO_4 and 4.5% CEPA), specifically yielding 3.2 and 2.9 kg/tree/year, respectively, versus 2.7 kg/tree/year [17].

Finally, 2,4-dichlorophenoxyacetic acid (known as 2,4-D) and 2(1-naphthyl)acetic acid (Figure 5) are also synthetic compounds related to phytohormones, used as herbicides and in stimulant paste formulations. In the study by Rodrigues et al., the use of paste containing 2,4-D and CEPA (1, 10, and 100 mM) was compared with the control paste (20% H_2SO_4 and 4.5% CEPA) [17]. The results showed that all concentrations studied led to an increase in resin yield of approximately 15% [17]. Neis et al. tested various compounds as stimulants, including 2(1-naphthyl) acetic acid (formulated with 20% sulfuric acid), which resulted in resin yields similar to trees treated with CEPA paste [11].

The use of phytohormone-based pastes may offer advantages in terms of safety and environmental impact, but as demonstrated in the studies above, they may be less effective in resin production compared to sulfuric acid. On the other hand, the use of synthetic analogues (in some cases halogenated) and/or herbicidal action may also present environmental issues. The choice between the two will depend on the specific requirements of the application and considerations of safety and sustainability.

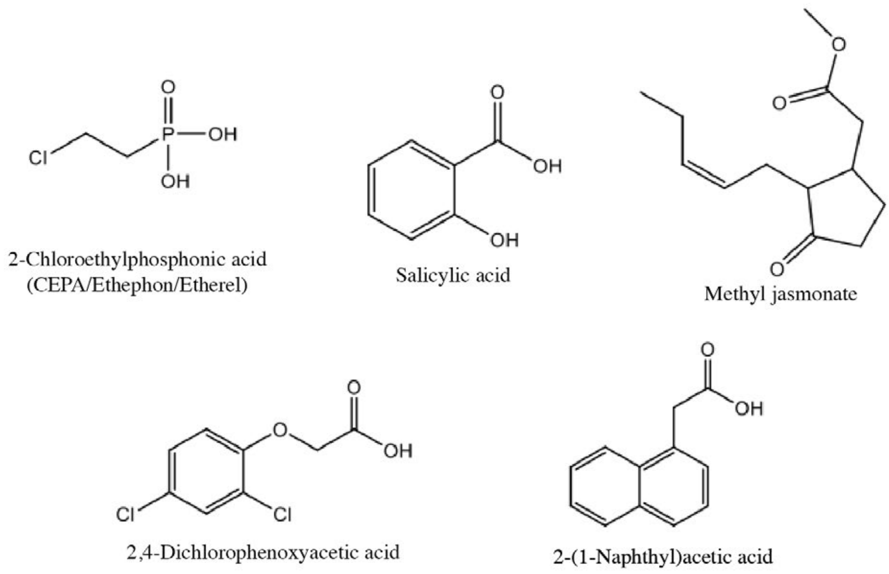

Figure 5 - Chemical structure of the main phytohormones studied as resin tapping stimulants [9, 16, 17].

Herbicides

Herbicides, particularly 1,1'-dimethyl-4,4'-bipyridinium dichloride, also known as Paraquat (Figure 6), have been studied as stimulant. This compound is of interest in formulating stimulant pastes because it alters metabolic pathways that increase resin production. However, a study conducted by Rodrigues et al. demonstrated that the application of Paraquat paste in a spray form with concentrations of 0.5%, 2.0%, and 4.0% (v/v) of CEPA resulted in relatively low resin production compared to those obtained with the application of CEPA paste (3.3, 3.0, and 2.4 versus 4.0 kg/tree/year) [18].

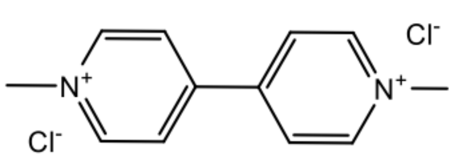

Figure 6 - Chemical Structure of the Herbicide Paraquat [17].

Metal Ions

In pine trees, monoterpene synthase enzymes depend on divalent cations, including Mn^{2+} and Fe^{2+}, as well as the monovalent ion K^{+}, to enhance their enzymatic activity. Both Mn^{2+} and Fe^{2+} act as cofactors for these enzymes, playing a crucial role in their function, while K^{+} serves as an enzyme activator. When used in stimulant paste production, these cations tend to increase terpene production in plants, resulting in greater amounts of resin being produced in pine trees [18]. In the work by Rodrigues et al., stimulant pastes containing metal ions (Mn^{2+}, Fe^{2+}, and K^{+}) were tested compared to the control paste (20% H_2SO_4 and 4.5% CEPA). The results showed that when a paste containing 100 mM of each of the metal ions was applied, the amount of resin produced was similar to that of the control paste (approximately 3.0 kg/tree/year) [18].

