CORK SCIENCE AND APPLICATIONS 2025

BOOK OF ABSTRACTS

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Book of Abstracts

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CORK SCIENCE AND APPLICATIONS 2025

Cork in Science and Applications 2025
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PREFACE

CSA 2025, the International Conference on Cork Science and Applications, took place in Lisbon, Portugal, from 13 to 14 October 2025, followed by a study trip on October 15. This is the 5th edition in a series of conferences on Cork Science and Applications (CSA), now well-established as international meetings that gather researchers, students, producers and companies around cork. CSA conferences started in 2014 (Porto), and continued in 2017 (Aveiro), 2019 (Palafrugell) and 2023 (Vila Nova de Gaia).

Cork is a biological product with an unusual and outstanding set of properties, sustainably produced in nature by cork oak forests with a unique ecosystem value and a millennial history of applications. Cork stoppers for wines and spirits are worldwide known. Still, the use of cork has spread across various sectors from construction, architecture and design to engineering solutions, from aerospace applications to areas of natural products, cosmetics and health.

The scientific study of cork started early, in the 17th century, with the first observations of its cellular structure. However, a clear framework of cork structural, chemical and physical properties as a cellular material was only established by the research endeavors carried out along the last 40 years. The research work is an ongoing path and knowledge gaps are still present. Meetings such as CSA 2025 allow the spread and discussion of results and are a seed to further investigation works and the opening of new applications, often with a collaborative approach.

The connection of cork to the tree from which it is produced (the cork oak, *Quercus suber*) and to the ecosystems where it grows is overwhelming and cannot be overlooked. For this reason, the 5th CSA edition brought an enhanced attention to the cork oak ecosystem and to the cork oak in view of a sustainable procurement of cork. It also opened to other less-known cork-rich trees, such as the species in the Brazilian cerrado and the *Quercus variabilis* in China and South Korea.

This Book of Abstracts gathers all the abstracts in CSA 2025: keynotes, oral presentations and posters. The oral presentations are organized in thematic sections: Cork oak forests and sustainability, Cork science and properties, Cork and wine, Cork in construction and engineering, and innovative cork products. The conference programme, including the study trip, has also been added for future reference.

Overall, the content of this Book Abstracts, which was complemented during the Conference with the interviews, round tables, and discussions, is evidence of a dynamic and evolving research arena where cork production and cork products are closely associated with the present sustainability and bioeconomy approaches. This field connects fundamental research, for instance on cork biology and oak ecophysiology, with applied science, technological development and innovation of products, applications and processes, in a context of climate challenges, emerging digital and AI-driven solutions, and market uncertainties. We all look forward to the insights the next CSA 2027 will bring us!

Helena Pereira, Ricardo Sousa, Duarte Neiva, Solange Araújo and Joana Amaral Paulo

CSA 2025 Organizing Committee

DESIGNING SMART CORK OAK MANAGEMENT AND CORK PRODUCTION MODELLING TOOLS IN THE CONTEXT OF CLIMATE AND TERRITORIAL CHALLENGES

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Keywords: Cork oak, forest models, smart cork oak management, climate change, forest simulators

Cork oak stands are highly important ecosystems in the Mediterranean region, not only for their contribution to the economy but also for the many other ecosystem services they provide, such as biodiversity conservation. These forests cover 2.2 million hectares, of which Portugal accounts for 33%, making it the country with the largest cork oak area. Within Portugal, cork oak represents 22% of the total forest area. Traditional cork oak forests, known as montados in Portugal and dehesas in Spain, typically have low stand density and are managed as silvo-pastoral systems that combine cork production with cattle or sheep grazing. In recent years, new plantations have been established in both countries, most with much higher stand densities than traditional ones. Decisions about whether to maintain these higher densities or to determine the best age to start debarking must be based on solid scientific evidence. An important issue is that some forest owners support—and are already applying—irrigation in these plantations to accelerate early growth and shorten the time until the first debarking, which by law can only occur once trees reach a DBH greater than 70 cm. It is therefore crucial to develop forest growth and dynamics models to support cork oak management decisions, especially for these new plantations. Today's forests face environmental (climate change), economic (diverse products within the bioeconomy), and social (recreation, non-wood products) challenges. Forests are complex ecosystems that provide multiple ecosystem services, and management must balance these within biophysical and social constraints. Modern forest models must be climate-sensitive, capable of simulating complex systems, and able to provide detailed outputs. To be practical, they need to be implemented in user-friendly forest simulators that can evaluate alternative management scenarios, helping landowners and managers make well-adapted decisions. The first management-oriented growth and yield model for cork oak, the SUBER model, was developed in 1997 and has been progressively improved with increasing amounts of data from permanent plots and trials established since 1981. These data are organized in the relational database SUBERDATA, managed by the Forest Research Centre (CEF) in Lisbon, and include tree and cork growth information as well as cork production. The SUBER model is an empirical growth and yield model and, as such, is not climate-sensitive. More recently, the 3PG model, which incorporates process-based components, has been calibrated for cork oak and linked to the SUBER model, making it climate-sensitive and capable of simulating the effects of irrigation. This presentation analyzes the SUBER model, its linkage with the 3PG model, and its integration into forest simulators. It also highlights the interaction between researchers—who develop the models—and users, who provide essential feedback on the improvements they need to address the challenges of day-to-day forest management.

UPDATE ON THE STRUCTURE AND REGULATED BIOSYNTHESIS OF THE APOPLASTIC POLYMER SUBERIN

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Keywords: Suberin, cork, biosynthesis, molecular genetics, biopolymer

Suberin is a hydrophobic biopolymer deposited in the bark or periderm of the cork oak tree (*Quercus suber*). Not only found in tree bark, suberin is produced by essentially all seedbearing plants, where it can be found in roots, seed coats, and as a component of plant responses to injury by wounding. Suberin plays a critical role in many aspects of plant growth, development, and physiology and is an important determining factor of the unique properties of cork oak tree bark that make it useful both in nature, as a form of protection for plants, and in industry. The mechanisms of suberin biosynthesis are relatively well understood thanks to just over two decades of molecular-genetic work model plant species such as thale cress (*Arabidopsis thaliana*). Recent advances in our understanding of suberin structure have arisen through the application of novel chemistries targeted at quantitative comprehension of intermolecular linkages, isolating intact suberins, and the application of advanced analytical techniques. The advent of high throughput DNA sequencing has facilitated the discovery of numerous genetic regulators of suberin biosynthesis. Herein we will provide an overview of aspects of suberin structure, biosynthesis, and regulation of that synthesis highlighting recent developments in our understanding of these facets suberin biology. We will further identify outstanding questions in these respective areas and provide perspectives on how to advance the field to address these questions.

R&D DRIVERS FOR CORK INDUSTRIAL SUCCESS: THE CASE OF AMORIM CORK

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Keywords: cork stoppers, TCA, wine evolution, comparative trials

Over the last 20 years, Amorim Cork, through R&D and innovation, has established itself as an important player in the global cork stopper market, becoming the undisputed world leader of it.
In fact, the problem of musty taint, produced by 2,4,6-Trichloroanisole (TCA), allowed alternative seals to achieve significant market shares and, consequently, affect the share of cork stoppers.
Through a consistent R&D program, it was possible to control the problem, be recognized for it and use R&D and innovation as an important competitive advantage.
We will present the initiatives, approaches, results and achievements that have allowed us to get the TCA problem under control.
We will also talk about new areas of research, where we highlight the importance of cork stoppers in the evolution of bottled wines and the reasons for the differences in the evolution of wines with other seals.

CORK NEW TRENDS IN ARCHITECTURE

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Keywords: Cork, sustainable materials, Architecture, culture

Cork is a very versatile natural material and adapts to different technological transformation processes, giving rise to several products that can replace traditional methods of production and different applications.

Cork products for the construction industry are most suitable and energy efficient, given their ecological characteristics. In addition, these products contribute to general comfort and indoor air quality. This is an opportunity in architecture for the use of cork as a primary material, as in the past. In the last decade, some examples of the use of cork have already emerged. Cork is a carbon sequestration material with good benefits of thermal comfort when applied to insulation, facades, or even flooring. Examples of these applications will show the long-term benefits of cork in architecture.

IDENTIFYING THE DRIVERS OF CANOPY GREENNESS TRENDS IN THE CORK OAK WOODLANDS OF PORTUGAL

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Keywords: Cork oak, NDVI, SPEI, BRTs, topography

The cork oak woodlands of Portugal are a relatively drought resistant system, however, increasing temperatures and intensifying drought conditions which are forecasted for the Mediterranean (IPCC, 2023) may impact the health and functioning of the tree species in this region. Therefore, it is imperative to disentangle the relationship between water availability and forest health for cork oak species. This work used the machine learning approach of Boost Regression Trees (BRTs) to model the climatic, edaphic, and biogeographical factors influencing trends in cork oak canopy greenness at the regional scale. Results indicated that long-term trends in water availability were influential drivers of the magnitude of change in canopy greenness, although areas experiencing a positive trend in greenness had a more rapid response to changes in water availability. Areas experiencing a negative greenness trend had a higher intensity of change under drier than normal conditions. Topography also played a relevant role, with higher magnitudes of increasing greenness predicted on north-facing slopes. This study highlights the interconnectedness of plant functioning and soil water availability, confirming that a changing drought regime will significantly impact the future health of cork oak woodlands in Portugal.

[1] IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.

FSC® Ecosystem Services Procedure - the role of certification in enhancing the value of forests

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Keywords: Impact verification; Valorization; Responsible Forest management; Communication; Sponsorship

ABSTRACT

Valuing responsible management and the ecosystem services provided by a variety of forests or agroforests, such as *montados/dehesas*, can be a valuable tool in promoting the resilience of these systems.
In this regard, FSC Forest Management certification already allows forest managers to demonstrate their commitment to responsible forest management and to preserving the ecosystem services (ES) provided by their forest.
However, managers are not always properly rewarded for their work in preserving or restoring ES. To promote the valorization of their work on ES, FSC has developed the Ecosystem Services Procedure. This procedure provides the forest managers with a structure for verifying impacts on different ES (Biodiversity, Carbon, Water, Soil, Recreation, Cultural Practices and Air Quality), giving them access to a set of credible data audited by an independent entity that attests to its integrity.
Based on this data, managers can establish contacts with organizations interested in sponsoring their efforts to conserve or restore services that their forest is providing to society.
For a total of 108,379 ha in the Iberian Peninsula, of which around 12,497 ha is in *montados* and *dehesas*, 22 FSC Certificate Holders have already demonstrated their commitment to responsible forest management, contributing to the maintenance and/or restoration of the ES provided by their forests. Some of these managers have already formalized partnerships that are supporting their efforts on the ground.

Forest Certification in Mediterranean Oak Woodlands: Drivers, Challenges and Management Impacts.

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Keywords: Forest certification, Management practices, Forest owners, FSC certification, *Quercus suber*

ABSTRACT

Cork oak woodlands hold significant socio-economic and biodiversity conservation value, but they face high tree mortality and decline. Over the last decades, cork oak mortality has increased due to a combination of abiotic and biotic factors, including inadequate management practices. Forest certification - a tool that aims to promote sustainable forest management by implementing socio-economic and environmental management standards - is expected to mitigate tree mortality and the decline of these woodlands.

Previous research has shown that forest certification can contribute to the conservation of cork oak woodlands. However, there is no research addressing forest owners and managers´ perspectives on drivers, obstacles, and impact of certification on these woodlands. Using Portugal's evergreen oak woodlands as a case study, we examine how forest certification affects owners' management practices. Additionally, we explore their motivations for adopting certification and the challenges they face.

We conducted a survey among members of seven FSC-certified Group Entities managing cork oak woodlands in Portugal. We identified 411 members, from which 113 responded (response rate of 27%). Results show that certification has led to changes in management practices, particularly in cork harvesting (e.g., disinfection axes after cork extraction). Another reported change is the identification and establishment of conservation zones prior to forestry operations. In the social pillar, full compliance with labor rights was identified as the main change. Nevertheless, few respondents reported ceasing vegetation control through soil mobilization, shrub clearing with heavy machinery, or soil mobilization on steep slopes, which suggests that some of the proposed best practices were already being implemented. Survey results also show that the main drivers of forest certification are environmental and heritage protection, as well as facilitated access to public funding. While market incentives play a role in forest certification, pressure from the cork industry to demand certified raw material does not appear to be a relevant driver. Respondents identified excessive bureaucracy, certification costs, and limited market demand for certified products as major challenges. Addressing procedural non-conformities in the certification process was also a barrier, although access to technical support was not considered a major obstacle.