Yeast Extract

Yeast extract is another alternative that can be used in the production of stimulant pastes. The application of such stimulant pastes can simulate the attack of pathogenic agents on pine trees, triggering a defensive response from the plants, which can lead to increased resin production. For instance, Rodrigues et al. observed that the use of pastes containing yeast extract and CEPA yielded resin production equivalent to that of the control paste (20% H_2SO_4 and 4.5% CEPA), approximately 3.5 kg/tree/year [17].

Iberian projects for the development of new stimulant pastes

The increasing need to find alternatives to the traditional resin-stimulating paste based on sulfuric acid has led to increased investment and research, resulting in several projects on the Iberian Peninsula. These projects aim to optimize the resin production process by exploring new collection methods, such as mechanized resin tapping (drilling methodology), in contrast to the traditional manual method. Additionally, there is a focus on developing more sustainable stimulating pastes to replace sulfuric acid-based formulas.

In the studied projects, several stimulating pastes were tested, including formulations based on citric acid, benzoic acid, salicylic acid, metallic ions (F_2^+ K^+, and Mn^{2+}), Paraquat, and 2-chloroethylphosphonic acid. The results show that higher acidity in the stimulating pastes (for example, higher concentrations of sulfuric acid) generally results in greater resin production. However, various factors can influence these results, such as climate, the resin tapping region, the age and species of the tree, as well as the extraction method used. This diversity of variables makes it difficult to draw consistent conclusions, especially due to the lack of direct comparisons between the results of different projects and the absence of statistically significant results in some cases.

DEVELOPMENT OF NEW STIMULATING PASTES WITHIN THE RN21 INTEGRATED PROJECT

In light of the increasing demand for resin-based products and the need to revive the Natural Resin sector at the national level, the Integrated Project RN21 was launched, funded by the Portuguese Recovery and Resilience Plan (PRR). This project aims to address some of the sector's challenges, focusing on developing new stimulants that are more efficient and sustainable. The responsibility for this task falls on the research team at CICECO - Institute of Materials of Aveiro, University of Aveiro.

So far, the CICECO team has developed several formulations that are currently undergoing field testing. The preliminary results obtained will undergo intense research activity in the coming months as part of the RN21 project. This investigation aims to deepen the effectiveness of the new pastes and their viability for the resin sector, thus contributing to the sustainability and productivity of the industry.

Inês S.L. Farias,[a] Nalin Seixas, Carmen S. R. Freire,[a] Carla Vilela,[a] Sónia A. O. Santos,[a] Armando J.D. Silvestre,[a]

[a]CICECO – Instituto de Materiais de Aveiro, Departamento de Química, Universidade de Aveiro