Our findings highlight the role of forest certification in influencing management practices in cork oak woodlands and underscore main drivers and barriers that may limit the expansion of certification.

FERTIGATION IN THE LAST YEARS OF A CORK PRODUCTION CYCLE – A CELLULAR APPROACH

Poeiras, Ana[1], Camilo-Alves, Constança[1], Günther, Björn[2], Ribeiro, João [1], Nunes, José [3], Vaz, Margarida[4], Almeida Ribeiro, Nuno[5]

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Keywords: Scanning Electron Microscope, Cork cell walls, Cork rings, Forest Management, Cork oak stands

ABSTRACT

This study presents an image-based analysis on cork cell in two cork rings from the same cork profile using a Scanning Electron Microscope. During the cork growth cycle, forest management practices have changed due to the additional fertigation applied to the plot, from the 2020 year onward. The plot is sited in *Herdade da Mitra*, Évora, property of the University of Évora, certified by the Forest Stewardship Council® (FSC). The cork oak stand is debarked every 10 years, which the last one occurred in 2023.

The objective of this study is to assess changes in cork cell walls and lumens in response to the additional fertigation—whether they follow their regular documented pattern or deviate due to the altered forest management approach.

The characteristics of the plot trees were analysed in terms of basal area, stem circumference at breast height, total height and stem height of harvesting before the 2023 extraction. The main goal is to predict the effects of additional water on cork production in adult trees.

ADVANCES IN INTENSIVE MONITORING PLOTS OF QUERCUS SUBER

Almeida Ribeiro, Nuno[1], Poeiras, Ana[2], Camilo-Alves, Constança[2], Ribeiro, João[2], Nunes, José [3], Rodrigues, Mariana[2], Fierravanti, Angelo[4], Raposo, Mauro[2], Maymone, Marta[5], Silva, Maria Emília[4], Fonseca, Teresa[4], Vaz, Margarida[6]

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Keywords: Cork oak, Forest management, Mediterranean forest system, Modelling strategies, Data rational

ABSTRACT

In Iberian Peninsula, the effects of climate change altered both precipitation and temperature regimes increasing the aridity in all territory. The extreme events are also increased with particular relevance to high temperature periods and prolonged drought. The new climatic dynamics and its unknow contribution to the forest systems functioning led to the necessity of new modelling approaches based on structural functional rational, more in line with basic sciences.

For that modelling purpose, a set of intensive monitoring plots where installed with continuous monitoring systems of radiation absorption, interception of precipitation, evapotranspiration, nutrient uptake, photosynthesis, respiration, photosynthate allocation, senescence and mortality in addition with the tree 3D periodic dendrometric data all collected in long term ecological Mediterranean forest research plots.

In the present work it is presented the complex data structure rational and the synchronic/diachronic statistics used for the presentation and analysis of the first results in cork oak forest systems. The results show the contribution of the functional structural variables on tree growth responses and permitted to develop the presented new modelling strategies.

USE OF A RESISTANCE DRILL TO STUDY THE INTERNAL STRUCTURE OF CORK OAK TRUNKS

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Keywords: cork thickness, forest inventory, bark biomass, resistograph, growth modelling

ABSTRACT

Methods usually applied in forest inventory and modelling for the determination of bark thickness present problems of lack of precision when applied to cork oak. In this work we analyze the potential of using a resistance drill to obtain accurate measurements of this thickness, while distinguishing between the phellem (cork) and the phloem (mother layer).

We used slices of cork oak trunks, obtained from felled trees in a thinning, to generate resistance profiles and measure the thickness of the different tissues by image analysis. We present the initial results, discussing on the advantages and difficulties that arise when using a resistance drill as a measuring instrument. We conclude that this non-destructive technique can be very useful for understanding the internal structure of the cork oak trunk and thus contributing to the development of improved models for cork production and biomass distribution in cork oak forests.

CORKCLASS: A MOBILE APPLICATION TO ENHANCE THE VALUATION AND COMMERCIALIZATION OF CORK BATCHES IN THE FIELD

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Keywords: Cork classification, Image analysis, porosity, thickness, cork stopper manufacturing

Natural cork stoppers are the most valuable product derived from cork, requiring high-quality raw material for their production. Only cork planks that meet strict quality standards can be used, as lower-quality materials are unsuitable. This ensures the durability and effectiveness of the final product.

The quality of cork planks—defined by their suitability for manufacturing natural cork stoppers—determines their commercial classification and, consequently, their economic value. All planks extracted from cork oak forests undergo classification, either in the field or during the preparation process. Those unsuitable for stopper production are set aside, while the rest are assigned to predefined categories. A specialized operator carries out this classification, assessing thickness and appearance based on porosity and the presence of anomalies. This assessment can be conducted while the cork is still on the tree, before harvesting, or after harvesting, when stacked.

To enhance the valuation and marketing of cork batches in the field, an Android mobile application called CorkClass has been developed to automate the classification process, building upon CorkClass 4.1, an Excel-based software application [1]. This work introduces the CorkClass app and explains its functionality, which can be summarized as follows. First, the app prompts the user to take a picture of the cork plank's transverse section. CorkClass then uses ImageJ, an image analysis software, to evaluate the plank's thickness and porosity. The user subsequently inputs data regarding any anomalies or defects in the plank. Based on this information, the application classifies the planks as either suitable or unsuitable for natural cork stopper production.

[1] Benito López, J.; Sánchez-González, M.; Perez Terrazas, D.; González Adrados, J. R. 2021. CorkClass 4.1: Una aplicación para la clasificación del corcho. Revista Montes, 145, págs. 29-33. https://www.revistamontes.net/Buscador.aspx?id=15115..

MITIGATING CORAEBUS UNDATUS DAMAGE: THE ROLE OF MIXED STANDS

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Keywords: *Coroebus undatus*, cork, silvicultural management, mixed stands, pest management

ABSTRACT

The jewel beetle *Coraebus undatus* feeds on the cork-generating layer of cork oak (*Quercus suber*) trees during its larval development excavating long, meandering galleries along the trunk. This activity severely impacts cork quality and hinders cork extraction, leading to significant economic losses in the cork industry. In some areas, beetle incidence appears to have increased, which may be partly related to climatic factors. Control management of this insect is difficult because its larvae and pupae develop inside the tree, making them inaccessible to conventional treatments. Currently, there are no effective chemical or biological control methods.

In this study, we investigate the impact of silvicultural management strategies on beetle infestation levels. Specifically, we compare attack intensity between pure cork oak stands and mixed stands of cork oak and stone pine (*Pinus pinea*), using paired plots from the same farm across seven in a north-south gradient of ecological regions. We also assess stand and tree dendrometric characteristics.

Our results show that pure cork oak stands experience significantly higher beetle incidence than mixed stands. In pure stands, attack intensity further increases with tree density and basal area, suggesting that higher host tree concentration enhances susceptibility. Additionally, there is considerable variability between farms, with attack intensity varying by more than 10-fold which might be related to soil and climatic factors as well as management strategies. The proportion of attacked trees also ranged widely from less than 10% to over 90%. Furthermore, our assessments indicate that cattle grazing intensity may exacerbate beetle infestation, likely by increasing tree physiological stress and susceptibility.

In conclusion, our findings suggest that mixing cork oak with stone pine and reducing cattle grazing intensity may serve as an effective adaptive management strategy to mitigate the damage caused by *C. undatus*.

SUSTAINABILITY OF THE MONTADO: CHALLENGES, STRATEGIES AND FUTURE PERSPECTIVES

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Keywords : Cork oak forest, cork, sustainability, cork oak, Mediterranean ecosystem

SUMMARY

The cork oak forest is one of the most important ecosystems in Portugal, both in ecological and economic terms. With 720 thousand hectares, Portugal is the world leader in cork production, with the cork oak being a protected species of great importance to the forestry sector [(1)].

The cork sector plays an important role in Portugal's economy and ecological identity, as it is the leading country in the production and export of this natural resource. The cork oak forest, a traditional agroforestry system, is essential for biodiversity and carbon sequestration.

Over the last few decades, the montado area has remained relatively stable, but its productivity faces significant challenges related to climate change, pests, changes in the cork market and forest management policies.

In this context, it becomes essential to analyze the evolution of the cork oak forest:

- How the area and density of the montado have evolved;
- What are the main challenges that threaten its sustainability;
- What strategies should be adopted to ensure its sustainability and resilience in the future.

The present work aims to take stock of the current situation of cork oak forests, which have suffered some decline, reinforcing the importance of sustained investment specifically aimed at improving, requalifying and increasing the areas of cork oak population.

The analysis of the evolution of the cork oak forest allows us to conclude that Portugal, despite being a world leader, has been observing a slight decrease in the area of cork oak forest, in addition to some degradation of the same, proven by the harvests every 9 years, with successive decreases in quantity and quality, something that requires a more in-depth analysis as it is of extreme importance for the future of the cork industry. Pure stands are predominant, but the number of trees per hectare is very small, less than 40 trees/ha [(2)].

It can be seen that the application of Community Funds to the forestry sector in Portugal contributed to the development of the forest, however, the funds applied specifically to the cork oak forest are -little studied and characterized, and there is no sign of a direct consequence of the investment in the increase in cork production.

In terms of national cork production, there has been -a decrease in recent years, certainly associated with the reduction in the area of montado, as well as some degradation of the same which results in a lower quality of the cork produced.

uneven, decrease, as this particularly affected the cork preparation subsector, resulting from the verticalisation and merger of many manufacturing units that have taken place over the last decade.

It is concluded that, despite the stability in the extension of the montado, there is a growing concern about its density and productivity. Forest management and incentive policies are essential to guarantee the sustainability of cork and the preservation of this unique ecosystem. The sustainability of cork oak forests requires a set of strategic policies and coordinated actions to ensure their conservation and the economic viability of the cork industry, which must include:

- Sustainable Forest Management - promotion of good practices for the maintenance of montado, such as the implementation of cork oak regeneration models, soil rehabilitation, pest control, maintenance of biodiversity and pasture management to avoid soil compaction;
- Public Policies and Incentives - implementation of measures already provided for in the National Forest Strategy (ENF) which sets targets for 2030 [(3)], including financial support for producers that promote sustainability;
- Economic Valorization of Cork - innovation and diversification of cork products and expansion into new markets and sustainable certification to increase the commercial value of the product.

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DOES FOREST CERTIFICATION CONTRIBUTE TO CORK OAK WOODLAND CONSERVATION?

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Keywords: Oak regeneration, *Quercus suber*, Forest Inventory, Stand biometry, Biodiversity

ABSTRACT

Forest certification, a conservation tool, which aims to promote the sustainable management of forest ecosystems, has been expanding globally and applied to different forest ecosystems including the cork oak woodlands. In Portugal, the country with the largest area of cork oak cover and the world´s leader of cork production, approximately 150 thousand ha (nearly 20%) of cork oak cover is under forest certification.

As part of the certification requirements, forest producers need to adopt management practices complying environmental and socio-economic standards. Additionally, landholders are required to set aside approximately 10% of the forest management unit, the so-called conservation zones, with the aim of promoting biodiversity and ecosystem services in their properties.

Here I synthetize results from our research group on the effects of forest certification on the ecological sustainability and the biometry of cork oak stands.

The results obtained when comparing the characteristics of cork oak woodland areas with and without forest certification, suggest that there is a widespread oak decline (measured as decrease in adult oak tree density), both in certified and non-certified stands. However, the decline is stepper in non-certified areas suggesting that forest certification may be having a role in mitigating oak decline. In which concerns conservation areas, results suggest that habitat heterogeneity, understory cover and diversity, as well as oak regeneration tends to increase in conservation areas, with results depending on time since conservation area implementation. Bird species monitoring in certified estates, show that the bird communities in conservation areas differ from the bird communities recorded outside conservation areas. In conservation areas, shrub dependent and insectivorous species are more abundant, while outside conservation areas tend to have higher abundances of bird species dependent on grassland patches. Overall establishing conservation areas as part of the forest certification processes increases bird and plant diversity at the property scale. Finally, when assessing the certification trends in the cork oak area of distribution in Portugal, we also found that certification started in areas of high landholder capacity building and technical knowledge and areas of traditionally high cork production. These results suggest that the first landholders engaging in certification are also those better organized, for example, into cork oak producer associations.

In general, the results suggest that forest certification expansion in cork oak woodland areas, is contributing to mitigated oak decline and that the implementation of conservation areas is contributing to increase habitat heterogeneity at the property scale, therefore benefiting biodiversity conservation.

CORK OAK PROTEINS AS MARKERS OF THE BIOLOGICAL PATTERN OF DECLINE INDUCED BY INTERACTING WITH *P. CINNAMOMI*

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Keywords: *Quercus suber*; *Phytophthora cinnamomi*; cork oak decline; proteomics; (α, β)-*k*-Feature Set Problem

The decline of cork oak in Mediterranean forests is a complex phenomenon observed with remarkable frequency in the southern part of the Iberian Peninsula, leading to the weakening and mortality of these woody plants. The soil-borne oomycete *Phytophthora cinnamomi* infects the roots of cork oak (*Quercus suber*) plants, causing necrotic lesions and the loss of fine roots. These findings, in combination with other factors, are the hallmarks of the decline of cork oak ecosystems.

SWATH-MS proteomic analysis of cork oak plants inoculated with *P. cinnamomi* allowed the quantification of 424 proteins and highlighted 80 host proteins that are relevant to the homeostatic states resulting from the oomycete-host interaction in the long term and in a distal organ [1]. To find the optimal set of proteins, markers of the biological pattern of interaction with the oomycete, we mathematically modelled the problem as an α, β-*k*-feature set problem [2].

The method allowed the identification of 29 proteins that, based on the quantification of the identified proteins, have the potential to effectively separate plants interacting with *P. cinnamomi* from plants not interacting with the pathogen. These proteins are highly interconnected in a network of protein-protein interactions consisting of three clusters revealed by STRING analysis. The clusters are linked by key proteins and disruption of their production may compromise protein synthesis, photosynthesis, chloroplast biogenesis and glyoxylate and dicarboxylate metabolism.

Monitoring the vegetative status of trees using protein molecular markers can greatly assist in the management of cork oak stands by helping farmers to identify plants that interact with *P. cinnamomi* but do not die suddenly or show observable signs of decline (asymptomatic). We hypothesize that these 29 markers may be critical in detecting trees that are declining due to interactions with the pathogen, thus assisting in the management of cork oak forest ecosystems.

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ESTIMATION OF ABOVE-GROUND BIOMASS IN A CORK OAK FOREST USING GEOSPATIAL TECHNIQUES

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Keywords: Aerial biomass, geospatial techniques. cork oak forest, precision monitoring and existing correlation analysis.

ABSTRACT

Cork is a biological material that supports an integrated value chain from forest to industry, with a significant economic, social and environmental impact in the regions where it is produced and processed. Spain is the second largest producer of cork in the world, after Portugal.

Cork is a renewable and sustainable raw material with unique properties that make it suitable for a wide range of applications. It is not only used for wine closures, but also in different sectors where it is an alternative to fossil and non-renewable raw materials. The use of cork contributes to the conservation of cork oak forests (Quercus suber L.), which are very well adapted to semi-arid regions, where they prevent desertification, provide other environmental benefits and are an important habitat for many species of flora and fauna. In addition, cork oak forests contribute significantly to rural development in the areas where they are located, creating employment opportunities.

The main objective of the work presented here is to estimate the above-ground biomass in cork oak forests using geospatial techniques. This pilot study was carried out in Calzada de Oropesa (Toledo). We have used data from the diameter obtained by band dendrometers, as well as the height of the trees obtained from the point cloud extracted by the LiDAR sensor, a sensor mounted on a drone. A monitoring of the studied cork oak forest was also proposed, based on aerial and satellite

images. The results obtained show that the combination of these geospatial techniques provides sufficient precision information to improve the management of these unique areas that make up the tree and its whole.

THE RATIONALE BEHIND CORK'S THERMAL PROPERTIES: A COMPREHENSIVE REVIEW

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Keywords: Cork, thermal properties, comprehensive review, rational, correlation with density.

ABSTRACT

Cork's exceptional thermal insulating properties have drawn growing interest [1]. However, even with extensive research, there is a noticeable gap in the literature: studies rarely provide a comprehensive analysis of cork's thermal properties across different types, forms (natural or agglomerated), or geographic origins. This gap persists despite increasing interest in the material over the past three decades. Surprisingly, until recently, even the thermal properties of natural cork, including its anisotropy and variability, were underexplored [2].

This work aims to address these gaps through a bibliographic review and experimental evaluation, revealing an emerging trend in the thermal conductivity of cork, which seems to be correlated with its density.

While thermal conductivity is not inherently a mass property, denser cork materials consistently exhibit higher thermal conductivities, a trend observed across both natural and agglomerated cork. The findings suggest a linear relationship for thermal conductivity ($k=a1\cdot\varrho+b1$) and specific heat ($Cp=a2\cdot\varrho+b2$) at lower densities. These relationships inform the hyperbolic dependence of thermal diffusivity ($\alpha=k/Cp$) on density. Thermal diffusivity is a key parameter in evaluating the cork's effectiveness as an insulating material under dynamic conditions, giving a measure of how the temperature wave propagates through the material.

By providing a perspective on cork's thermal behavior, this review establishes a foundation for researchers and industry partners, reinforcing cork's relevance for sustainable thermal insulation solutions, and a guidance for application of cork's products in thermal insulators.

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UNDERSTANDING DEFORMATION MECHANISMS OF CORK UNDER COMPRESSION LOADING USING DIGITAL IMAGE CORRELATION

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Keywords: Cork, Digital Image Correlation, Mechanical testing, quasi-static loading, Structure-mechanical relationship

While the mechanical response curve of cork-based materials under quasi-static compression loading is well established, the underlying deformation mechanisms remain poorly understood. However, the cork microstructure gives these materials unique properties including thermo-acoustic insulation, impact resistance as well as gas and liquid barrier properties, which are sought-after in a wide range of industrial applications including wine stoppers, aeronautic components or building materials. It appears therefore necessary to study the cork microstructure evolution under mechanical loading, in order to anticipate the evolution of such properties. The objective of this work is to study the strain field of cork materials subjected to quasi-static compression loading. Filmed compression tests were performed on centimetric-sized cubes of natural and (micro/macro) agglomerated cork. The strain field of the cube faces were determined using Digital Image Correlation (DIC). We show that cork materials are subjected to highly heterogeneous strain field, with very localised compression band mainly oriented in transverse direction. For natural cork, the strain localisation is affected by lenticels.

STUDY OF THE COMPRESSIVE BEHAVIOUR OF NATURAL CORK UNDER EXPOSURE TO WATER AND ETHANOL VAPOURS DURING AGEING

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Keywords: compressive behaviour, elastic modulus, ageing, progressive repeated loading, stored energy

ABSTRACT

The primary use of natural cork is to produce stoppers intended for oenological applications. To study the effects of the storage condition on its compressive behaviour, cork cubes were placed in contact with saturated vapour of water, ethanol, or a water-ethanol mixture at 90-10 % v/v, at a constant temperature of 25°C. Quasi-static (QS) and Progressive Repeated Loading (PRL) tests were conducted on samples after 3 and 12 months of storage.

From the QS test performed after 3 months, a significant difference in elastic modulus was observed between samples exposed to water vapour (9.6 ± 3.2 MPa) and ethanol vapour (14.3 ± 4.2 MPa). Additionally, after 12 months, a notable reduction in cork stiffness, with a decrease in elastic modulus to 6.3 ± 0.8 MPa, was detected in samples exposed to ethanol vapour. In contrast, no difference was observed for those in contact with water.

The PRL test revealed that cork's storage capability decreased by approximately 40% between 3 and 12 months when exposed to ethanol vapour, whereas it increased by about 15% after exposure to water vapour over 12 months. These findings suggest that ethanol vapour may accelerate cork aging, leading to significant changes in its compressive behaviour compared to water vapour.

DYNAMIC COMPRESSIVE BEHAVIOR OF CORK AGGLOMERATES COMBINED WITH SHEAR THICKENING FLUIDS: EXPERIMENTAL AND COMPUTATIONAL APPROACHES

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Keywords: Shear thickening fluids, Cork agglomerates, Numerical modelling, Energy absorption, Finite element analysis (FEA)

ABSTRACT

Cellular materials, such as agglomerated cork, are widely utilized in engineering applications due to their exceptional properties, including fire resistance, excellent crashworthiness, low thermal conductivity, permeability, non-toxicity, and low density. This study employs finite element analysis (FEA) to model the dynamic compressive behavior of agglomerated cork, focusing on understanding the relationship between material density, stress relaxation behavior, and the influence of combining cork with shear thickening fluids (STFs). By incorporating STFs into the material matrix, as well as modeling stress relaxation and rebound effects, the study further examines and simulates the dynamic response under both initial and subsequent impacts.

Dynamic compression tests were conducted on agglomerated cork composite samples, to provide experimental data for the numerical model. The numerical model successfully replicates the response of agglomerated cork to multiple impacts, capturing both the initial dynamic compressive behavior and the material's subsequent rebound phases. The inclusion of the Mullins effect in the constitutive modeling explains the reduction in stiffness and stress softening seen after repeated loading, while the addition of STFs provides enhanced energy absorption during impacts.

This research offers a significant contribution by integrating the study of rebound phenomena and the combination of agglomerated cork with shear thickening fluids, a topic that had not been previously investigated in this group's earlier work. The findings expand the understanding of cork-STF composites in dynamic impact scenarios, with important implications for engineering applications requiring high energy absorption and resilience.

MITIGATING VISUAL PERCEPTION OF PHOTODEGRADATION THROUGH MIXTURES OF UNTREATED AND HEAT-TREATED CORK GRANULES: AN IMAGE-BASED ANALYSIS

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Keywords: *cork granules; Quercus variabilis; Heat treatment; UV exposure; visual discoloration; CIEDE2000 (ΔE00); image-based colorimetry*

Several *Quercus* species are native to Korea, including *Q. aliena*, *Q. acutissima*, *Q. dentata*, *Q. mongolica*, *Q. serrata*, and *Q. variabilis*. Among them, only *Q. variabilis* develops a distinctly recognizable cork layer. However, the absence of a domestic supply chain and the lack of periodic harvesting have led to the use of cork in its virgin form, typically including the outer bark. Although virgin cork has a chemical composition similar to that of reproduction cork, its smaller cell size and higher density result in superior compressive strength but lower elastic recovery and workability.

To improve these material limitations, cork modification strategies such as heat treatment and thermal expansion have been explored. Heat treatment, in particular, also affects cork granule color and photodegradation behavior, which are critical for practical applications. In real-world cases, discoloration complaints have been reported in outdoor-use products containing cork granules, such as exterior materials and pavement applications.

This study investigated the photodegradation behavior of cork granules under various thermal treatment conditions after artificial UV exposure. To quantify visual changes more accurately, an image-based analysis method was applied instead of relying solely on conventional colorimetry. In addition, a granule mixing strategy using both untreated and heat-treated cork was proposed to reduce visual discoloration while maintaining material workability.

Using a structured image-based workflow, we measured the color change (ΔE_{00}) of the mixed granules. Compared to single-type cork controls, the mixed samples exhibited less discoloration. Furthermore, color change was lower than that predicted by areal-mixing calculations, indicating a synergistic effect in visual mitigation. Mechanistic insights were

supported through FT-IR analysis (e.g., oxidation-related band shifts) and TGA–DSC (e.g., mass loss stages, residual mass, and thermal transitions).