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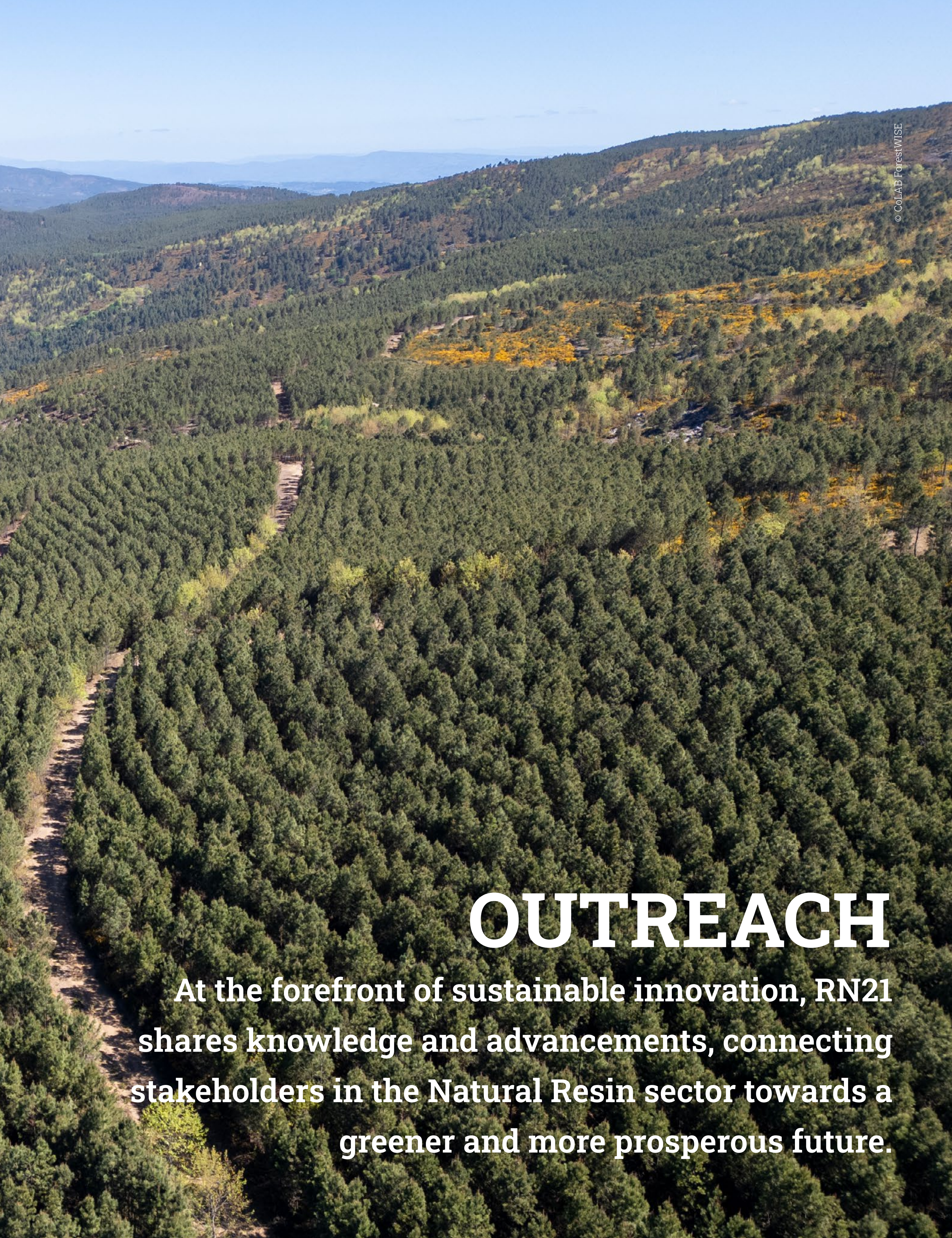

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OUTREACH

At the forefront of sustainable innovation, RN21 shares knowledge and advancements, connecting stakeholders in the Natural Resin sector towards a greener and more prosperous future.

PROMOTING MARITIME PINE RESIN THROUGH TRADEMARK DEVELOPMENT

Within the scope of the Integrated Project RN21, various initiatives are being developed to promote the use of Natural Resin, with an emphasis on resin extracted from maritime pine (*Pinus pinaster* Ait.), a renewable raw material with the potential to replace fossil-derived products. This Project, focused on promoting sustainable practices, is part of Component C12 of Sustainable Bioeconomy, reinforcing the importance of Natural Resin as a strategic resource for Portugal, both economically and environmentally. Natural Resin not only contributes to reducing dependence on fossil resources but also enhances the potential of maritime pine areas, an endemic species of strategic importance, creating opportunities for sustainable economic development.

One of the crucial goals of the project is the registration and implementation of a distinctive, attractive, and identity-driven trademark that distinguishes products containing resin from *P. pinaster* and ensures the quality, traceability, and sustainability of the products carrying it. In this regard, the trademark "**Resinae - Pinaster Natural Resin**" has been created. Aimed at promoting products that incorporate a renewable raw material sourced from well-managed forests, ensuring environmental, social, and economic sustainability based on internationally recognized certification systems, thereby reinforcing its credibility with consumers and commercial partners.

The guidelines for using the trademark are established through a regulation that guarantees its consistency and ensures its integrity in a clear and detailed manner. The regulation establishes the eligibility criteria required throughout the value chain, from the extraction of resin in the pine forest to the final stages of production and commercialization, ensuring that the trademark is used exclusively by entities that meet a strict set of criteria. The established criteria define the control standards that ensure traceability throughout the process and are audited by independent entities that verify all stages of the production processes. By following these guidelines, it is ensured that the products bearing the trademark are authentic, promoting consumer trust and enhancing the competitiveness of products on national and international markets.