This approach supports practical formulation strategies for cork-containing products, such as pavement materials, by reducing visual weathering and user complaints. It also enables cost-effective, high-throughput screening. Next, we will (1) validate performance under field conditions, (2) reduce discrepancies between image-based colorimetry and a contact colorimeter (ΔE_00), and (3) optimize thermal treatment—including roasting—by systematic variation of temperature, time, and atmosphere.

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VALORIZATION OF WINTER CORK THROUGH NIRS-BASED CHARACTERIZATION

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Keywords: winter cork, valorization, NIRS, image analysis, granulate characterization

An adequate management of cork oak forests prevents shrub accumulation, which can compromise productivity due to competition for resources, as well as increase wildfires risk. However, in recent years, the decrease in profitability of silviculture operations has limited these practices.

One way to restore profitability to silvicultural management is through the valorization of the residues generated during these activities, as winter cork. This material is obtained from pruning and thinning operations, which are carried out outside the cork harvesting season. Cork harvesting takes place from late spring to mid-summer, when the phellogen is physiologically active and its cells are fragile. Outside this period, phellogen cells do not separate easily, which results in winter cork always containing fragments of wood or "impurities".

To commercialize the different fractions with distinct characteristics (cork and wood), a process of grinding and separation is necessary, which is costly and lacks efficient mechanization solutions. The characterization of this granulate based on cork content could allow the estimation of the viability of an investment to process and separate the cork from the wood particles.

This study focuses on evaluating the feasibility of using Near-Infrared Spectroscopy (NIRS) for this characterization: in first place, cork and wood from pruning and thinning operations are received in the ICIFOR-INIA-CSIC cork laboratory. There are first grounded to obtain homogeneous granulate of 0,5mm. From these processed materials, 150 samples are prepared with known cork-to-wood proportions (2%, 25%, 50%, 75%, and 100%). These constitute the calibration set.

Diffuse reflectance NIR spectra are acquired from all samples using a Bruker MPA I FT-NIR spectrophotometer, equipped with a rotating integrating sphere and a 2.5 cm-diameter measurement channel. Spectra are collected across the 12.500–4.000 cm^{-1} range, at an 8 cm^{-1} resolution.

A quantitative analysis is applied using Partial Least Squares (PLS) regression to develop the calibration equation that allows the prediction of the percentage of cork present in a granulate sample based on its NIRS spectrum.

COMPARISON OF VOCUS CORK ANALYZER AND ISO 20752:2023 AS QUALITY CONTROL METHODS IN THE CORK INDUSTRY

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Keywords: Cork, TCA, Trichloroanisole, Mass Spectrometry, Gas Chromatography

ABSTRACT

The quantification of chloroanisoles and their corresponding phenolic precursors in cork by means of HS-SPME-GC-MS techniques is now a well-established tool for quality control in the cork industry and has been standardized in ISO 20752 [1]. However, due to the destructive nature of the method towards the sample and the time-consuming sample preparation and chromatographic runs, this type of approach is only applicable to statistical batch sampling and not to the entire production. Recently, a new analytical technique [2,3] based on thermal desorption and direct real-time mass spectrometry (Vocus Cork Analyzer) has revolutionized the quality control process in the cork sector: the method is non-destructive, real-time, and more sensitive compared to GC-MS techniques based on TCA extraction via soaking in hydroalcoholic solution. Moreover, it allows the individual screening of single cork stoppers during their production. Although the method based on TCA soaking extraction followed by HS-SPME-GC-MS has been standardized, a complete validation of the method is still missing. Particularly, the reported validation parameters of the method (e.g. uncertainty ranging from 10-30% as indicated by many accredited laboratories) are only referred to the extraction solution, while the contribution associated with the cork matrix variability is not taken into account. Our study has two different objectives: 1. To expand the validation of the standard method, by studying the contribution of the intrinsic variability of the cork matrix to the validation parameters; 2. To compare the precision, accuracy, and uncertainty of Vocus Cork Analyzer method with the standard method, in such a way to highlight the similarities and the differences between the two methods and to better interpret the data originating from individual cork analysis when compared to statistical batch analysis.

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UNRAVELING THE ROLE OF PECTINS IN THE ACCUMULATION OF TRICHLOROANISOLE IN CORK

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Keywords: cork, *Quercus suber*, trichloroanisole, pectins, cell wall polysaccharides

Wine and cork stoppers production are major global industries, with Spain producing 30% of the world's cork [1]. High-quality cork stoppers are essential for wine preservation; however, they are susceptible to contamination by 2,4,6-trichloroanisole (TCA), which deteriorates their organoleptic properties, severely affecting wine quality and leading to significant economic losses [2]. While the mechanisms underlying TCA biosynthesis remain unclear, microbial activity is thought to contribute [3], with the cork cell wall structure potentially influencing microbial colonization or the diffusion of precursor compounds [4]. In this context, we have determined that cork from two different *Quercus suber* populations, one from Cassà de la Selva (CS, Spain) and other from Porto Torres (PT, Italy), accumulates different levels of TCA, with PT having more TCA content than CS. This natural variation provides an opportunity to examine how differences in cork cell wall composition might influence microbial colonization and, consequently, TCA accumulation. Transmission electron microscopy analysis of cork samples revealed differences in pectin-rich cell wall regions, suggesting variations in pectin content. To explore this further, we analyzed the polysaccharide composition of crude, extractive-free and desuberized cork from both populations, isolating pectins and crosslinked hemicelluloses through fractionation. Our results showed a significant enrichment of extractable pectins in crude cork of PT, consistent with transcriptomic data indicating higher expression of pectin catabolism-related genes in PT compared to CS. Additionally, PT cork exhibited higher levels of arabinose, galactose, and rhamnose -sugars associated with branched rhamnogalacturonan I (RG-I)- suggesting a greater abundance of this pectin domain in its cell wall. Mannan-family polysaccharides, which are known to contribute to water retention and a more dynamic, hydrated cell wall matrix [5], were also more abundant in PT cork. In summary, our results reveal population-specific differences in cork cell wall composition that could provide new insight into the relationship between cell wall structure and cork properties. These differences could have an impact in TCA levels and modulate microbial colonization or the diffusion of TCA precursors in CS and PT corks.

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PHENOLIC COMPOUNDS ABLE TO PASS FROM CORK TO WINE: REACTIVITY AND SENSORY IMPLICATIONS

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Keywords: Phenolic compounds, Cork, Wine, Color, Flavour

This work sought to understand how the chemical composition of cork, in cork stoppers, affects the chemical and sensory characteristics of wines. To achieve this objective, start with the chemical characterization of cork, particularly in terms of its phenolic composition, followed by the way in which some compounds present in cork can affect the color and flavor of the wine, and finally the detection of these compounds in white and red wines.

The work showed that it was possible to extract phenolic compounds from cork, both by traditional maceration and by the two extraction techniques used (UAE and MAE)[1]. This was followed by the reactivity of different fractions of cork, of different molecular weight, with salivary proteins. This study demonstrated that all of them have the capacity to precipitate salivary proteins and contribute to astringency phenomena. Furthermore, there also seems to be a matrix effect (presence of other compounds) on the ability of these compounds to interact with proteins[2]. Moving on to the co-pigmentation process, PGG and sinapic acid were chosen as reference compounds in cork to be used as co-pigments, and both showed a great ability to complex with malvidin-3-*O*-glucoside[3].

Finally, moving on to the impact on the wine, the results revealed that the cellar conditions and the orientation of the bottle closed with a natural cork stopper have an impact on the chemical composition of the corresponding Port wine. The samples stored in the traditional cellar, with greater temperature ranges, showed a greater yellow hue, less tannin specific activity and higher levels of furfural and 5-methylfurfural (oxidation markers). In addition, samples stored horizontally showed significantly higher levels of total proanthocyanidins and higher tannin specific activity than samples stored vertically. A derivative of ellagitannins (Corklin) was also detected in wines stored in a horizontal position, which results from the reaction of cork compounds with the phenolic compounds present in wines. In line with the search for compounds that can be formed by the interaction between wine components and cork stopper components, a new catechin-caffeic acid adduct was successfully identified[4].

In general, this work allowed us to increase knowledge about the capacity of the compounds that migrate from cork to wine and how they can affect their sensory characteristics. This information can be of great use to the cork and wine industry as it can direct the class of stoppers that are most suitable for the type of aging that the producer wants for his wine.

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IS WINE BOTTLE OVERCAPPING WAX AN EFFECTIVE OXYGEN BARRIER OR JUST AN AESTHETIC ELEMENT?

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Keywords: Overcapping waxes, Cork stoppers, Gas transfer, Aging

The use of waxes and resins for sealing wine bottles dates back thousands of years, as evidenced by archaeological findings. Historically, their application has been based on the assumption that they help limit the wine's exposure to oxygen. However, despite this long-standing use, the precise role of waxes and resins as oxygen barriers has been seldom studied, particularly in their function as overcapping materials. Previous research on the oxygen permeability of various waxes—including beeswax, microcrystalline wax, and paraffin—was conducted over two decades ago and focused on thin wax films used as food coatings or surface treatments for cork stoppers [1,2].

The aim of this study was to evaluate the oxygen barrier properties of overcapping wax, either alone or in combination with cork-based stoppers [3]. Oxygen transfer through corked bottles, with and without wax, was monitored over a one-year storage period. Two types of stoppers were used in the experiments: natural corks and micro-agglomerated corks, some without surface treatment to simulate a leak at the glass/cork interface. Corks were inserted 3.5 mm below the bottleneck, and wax was applied at 120°C, forming a 3.5 mm solidified layer. For surface-treated corks, wax was applied a month later to prevent deformation from cork outgassing. For untreated corks, wax was applied immediately to reduce oxygen ingress. Samples were stored at 25°C and 50% relative humidity, with oxygen transfer monitored for a year by chemiluminescence.

The results showed that the use of an overcapping wax leads to different results, depending on the initial oxygen barrier performance of the wax and that of the corks. On one hand, in the case of the micro-agglomerated corks used in this study, the barrier performance of the cork was already found to be very high, being of the same order of magnitude as that of the wax disc. Consequently, the addition of wax to these stoppers did not confer any additional protection against oxygen. On the other hand, the greater variability in oxygen permeability of natural cork stoppers, widely described in the literature [4,5], does not allow the role of wax addition to be accurately assessed. Finally, in the case of corks without surface treatment, whether natural or micro-agglomerated, very significant oxygen

transfer at the glass/cork interface occurs and is equivalent to a leakage-type defect. In this case, the addition of wax can considerably limit leakage at the glass/stopper interface, thus compensating for the absence of surface treatment [6,7].

This study was carried out over a period of one year under laboratory conditions on empty bottles with constant external temperature and relative humidity. With regard to the longer-term storage of wine in bottles, other questions remain, such as the impact of cork hydration on the oxygen barrier properties of the cork and wax, and the evolution of the physico-chemical properties of the cork and wax over time as a function of storage conditions.

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Vocus Cork Analyzer: Real-Time Technology for Industrial Quality Control of Natural Corks and Discs for Still and Sparkling Wines, and for Monitoring Contamination in Cork Harvesting Areas.

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Keywords: Cork, Trichloroanisole, Chlorophenols, Mass Spectrometry

Abstract. The analytical method for quantifying TCA in cork, based on high-resolution real-time Vocus CI-TOF mass spectrometry [1], has proven to be an excellent tool for industrial quality control, thanks to its rapid analysis capabilities, high sensitivity, and specificity. The instrument based on this technology, the Vocus Cork Analyzer [2], is now regarded as the gold standard in the cork industry for the real-time quantification of TCA in natural cork stoppers destined to still wines. The present study presents the first scientific evidence of the real-time quantification of TCA in natural cork disks used in the production of 0+2 wine stoppers, comparing the results with those obtained using ISO20752, since the sparkling wine industry is now asking for a high-tech solution for cork closures. Another important aspect of Vocus technology is the possibility to simultaneously detect, among a plethora of other volatile compounds, all chloroanisoles (CAs), bromoanisoles (BAs) and their corresponding phenolic precursors (chloro- and bromophenols, CPs and BPs) [3], without requiring any sample pre-treatment or pre-concentration. In this way, with a single instrument it is possible to record the high-resolution mass spectra of up to 40,000 cork samples per day - amounting to more than 10 million in one year - resulting in an immense dataset on cork contamination by CAs, BAs, CPs, BPs. This wealth of data is the first example of a scientific volatilomic dataset on cork and can be used, for instance, to track the evolution of cork contamination by volatile off-flavors (and indirectly the microbial activity) across extensive cork harvesting areas.