The brand's visual identity consists of a strategic set of graphic elements that reflect its essence and personality, ensuring coherent and effective visual communication across both licensed product labels and promotional materials. This identity defines the brand's logo and specifies essential characteristics, such as color and typography, which guarantee consistency and immediate recognition. By conveying a message of trust and quality, the visual identity strengthens consumers' emotional connection to the products and positions the brand distinctively.

The primary goal of creating, utilizing, and promoting the **"Resinae - Pinaster Natural Resin"** trademark is to foster the differentiation and value of Natural Resin sourced from maritime pine. The aim is also to strengthen the sector's competitiveness through marketing strategies that enhance the image of companies and products, attracting customers and distinguishing them from fossil-based alternatives, while simultaneously boosting national resin production and promoting sustainable forest management in this field. Ultimately, the objective is to expand both national and international offerings within the sector, penetrate new markets and niches, increase domestic sales and exports, and strengthen the National Bioeconomy.

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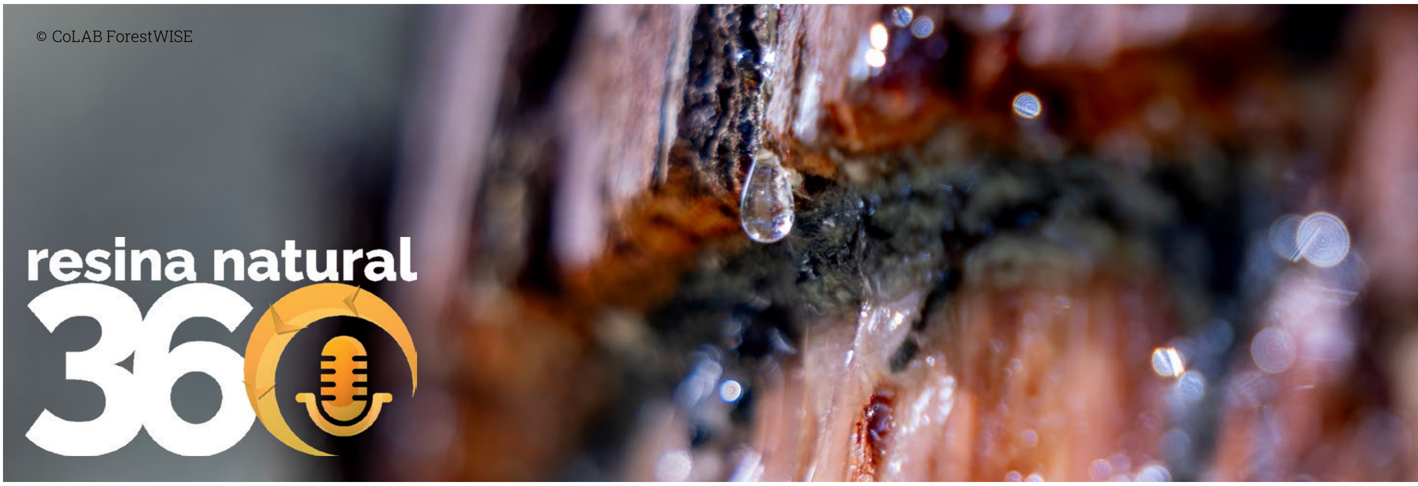
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SOCIAL MEDIA

Our social media channels for the Integrated Project RN21 have the goal of strengthening our relationship with the audience and creating an informal mean of communication. This initiative reflects our commitment to keep all stakeholders updated on the latest developments of the Project, providing a space for closer interactions, sharing valuable information, and creating a community engaged around Natural Resin and our vision for a more sustainable future.

RN 360º PODCAST

Our initiative aims to promote knowledge about Natural Resin and its incredible contribution to a sustainable future. Each episode, approximately five minutes long, is an opportunity to expand your knowledge about this valuable resource. Join us in engaging episodes where we explore the Natural Resin sector and its various applications.

You can find all the episodes at https://rn21.forestwise.pt/podcast

WEBINAR RN21

Each webinar offers insights from experts, researchers, and professionals in the field on the importance of natural resin, its properties and applications, traditional and innovative extraction techniques, among others. Join us on this exciting journey of learning, discovery, and innovation as we unveil the economic potential, forest sustainability, and entrepreneurial opportunities driven by Natural Resin.

You can review all the webinars at https://rn21.forestwise.pt/webinar

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