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IMPACT OF STORAGE CONDITIONS ON OXYGEN TRANSFER DURING WINE BOTTLE AGING

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Keywords: Gas transfer, Oxidation, Agglomerated cork, Interface, Aging

The shelf life of wine is a major concern for the wine industry. This is particularly true for wines intended for long cellaring, which are supposed to reach their peak after an ageing period ranging from a few months to several years, or even decades [1]. Low, controlled oxygen inputs through the closure system are generally necessary for the wine to evolve towards its optimum organoleptic characteristics [2]. Previous studies have demonstrated that the interface between the cork and the bottleneck plays a crucial role in regulating oxygen transfer into bottled wine [3,4]. However, how does this oxygen transfer evolve over time, and how is it influenced by storage conditions?

A study of the evolution of the oxygen-barrier properties of the closure system was therefore carried out, over a 24-month aging period, under controlled conditions simulating the conservation of wine in bottle [5]. Surface-treated micro-agglomerated corks were compressed into bottlenecks cut 70 mm from the top. After corking, only 6 mm of cork remained in the bottleneck. To examine the impact of wine on oxygen transfer, samples were stored either in the presence or absence of 10 mL of a model wine solution, sealed in an inert argon atmosphere with a glass disk affixed to the bottleneck's base. The samples were positioned to mimic either vertical storage (with exposure to the vapor phase) or horizontal storage (direct liquid contact). For horizontally stored samples, three temperatures were tested: 20°C, 35°C, and 50°C. Oxygen permeation measurements were carried out by manometry [6], in two successive stages: (i) on the complete system including the cork wafer compressed in the bottleneck, (ii) on the wafer alone, allowing for the determination of interface transfer by subtraction.

The findings revealed that the intrinsic oxygen diffusion coefficient of the micro-agglomerated cork remained unchanged across all storage conditions, even after 24 months. However, in the complete closure system, oxygen transfer predominantly occurred at the glass/cork interface, with this effect being influenced by storage conditions. At 20°C, the presence of model wine increased oxygen transfer at the interface compared to the dry condition. Storage orientation (upright vs. horizontal) had no impact on oxygen transfer. Temperature, however, significantly affected permeability. At 20°C, the closure system maintained stable barrier properties over 24 months, with equilibrium in water and ethanol sorption reached within the first three months. In contrast, at 35°C, interface barrier

properties began deteriorating after nine months, leading to a 1,000-fold increase in oxygen transfer. At 50°C, this deterioration occurred within just three months, causing a 10,000-fold rise in transfer. This drastic increase in oxygen permeability at elevated temperatures is likely due to alterations in the cork surface treatment and/or changes in the cork's mechanical properties.

These findings provide a novel perspective by highlighting the impact of the glass/closure interface on the shelf life of bottled wines under controlled storage conditions. To extend these results, obtained from a model system, to real-world wine preservation using a comprehensive oxygen transfer model, several additional parameters must be considered. These include the type of closure, its hydration state over a greater length, the surface treatment applied, and the long-term evolution of its mechanical properties.

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USE OF CORK IN CONSTRUCTION: PROFESSIONAL PERCEPTIONS AND CHALLENGES TO ITS ADOPTION

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Keywords: Natural resources, Architectural education, Building innovation, Sustainable materials.

ABSTRACT

Cork has been used in construction for centuries [1,2] due to its technical properties: it is lightweight, has thermal insulation properties and is a renewable natural resource [3,4]. In recent decades, there has been much research into the physiology of cork [5], as well as its physical properties, thanks to which it is used in various parts of the construction [6] and everyday life [7]. However, how construction professionals view its use remains unclear, especially in visible applications such as building façades.

This study, carried out as part of the CorkinArch project [8], aimed to explore this dimension by combining a survey targeted at technical specialists and architects with interviews involving scholars engaged in the topic. The survey received 23 responses. Its main finding is that cork is widely recognized as an effective material for thermal and acoustic insulation. Sustainability was also often highlighted as an advantage. However, its practical application still faces obstacles –cost is considered high, and many respondents reported insufficient knowledge about its proper use.

Interviews with scholars from various universities provided a complementary perspective. Twelve professionals with both academic and practical experience in the field were interviewed. They highlighted the value of cork and the gap between what is taught and what is used in practice. Many confirmed that, despite its potential, cork remains underused in real design solutions. The material is often applied as a "hidden" element, especially in renovation projects.

A comparative analysis (csQCA) of the responses received helped identify patterns: the presence of cork in academic curricula and the perception of its sustainability emerged as key factors influencing the adoption of the material. Direct experience alone proved less influential when isolated from these two aspects. In parallel to the survey and interviews, a detailed analysis of cork-realted courses in Portuguese higher education was conducted. A total of 182 courses focused on materials and sustainable construction were identified across 20 universities and polytechnic institutions. While this presence is positive, the data indicate a predominantly theoretical approach with limited emphasis on practical applications. Investment in workshops could help future professionals engage more closely with sustainable solutions.

The study explored perceptions of cork oak forests. Most respondents acknowledged their role in biodiversity protection and cork production, particularly in the Alentejo region, whose ecosystems were considered by respondents to have high ecological and economic value. Respondents highlighted their contributions to water retention, biodiversity conservation and fire prevention.

In summary, experts recognize cork's potential in sustainable construction but point to existing barriers that limit its wider adoption. Strengthening technical education and raising awareness of cork's environmental benefits may be key to increasing its use. In the future, it will be important to:

- Strengthen the teaching of cork in architecture and engineering courses;
- Promote its sustainable benefits among professionals;
- Invest in ongoing training and practical initiatives that bridge the gap between theory and construction practice;
- Conduct further research to assess the effectiveness of training in changing practices and implementing sustainable materials such as cork in real-world construction.

These findings complement those from the first phase of the study [8], in which the general public showed a positive but poorly informed perception of cork in construction. In contrast, professionals demonstrated greater technical knowledge and clearer understanding of the obstacles to its practical implementation.

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END-OF-LIFE OF CORK PRODUCTS – MYTHS, LIMITATIONS AND SUSTAINABLE OPPORTUNITIES

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Keywords: circular economy, recycling, end-of-life, cork stoppers, cork insulation

The end-of-life of cork products, namely the 4 options: composting, landfill, incineration and recycling are still strongly debated in the scientific literature and in the cork industry in terms of the environmental impacts of each option.

A significant amount of doubts and technical questions remain: although cork is a natural material, its biodegradability, due to its hemicellulose and lignin content, is limited as well as its disintegration without mechanical support which may preclude its use in composting. Additionally, this limited biodegradability strongly influences the amount of methane and carbon dioxide it can emit in landfill conditions, but there are no studies that specify this amount. Furthermore, it is also unclear how to model flaring/capture of methane as not all landfills currently fulfil this role (the European Environment Agency estimates 35% of methane produced is captured or flared in the UE [1]).

In terms of incineration, biomass waste-to-energy schemes are no longer considered to be fully neutral due to the concurrent, albeit low, emissions of methane and N_2O which are strong greenhouse gases. Studies indicate that different biomass sources lead to significant differences in emissions of these gases [2] although no specific data is available for cork. Furthermore, the impact of auxiliary material, such as polyurethane adhesives used in technical cork stoppers, need to be fully assessed.

In terms of recycling, cork waste is rather unique – it cannot be integrated in existing waste flows, requiring specific collection systems, and its an industry highly concentrated in the Iberian Peninsula. This presents challenges that limit the volume of collection and recycling options – regional recycling opportunities and reuse of resulting raw materials must be created.

Recycling enables delayed emissions of biogenic carbon [3], effectively increasing the time of CO_2 sequestration within the products, which can be further delayed by another recycling cycle.

The present study will discuss all these aspects, contributing with a mixture of laboratory tests in terms of biodegradability and emissions of cork combustion with logistic scenarios for recycling, simulated in Simapro to contribute to the scientific debate in terms of the impact of end-of-life of cork products, with particular emphasis in cork stoppers.

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GREEN TWIN: SELF-SUPPORTING INTERIOR PARTITION WALL FROM RECYCLED AGGLOMERATED CORK COMPONENTS WITH INTEGRATED GREENERY AND PLANT ENERGY SYSTEM

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Keywords: Recycled Cork, Cork waste, Green Wall, Modular Design, Digital Fabrication

ABSTRACT

The growing demand for sustainable and adaptable building materials has driven innovative applications of natural resources in architectural design. Cork, known for its durability, lightweight properties as well as thermal and acoustic insulation, presents a valuable material for construction. Furthermore, cork can be classified as a carbon negative and bio-material (Tártaro et al., 2017) , contributing to achieving decarbonisation challenges when it is applied either in indoor or outdoor environments. This effect can be further enhanced by the integration of plants and the use of cork waste. The Green Twin project explores the development of a parametric interior partition wall composed of agglomerated cork components fabricated with cork waste, integrating greenery with an automated irrigation and energy production system to enhance ecological performance and indoor comfort. The research examines the material behavior of recycled cork, modular construction, and digital fabrication techniques to propose an eco-efficient partition system, including the implementation of a full-scale prototype within an open space office and academic facility.

Traditionally used in bottle stoppers, cork has expanded into construction applications through agglomerates and subtractive manufacturing. Through iterative testing, the cork components of this green wall are made out of recycled cork from bottle stoppers, and thermally pressed to form structural elements without synthetic adhesives. This innovation enables the production of 100% cork components, ensuring reusability and minimizing waste. The key aspects of this research are the testing of different material granules, development of an interlocking system without external fasteners, development of a replicable cork module which can also host plants and testing the applicability of different textures achieved through CNC milling process on cork panels.

The interior wall of Green Twin is a modular system designed for adaptability across various spaces, intuitive assembly, expansion, and reconfiguration, shifting complexity from assembly to prefabrication, improving efficiency and flexibility for the user.

The module of the system is a cork brick of 450 x 200 x 200mm which includes cavities for integration of soil and plants, electrical systems needed for the integration of a plant microbial fuel cells systems for the production of electricity, cables for the monitoring systems and pipes for the irrigation systems. Due to the geometric complexity and texture experimentation of cork bricks, the manufacturing process utilizes a layered assembly approach where each layer is cut from uniform cork panels using CNC milling and joined with wooden dowels. CNC milling allows for intricate forms and textures, while the milling residues can be reused in the same developed pressing methodology and thus establishing a zero-waste manufacturing approach.
These parameters guided the design development resulting in a prototype implemented and tested in an indoor open space, consisting of 99 cork bricks, with overall dimensions of 4 x 2 Meter, incorporating 25 planters. This prototype is the first of a series of prototypes for indoor and outdoor spaces that will be developed to showcase innovative approaches to applying recycled cork in the AEC industry through material research, design exploration, and the application of advanced fabrication techniques.

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A SUSTAINABLE APPROACH TO AEROSPACE THROUGH CORK

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Keywords: Cork, Additive Manufacturing, Aerospace, Thermal Protection Systems

ABSTRACT

Cork is a natural material, a symbol of Portuguese heritage, primarily composed of suberin and lignin. Structurally, it exhibits an alveolar shape, and its unique combination of chemical composition and morphology results in unique properties, highlighting its lightness, compressibility, thermal insulation and ablative nature. These characteristics give cork-based materials great potential beyond their well-known use as stoppers, extending to technical applications ranging from sealing solutions to aerospace technology.

The present work aims at presenting an overview of the disruptive processing of cork powder residues by powder-based additive manufacturing (AM) technologies [1]and the study and development of technical solutions for aerospace applications. An example is the study and development of reusable hybrid ablative-replaceable cork tiles for thermal protection systems (TPS). The hybrid solution assumes a modular design, that combines high-performance thermoplastics and cork, instead of fully sacrificial cork-based TPS. The density of the final prototype solution will be optimized by AM.

The development of sustainable aerospace solutions is essential to minimize space debris and ensure the viability of future and long-term orbital operations.

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USE OF *AMADIA* AND UNMATURED CORK MIXTURES TO CORK-POLYPROPYLENE COMPOSITES FOR CONTACT WITH FOOD. SAFETY ASPECTS

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Keywords: Cork-polypropylene composites; Amadia cork; Food contact materials; Migration testing; Safety assessment

ABSTRACT

Cork has been widely used as a material in contact with food (FCMs), particularly for closures, either in its natural state or as granules bonded with a synthetic binder, typically polyurethane resin. The safety of these FCMs has been scrutinized through food contact notifications (FCN) to the FDA. Moreover, cork is recognized for its potential as an additive in polymeric matrices. The safety assessment of migrants from plant-based materials necessitates a case-by-case evaluation. Additionally, the incorporation of cork as a plastic additive should adhere to established rules in the EU Regulation 10/2011 and by guidelines [1].

This work aimed at to study relevant aspects related to the composition, processing and migration of *Amadia* and unmatured cork in cork-polypropylene (C_PP) composite. In particular, the influence of cork incorporation on migration of PP migrants was explored. Cork granules of different nature was analysed and a mixture was incorporated (15%) in PP. FTIR, DSC, metal analysis and screening analysis by GC-MS (volatile and semi-volatile), were performed in cork granules. Migration tests (ethanol 10%, acetic acid and oil) and sensorial analyses were conducted for the composites. Migration kinetics and repeated use tests were performed. Simulants were analysed by GC-MS and LC-MS. The composite samples after contact with simulants were analysed by scanning electronic and optical microscopy to evaluate surface integrity due to contact with the several simulants. Incorporation of cork granules on did not cause an increase of migration of the catalyst 9,9-bis(methoxymethyl)fluorene or the antioxidant Tris(3,5-di-tert-butyl-4-hydroxybenzyl) isocyanurate. Screening analysis showed potential cork migrants, in particular friedelan-3-one and 3,12-oleandione and high levels of furfural (~ 1 mg/kg), but this latter was not detected in the cork granules before incorporation. Therefore, is a NIAS from the extrusion and injection process. Cork components were not detected in the migration simulants (LOD 30 µg/kg).

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RNA-BASED BIOPESTICIDES FOR CORK OAK PROTECTION

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Keywords: Cork oak, RNAi, sustainable, phytopathology

Cork oak (*Quercus suber* L.) is an evergreen tree species that significantly impacts both the ecology and economy of the Mediterranean basin. Despite its widespread distribution, the population of *Q. suber* has been declining over the past 80 years, a trend potentiated by climate change. For instance, severe drought conditions are increasing stress on cork oaks, making them more susceptible to pathogenic attacks. Consequently, the incidence of cork oak diseases such as charcoal disease (caused by *Biscognauxia mediterranea*) and canker (caused by *Diplodia corticola*) has risen in recent years. The absence of specific treatments for these diseases, along with the progressive ban on chemical fungicides in the EU, highlights the need for new and innovative solutions. In this context, RNA interference (RNAi)-based fungicides represent a promising strategy. Spray-induced gene silencing (SIGS) is a cutting-edge RNAi method that silences target genes in phytopathogens. Preliminary results from our research indicate that targeting essential genes through SIGS disrupts the normal development of cork oak pathogens, resulting in reduced growth rates and the emergence of morphological anomalies. Given the high specificity of this approach, target-specific RNAi strategies hold significant potential as a new method for plant protection.

DEVELOPMENT OF CORK COMPOSITES FOR ECO-FRIENDLY SHOE INSOLES USING BIOBASED POLYURETHANE PREPOLYMERS

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Keywords: Bio-based Polyurethane; Prepolymer; Footwear; Cork Composites.

The footwear industry increasingly demands sustainable processes, emphasizing the replacement of synthetic raw materials with bio-based alternatives to produce eco-friendly materials [1]. This investigation seeks eco-friendly cork composites designed for shoe insoles using new polyurethane prepolymers as binders. Polyurethane prepolymers were synthesized with commercial polyester polyols containing 80%–100% bio-based content. To enhance the product's environmental sustainability, aliphatic isocyanate was used as an alternative to the typically used aromatics, reducing toxicity, hazardous by-products, and volatile organic compound (VOC) emissions without compromising performance. The synthesis involved a polycondensation reaction generating polyurethane intermediate prepolymers containing free isocyanate groups [2]. Chemical and physical characterization was used to assess the stability of the isocyanate content over time to ensure industrial viability, estimated using the standard method for determining NCO content (ASTM D2572-97) and Fourier Transform Infrared Spectroscopy (FTIR).

Cork composites were developed on a laboratory scale to identify the most promising prepolymer among those synthesized. Mechanical tests were conducted to assess key properties, including stress at break (σ), strain at break (ε), and modulus of elasticity (E). Based on these results, the system demonstrating superior flexibility and resistance was chosen for scale-up.

Later, shoe insoles were produced on a pilot scale using the selected prepolymer combined with the cork of two-grain sizes (0.2–0.5 mm and 0.5–1 mm) in a 50/50 ratio. The mixture was subjected to controlled agitation for 10 minutes, with batch sizes of approximately 1.25 kg. The resulting blend was then placed in a hydraulic press and subjected to 100 bar at 135 ºC for varying durations. The results confirmed the effective integration of synthesized prepolymers into cork composites, demonstrating promising flexibility, durability, and structural integrity for shoe insole applications, as illustrated in Figure 1.

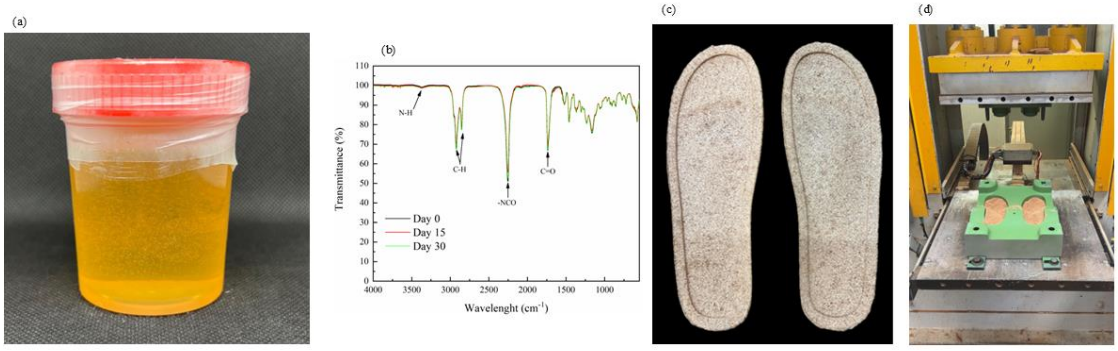

Fig.1. (a) Prepolymer synthesised with 10% NCO Content; (b) FTIR spectra of the synthesised PP with 10% NCO content; (c) Shoe insoles; and (d) Hydraulic press.

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DYNAMIC MECHANICAL PROPERTIES OF CORK AND CORK-SHEAR THICKENING FLUID COMPOSITES

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Keywords: Cork, Shear Thickening Fluids, Dynamic Tests, Mechanical Properties, High strain rate

ABSTRACT

Cellular materials such as agglomerated cork are widely used in engineering applications due to their exceptional properties, including fire resistance, excellent crashworthiness, low thermal conductivity, permeability, non-toxicity, and low density. This study employs two experimental setups to evaluate the dynamic compressive behaviour of agglomerated cork, both with and without the addition of shear thickening fluids (STFs), over a broad range of strain rates. The aim is to understand the relationships between material density, stress relaxation behaviour, and the influence of STFs, with an emphasis on high strain rates.

Dynamic compression tests were conducted across strain rates ranging from the quasi-static regime up to approximately 2000 s^{-1}. Quasi-static and intermediate strain rate tests (up to approximately 150 s^{-1}) were performed using an in-house developed mechanical testing device with linear motors. High strain rate experiments were conducted using a split Hopkinson pressure bar. All tests were recorded using a high-speed camera to capture the deformation behaviour of the specimens, and full-field data were processed using the digital image correlation (DIC) method. The results investigate strain rate sensitivity and high strain collapse of the material. The results of agglomerated cork and composites filled with STFs are compared to investigate the influence of non-Newtonian fluids within the cork matrix.

This research makes a significant contribution by expanding the study of agglomerated cork combined with shear thickening fluids over a broad range of strain rates—a topic not previously investigated by this research group. The findings advance the understanding of cork-STF composites in dynamic impact scenarios, offering valuable implications for engineering applications that require high energy absorption and resilience.

VARIABLE VISCOSITY IN CORK-BASED BIOCOMPOSITE EXTRUSIONS THROUGH ROBOTIC 3D PRINTING

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Keywords: Viscous Materials; Extrusions of Cork Biocomposites; Recycled Cork; Additive Manufacturing; 3D Printing; Robotic Fabrication.

ABSTRACT

Cork extraction, primarily sourced from the cork oak tree (i.e. *Quercus suber*), abundant in the western Mediterranean[1], is a sustainable practice occurring in cycles of a minimum of nine years, which preserves the tree's health[2]. Traditionally, cork has been used mainly for stoppers, but it's also employed in construction through agglomerates and subtractive manufacturing, albeit both processes with drawbacks like reduced natural properties and limited form and application. Consequently, these processes often involve high energy consumption, generate significant waste during material removal, and do not fully leverage cork's eco-efficient properties[3]. Therefore, despite being naturally derived, most binders—such as latex, resin, or polyurethane—exhibit limited compostability.[4]

Building in this context, recent studies highlight a growing demand for cork due to its lightness, long-lasting durability, and anti-microbial properties, along with increasing acoustic, thermal and eco-friendly applications in furniture and building design[5]. It is therefore vital to develop new advanced manufacturing techniques for cork biocomposites to maximize the life cycle of this limited but highly valuable material for a bigger range of sustainable applications. In turn, this study explores the potential of using recycled cork stopper waste as an extrudable sustainable bio-composite. Hence, the cork, sourced from post-consumer stoppers, was shredded and repurposed to extend the material's life cycle, addressing the lack of consistent reuse pathways. This circular approach seeks to add value to a widely available yet underutilized by-product. With an estimated 4,000 tonnes of cork stopper waste generated annually in Spain, as reported by the Fundació Institut Català del Suro (ICSURO), this research highlights the importance of finding innovative applications for cork waste.

In light of this, additive manufacturing offers tremendous potential, as they promise efficient material use and significant reductions in operational energy[6]. The research proposes novel robotic fabrication techniques for extrusions of highly-filled polymers[7], utilizing screw- and piston-based end-effectors to precisely control the viscosity of the material. While previous studies for non-fossil-based resources have explored these techniques in construction[8], there was a lack of focus on variable viscosity and planarity in cork extrusions with specific structural properties. Parameters such as flow change, flexibility, and adhesion are adjusted to enhance the scalability and complexity of biocomposites derived from recycled cork stoppers. The article showcases various designed prototypes to illustrate the proposed framework's feasibility, implications, and limitations.

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BIOTECHNOLOGICAL UPCYCLING OF CORK POWDER

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Keywords: Cork powder, circular bioeconomy, enzymatic hydrolysis, lignocellulosic biomass, green biotechnology.

ABSTRACT

The cork industry generates a diverse range of by-products during processing, most of which remain underexploited despite their potential as renewable resources. In this study, three primary by-products – cork powder (CP), cork boiling wastewater (CBW), and black condensate (BC) – were characterised to assess their suitability for biotechnological valorisation through enzymatic hydrolysis aimed at sugar recovery.

Cork powder, a fine particulate residue obtained from cork cutting and sanding, exhibited the highest potential due to its higher polysaccharide content, low moisture, and solid consistency, making it easier to handle and process. In contrast, CBW and BC were found to contain valuable compounds but were less suitable for direct application in enzymatic hydrolysis.

Focusing on cork powder, a hydrothermal pre-treatment (10% S/L, 175 °C, 45 min) was applied to disrupt the lignocellulosic matrix and improve enzyme accessibility. The pre-treated material was then subjected to enzymatic hydrolysis using cellulase (Cellic CTec 3, Novonesis, Denmark) at a loading of 30 FPU/g DM, enriched with hemicellulase (NS 22244, Novonesis, Denmark) at 400 µL/g DM. The reaction medium was further supplemented with hydrogen peroxide (65 µM) and Tween 80 (521mg/g DM) to facilitate cell wall disruption and improve enzyme accessibility. The impact of pre-treatment was confirmed by increased sugar yields compared to untreated samples.

Process optimisation was carried out using a 2^3 Central Composite Design to evaluate the effect of solid loading (5 to 15% w/v) and enzyme dosages (cellulase from 10 to 50 FPU/g DM, and hemicellulase from 50 to 750 µL/g DM). The optimal conditions led to a significant improvement in sugar release, supporting the efficiency of enzymatic hydrolysis as a green, low-impact processing route for cork

powder valorisation.

This work highlights the potential of enzymatic hydrolysis as an efficient, low-impact method to convert cork industry by-products—particularly cork powder—into sugar-rich hydrolysates. These intermediates can serve as versatile building blocks for bio-based chemicals, materials, or fuels, supporting the development of circular and sustainable value chains across multiple industrial sectors.

Acknowledgements: This work was supported by the Portuguese Foundation for Science and Technology (FCT) through a PhD grant number 2022.10290.BD. The authors would also like to thank JPS Cork Group for providing the cork by-products.

EFFECT OF SCRUB CLEARING ON ACORN PRODUCTION AND REGENERATION IN CORK OAK FORESTS OF THE SERRA D'ESPADÀ (CASTELLÓ)

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Keywords: Scrub clearing, cork oak, regeneration, acorn production, acorn predation

Shrub clearing is usually a desired intervention by cork productors in cork oak forest to reduce competence to adult trees and to facilitate cork estraction tasks. However little is known about its interactions with the natural regeneration of this forest, especially in complex orografic areas and highly variable precipitation regime as the one in the Espadà Mountains (Valencia, Spain)

Regeneration in oaks is the result of a multi-step uncoupled process [1]. Here we show our first results of the ongoing study to evaluate the acorn production, dispersal, predation, germination and establishment in six 1 Ha cleared patches and near control cork oak forest with diferent slopes and orientation with the aim to asses the magnitude and sign of each step in the final outcome.

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METHODOLOGY FOR OBTAINING ANATOMICAL SLIDES OF THE PHLOEM FROM *QUERCUS SUBER* L.

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Keywords: cork oak, phloem, anatomy, microscopy, sectioning

The cork of *Quercus suber* originates from the phellogen (cork cambium), which produces phellem (cork) outward and phelloderm inward. Unlike most species, where the phellogen remains active for only a few years, in cork oak it can persist throughout the tree's lifetime. While extensive research has been conducted on the xylem and phloem (bark) of this species, studies specifically analyzing the anatomical structure of the phloem remain scarce. This study presents a methodology for obtaining suitable preparations for the microscopic examination of this tissue. To this end, previously dehydrated samples are embedded in polyethylene glycol, with adhesive tape used to facilitate sectioning and various staining techniques applied to highlight the phloem structures. The methodological description is complemented by microphotographs taken under visible and polarized light.

ANATOMICAL AND PHYSIOLOGICAL CONSEQUENCES OF CORK HARVESTING

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Keywords: *Quercus suber* L., dendroanatomy, vessels, management.

ABSTRACT

The cork oak (*Quercus suber* L.) is a species of high ecological and economic importance, particularly in the Iberian Peninsula. In managed areas, trees are debarked every 8-11 years as a source for the cork industry, with important consequences for tree physiology and wood anatomy. Some studies have indicated a reduction in the vessel size following bark removal, which may potentially affect their hydraulic conductivity and, ultimately, tree growth. However, the extent to which vessel formation is affected and the ability of cork oaks to recover their original vessel patterns remain poorly understood. Here, we quantify the immediate effects of bark removal on vessel size and number in a managed woodland in southern Spain. Anatomical traits were analysed using polished core samples and images obtained with a stereo microscope. Image analysis techniques were used to measure hydraulic diameter (*Dh*), vessel area, and vessel frequency in wood rings formed before and after debarking, as well as and in trees that had never been debarked. We found evident differences in vessel formation between debarked and never-debarked trees. Specifically, there was a notable reduction in vessel size following bark removal, while the number of vessels increased. Furthermore, these anatomical changes persisted over subsequent years, indicating long-term alterations in wood development. Such changes may affect the trees' ability to cope with rising temperatures and water scarcity. In this sense, adjustments to management practices may be necessary to ensure the viability of the most vulnerable populations.

IMAGE ANALYSIS OF THE CORK FROM *Kielmeyera coriacea* MART. IN THE BRAZILIAN CERRADO

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Keywords: Cerrado, Brazil, quality, image analysis, pau-santo

ABSTRACT

Kielmeyera coriacea, commonly known as pau-santo, is a tree species characteristic of open areas in the Brazilian Cerrado. Due to the unique characteristics of this biome, which has two well-defined seasons—a rainy summer and a dry winter—along with the frequent occurrence of fire, tree species tend to develop trunks with a substantial amount of cork tissue. An effective method for assessing cork quality is anatomical image analysis. High-quality cork should exhibit minimal porosity and be free from encrustations, whether caused by insects or inherent genetic factors. Given the importance of identifying promising cork-producing species in the Brazilian Cerrado, this study aims to analyze the macroscopic structure of *K. coriacea* cork through image analysis, focusing on potential irregularities in periderm formation. Samples were randomly collected from native tree populations in the region of Luminárias, Minas Gerais, Brazil. Twenty trees were selected for image analysis and classified into five different diameter classes. Cork samples for macroscopic structural analysis were processed using a bandsaw to ensure proper orientation in the transverse, tangential, and radial planes. The surfaces were polished using a bench sander with P100 sandpaper and then cleaned with compressed air. The prepared surfaces were photographed using a Samsung 10 MP L201 digital camera and analyzed with Leica Qwin image analysis software. Both tangential and non-tangential (transverse and radial) planes were examined. In general, the cork samples exhibited certain structural characteristics that are considered defects affecting their quality. Most analyzed samples displayed dark brown lines along the transverse and radial sections, identified as included phloem tissue or "prego." This type of tissue is embedded in small portions within the cork mass due to an abscission process resulting from the formation of partial periderms in a phase subsequent to phellogen activity. Another significant observation from the image analysis was the presence of lenticular channels or lenticels in the transverse and radial sections. These channels were predominantly filled with a brownish, powdery tissue, known as "terrentos," which negatively impacts cork quality. From a physiological perspective, lenticular channels are essential for gas exchange between the tree's living tissues and the external environment. However, from a technological standpoint, they are considered a depreciating factor for

cork quality. The presence of "terrentos" lenticels results from an anomaly in the function of the lenticular phellogen, where instead of producing typical, tightly packed suberized cells, it generates a loose tissue composed of rounded cells with intercellular voids. The walls of these cells do not always undergo complete suberization, leading to inadequate filling of the lenticular channels. Additional imperfections were identified throughout the sections, including extensive and sinuous cavities in the suberous tissue caused by insects such as termites and ants, which are common in the collection region. It was also observed that the suberous tissue does not develop continuously in the initial layers, resulting in pronounced fissures. This characteristic is also observed in *Quercus suber* and is known as "enguiado". It occurs mainly in the first and second cork layers produced by the tree, compromising quality. These fissures originate due to radial growth stresses in the xylem, phloem, and phellem, creating tangential tensions that lead to their formation in the peripheral suberous layers. A reduction in these fissures is observed in *Q. suber* trees that have undergone multiple cork harvesting cycles, with significant improvement noted after the third harvest in a nine-year debarking cycle. However, the cork from *K. coriacea* in this study had not been previously debarked, classifying it as virgin cork. Based on all analyzed images, no distinct annual growth layers were identified in the cork of *K. coriacea*. In contrast, these layers are often evident in *Q. suber,* appearing as alternating lighter and darker bands corresponding to spring and autumn growth, respectively. The absence of clearly defined growth layers in *K. coriacea* is likely due to the tropical climate of the study region, where seasonal variations are less pronounced than in temperate climates, making these growth rings less distinguishable. The distribution and abundance of lenticular channels are predominantly genetically determined. Therefore, future studies should include a broader sampling strategy to assess whether cork quality varies across different geographic locations of the species. Through image-based analysis, the cork samples exhibited several macrostructural characteristics that could be classified as defects relevant to their quality assessment. In summary, most samples displayed dark brown lines along the transverse and radial sections, identified as included phloem tissue, which may compromise the commercial value of the cork.

Effect of temperature on the crystallinity of cork polysaccharides

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Keywords: Crystallinity, polysaccharides, cellulose, hemicellulose, X-ray diffraction.

Cork is made up of cell walls containing different natural biopolymers such as lignin, suberin, and polysaccharides. This unique cellular structure confers specific mechanical properties allowing the production of cork stoppers suitable for sealing and preserving wines. The mechanical properties of cork are affected by humidity, temperature, and mechanical stresses, suggesting that they are changing the structure/interactions of cork polymers, particularly the crystallinity of the polysaccharides. Therefore, the objective of this study is to evaluate the crystallinity of the different polymers in cork and the effect of temperature on them, comparing two corks of different origins - Cassà de la Selva (CS, Spain) and Porto Torres (PT, Italy).

Corks were ground to obtain granules with a diameter between 0.35 and 0.7 mm, and their crystallinity was studied at different temperatures. When cork granules are treated at 25°C and analyzed using X-ray diffraction (XRD), four intense peaks associated to crystalline cellulose (2θ values at 15°, 21°, 35° and 40°) and three lower intensity peaks associated to lignin (2θ values at 43°, 63° and 75°) are detected. However, heat treatment at 150°C results in increased intensities of the cellulose peaks at 2θ values of 15°, 20° and 35° and an increased intensity of a new peak of 19°, which may be associated to hemicellulose. The XRDs of CS and PT granules show the same peak patterns at 25ºC, except the existence of an additional cellulose peak at 2θ value of 21° that appears in PT granule only. The intensities of all cellulose peaks measured at 25°C (2θ values of 15°, 21°, 35° and 40°) and lignin (2θ values of 43°, 63° and 75°) are significantly lower in PT granule.

In summary, polysaccharide crystallinity has been observed in corks from both populations and the changes in the crystallinities of cellulose and hemicellulose by temperature and humidity have been demonstrated. Therefore, this study has shown that corks from different origins present different degrees of crystallinity. This parameter could influence the mechanical properties of cork stoppers.

NATURAL COMPOSITES OF EXPANDED CORK GRANULATES WITH WOOD AND BARK CHIPS

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Keywords: bark, wood chips, expanded cork, composites, insulation, surfacing panels.

ABSTRACT

Buildings are increasingly searching for new construction materials that combine a favourable ecological footprint with suitable properties such as lightness and insulation. Forest-based products fulfil sustainability requirements, and a general call is underway to use more wood and wood boards in civil engineering. In this context, cork and cork agglomerates are highly valued since they have an outstanding set of properties combining low density, hydrophobicity, durability and very good thermal properties. Expanded cork agglomerates are used as wall insulation layers and have recently been applied as an external cladding of buildings. These expanded corkboards are produced without resin binding and therefore between granules adhesion do not allow high tensile resistance.

Innovative composite boards were produced using polyurethane-bound expanded cork granulates (6 mm) with wood and bark chips of *Eucalyptus maculata* aiming towards a possible use in construction. The glue was 4% in volume of the mixture, and the wood or bark chips were added to the cork granules at a volume ratio of 40:60. The composites were produced in a lab press with heated plates at 150ºC and 50 bar pressure during 30 min, to a 1 cm final thickness. Well bound prototypes were obtained that were tested regarding density, hardness, tensile strength and thermal conductivity.

The visual appearance of the boards was striking ranging from a dark brown surface of the expanded cork composite to a surface mixing light coloured wood chips with dark cork granules.

The composites density ranged from 191 kg m^{-3} to 316 kg m^{-3}, Janka hardness from 1.6 MPa to 2.9 MPa, and thermal conductivity from 0.045 W m^{-1} K^{-1} to 0.051 W m^{-1} K^{-1}. Tensile strength was 0.16 MPa for the expanded cork composites and 0.09 MPa and 0.17 MPa for the composites with wood and bark chips respectively.

The results show that it is possible to mix expanded cork granules with lignocellulosic chips into composites that have good insulation properties and low density, and although not mechanical resistant as other materials, they may be applied as surfacing materials in construction. Optimization of process conditions should be a next step for further designing such innovative expanded-cork based composites.

PYROLYSIS AND COMBUSTION OF VIRGIN CORK AND CORK STOPPERS: CHARACTERIZATION AND THERMODYNAMIC ANALYSES

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Keywords: Virgin Cork, Cork Stopper, Biofuel, Circular Economy

ABSTRACT

Cork is a tissue that forms part of the bark of the cork oak (Quercus suber L.), a native tree species typical of the Mediterranean forest. Around 2.7 million hectares of cork oak forests are currently conserved in the world, of which more than 60% are concentrated in Europe [1]. Currently, The Iberian Peninsula has the highest rate of cork extraction worldwide, at more than 80% [2]. Nowadays, the natural cork stopper is still the most valued product of the cork industry, and is the axis around which all related products and elements revolve.

However, not all cork extracted from the cork oak has the quality required for the production of cork stoppers. For instance, in the case of virgin cork, which is the cork obtained from the first extraction of the cork oak and is characterized by being a very irregular and porous material. On the other hand, the cork stopper is a residue after being used for the closing of bottles. Therefore, virgin cork and recycled cork stoppers are two examples of products that are in line with the principles of the green economy and the circular economy, so that the energetic use of these wastes can be key to the competitive improvement of the sector.

Specifically, a characterization of two samples of virgin cork from different years and a sample of cork stopper has been carried out. The tests proposed for characterisation are as follows: moisture and proximate analysis, ultimate analysis, major and minor elements. Besides, an energy study of the pyrolysis and combustion process has been carried out by means of Thermogravimetric Analysis (TGA), Differential Thermogravimetry curve (DTG) and pyrolysis and combustion indexes.

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MORPHOLOGICAL ASPECTS OF THE CORK OF *ANADENANTHERA PEREGRINA* VAR. *FALCATA* (BENTH.) ALTSCHUL

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Keywords: Cerrado, Morphological Aspects, Structural Adaptation, Functional Properties

The Cerrado, a vast tropical savanna ecoregion in Brazil and the second-largest biome in the country, is a global biodiversity hotspot facing threats such as deforestation, industrial agriculture, and climate change (1, 2). In this context, adapted tree species with thick bark rich in cork play an important role in protecting against adverse conditions and environmental impacts.

Cork stands out for its unique properties, such as low density, thermal insulation, water impermeability, durability, and chemical inertness, which result from its cellular and chemical characteristics (3), making it a valuable raw material for industry. However, most cork-producing species in the Cerrado remain underexplored, limiting their potential for valorization.

This study aims to analyze, for the first time, the morphological aspects of cork cells of *Anadenanthera peregrina* var. *falcata*, expanding knowledge about this resource and its possibilities for sustainable applications. Bark samples of this species were collected at a height of 1.30 m from eight trees in Campo Grande-MS, Brazil, with heights ranging from 6 to 10 m and diameters from 10 to 20 cm. After manually separating the cork layer, 5 mm cubes were prepared, coated with gold-palladium, and analyzed using a Hitachi S-2400 scanning electron microscope (SEM). Cellular measurements were performed on 900 cells using the ImageJ software, following the methodology described by Pereira et al. (4) and Pereira (5).

In cross-sections of the bark of *A. peregrina* var. *falcata*, an extensive phloem is observed, covered by a periderm that develops continuously around the stem as the trees age. The cork layer is prominent, with a light brown coloration, visible fissures, and growth rings well-defined by dark boundaries. The radial width of the cork layers ranges from 1 to 4 mm.

In tangential sections, cells show a polygonal shape in a honeycomb-like arrangement, whereas in non-tangential sections (radial and transverse), they are rectangular and arranged in parallel lines similar to brick walls. Most cells have 6 sides (55% in tangential sections and 42.5% in non-tangential sections), followed by cells with 5 sides (23% and 32%, respectively). Growth rings consist of larger cells in earlycork (6 to 9) and smaller cells in latecork (2 to 4), with radial wall thicknesses of 1.84 µm (earlycork) and 2.11 µm (latecork). Average dimensions include prism height of 28.54 µm in earlycork and 15.28 µm in latecork, prism base edge of 23.97 µm for both, and mean base area of 1.492×10^{-5}

cm^2. Total cell volume was 4.259×10^{-8} cm^3 for earlycork and 2.280×10^{-8} cm^3 for latecork. Cell density per unit volume was 2.489×10^5 cells/cm^3 in earlycork and 4.386×10^5 cells/cm^3 in latecork. The solid volume fraction was 15.8% for earlycork and 22.3% for latecork.

The results highlight the morphological characteristics of cork from *Anadenanthera peregrina* var. *falcata*, such as distinct cellular organization and structural variability between earlycork and latecork, which reinforce its adaptation to the Cerrado, a hot, dry, and fire-prone environment. These features provide cork with protective insulating properties, along with functional attributes such as thermal insulation and low density. For potential applications, it is important to determine the porosity ratios of cork from these tree species and explore their relationships with chemical and structural properties.

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CHEMICAL COMPOSITION OF THE CORKS OF SPECIES FROM THE CERRADO BIOME: *Erythrina Mulungu*, *Enterolobium Gummiferum*, AND *Platymenia Reticulata*

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Keywords: Extractives, Lignin, Suberin, Industrial Applications, Bioeconomy

The Cerrado, the second-largest vegetation formation in Brazil, is considered one of the world's main biodiversity hotspots. Despite its ecological importance, the Cerrado faces severe threats, such as the suppression of native vegetation due to the expansion of industrial agriculture and the impacts of climate change, which intensify droughts and frequent fires.

Among the adaptations of Cerrado trees to adverse conditions are their thick barks, rich in cork, which act as natural barriers against high temperatures, water loss, and biotic attacks. Cork, with its unique properties such as low density, thermal resistance, water impermeability, and chemical inertia, is valuable for industrial uses. However, the lack of detailed studies on its chemical composition and structure limits its sustainable exploration and economic utilization.

Within this context, the species *Erythrina mulungu* Mart. ex Benth., *Enterolobium gummiferum* (Mart.) J.F.Macbr., and *Platymenia reticulata* Benth., native to the Cerrado, have economic, medicinal, and ornamental relevance. They are distinguished by their thick barks, characterized by a continuous and circumferential periderm, accompanied by a substantial cork layer marked by deep longitudinal fractures caused by stem radial growth. Their corks exhibit a typical radial cellular organization, similar to the cork of *Quercus suber*. However, in *E. gummiferum*, the earlycork cells display greater heterogeneity, with more radially elongated shapes [1, 2].

In this scenario, this study aims to analyze the differences in the chemical composition of the corks of these three species, evaluating their unique properties and potential industrial applications.

The corks were collected in a Cerrado area in northern Minas Gerais, Brazil. Chemical analyses were performed with composite samples that were ground, sieved between 40 and 60 mesh, and conducted in triplicate. Extractives were determined using sequential Soxhlet extractions following the TAPPI T 204 cm-97 (1997) standard. Suberin was quantified using the method described by Pereira [3], while Klason lignin was analyzed following adaptations of the TAPPI T222 om-02 (2002) standard. Soluble lignin was measured by spectrophotometry (TAPPI UM-250, 1991), and ash content was obtained in a muffle furnace at 550 °C (TAPPI T211 om-02, 2002). Polysaccharides were estimated by the difference in total chemical composition.

The cork of *E. mulungu* had the highest total extractives content, totaling 38.4%, with 17.9% nonpolar compounds soluble in dichloromethane and 82.1% polar compounds solubilized by ethanol and water (18.9% and 12.4%, respectively). In addition, it has high levels of total lignin (36.8%) and polysaccharides (20.8%), along with 4.7% suberin and 1.0% ash.

The cork of *E. gummiferum* presented a more moderate total extractives content, with 20.3%. Of this total, 8.4% corresponds to nonpolar compounds and 91.6% to polar compounds (5.4% solubilized by ethanol and 12.12% by water). This species exhibited the highest levels of polysaccharides (36.6%) and total lignin (38.6%), while suberin and ash accounted for 3.8% and 0.80%, respectively.

The cork of *P. reticulata* had the lowest total extractives levels, with 12.7%. Of this total, 26.7% were nonpolar compounds and 73.4% polar compounds (5.7% solubilized by ethanol and 3.6% by water). However, it stands out for the highest suberin content among the three species, reaching 24.7%, while total lignin was recorded at 34.5% and polysaccharides at 20.9%. Ash content accounted for 1.0%.

The corks of the three species show chemical differences that indicate distinct industrial potentials. The cork of *E. mulungu* stands out for its chemical diversity, being ideal for industrial applications that value extractives. *E. gummiferum* has a balanced profile, with high lignin and polysaccharide contents, making it suitable for structural and biotechnological uses. *P. reticulata*, on the other hand, is more suitable for insulation and coating due to its high suberin content. The fundamental role of these species in industrial and bioeconomic applications is highlighted, reinforcing their alignment with efforts to conserve the species of the Cerrado biome.

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PRELIMINARY OBSERVATIONS OF *Hedera* SPP. AND CORK PANELS INTERACTIONS AS GREEN FAÇADE THROUGH PHOTOGRAPHIC MONITORING AT AJUDA BOTANICAL GARDEN

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Keywords: Native climbing plants; Sustainable facade materials; Expanded Insulation cork panels; Plant attachment dynamics; Nature-based urban solutions

ABSTRACT

The utilization of climbing plants in indirect green facades as nature-based solutions in cities offers numerous benefits, including species conservation, biodiversity enhancement, and contributions to sustainability, thermal stability, and energy savings. However, long-term building damage — such as deterioration of wall surfaces or paint, moisture infiltration through walls, and maintenance issues related to the use of traditional supporting materials like plastic and metal — raises concerns about sustainability and environmental impact. Moreover, the predominant use of exotic species in green facade cultivation, along with the water consumption of these species, often does not align with the climatic conditions of the region. Information on the applicability of native species for green facades remains limited.

To address these obstacles, a long-standing experimental project has been conducted since 2021 at the Ajuda Botanical Garden in Lisbon, Portugal, where cork panels were installed on a brick and cement wall as a sustainable low-cost alternative to green walls for supporting native ivy species (*Hedera iberica* and *H. hibernica*) in indirect green facades.

The initial results of this project indicate that the plants were able to find the cork panels and attach to the structure.

In the second stage of the experiment, systematic photographic monitoring of plant behavior on cork substrates initiated in December 2024. The surface of all cork panels at the same distance and at the same point in each photo photographed across time to track changes in plant attachment and growth. The analysis, based on comparative cropping of the same regions, revealed that the ivies progressively established themselves, with their fine roots penetrating into the pores and micro-crevices of the cork panels. Subsequently, a gradual increase in plant growth observed, and the plants climbed to the upper parts of the cork panels. Notably, a marked increase in foliage growth occurred during the spring

months, highlighting seasonal influences on plant–cork interactions. Since the leaves of *H. hibernica* differ from those of *H. iberica* and have a larger surface area, therefore *H. hibernica* was able to cover a greater portion of the panels—an aspect that can be considered in future research during the species selection process. Although the study is ongoing, these early findings suggest cork's promising role in supporting living systems for applications in sustainable design, vertical gardens, and bio-architecture. Further quantitative assessments are planned to deepen the understanding of these interactions.

CHARACTERIZATION OF SOIL COMPOSITION AND MACRONUTRIENT UPTAKE IN CORK OAK TREES OF DIFFERENT AGES IN THE MONTADO OF ÉVORA

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Keywords: agroforestry ecosystems, cork oak, leaf and soil analysis, macronutrients, Portugal

ABSTRACT

In the Iberian Peninsula, "Montado" or "Dehesa" are Portuguese and Spanish terms (respectively) for a traditional agroforestry system common to both countries. In Portugal, this landscape is characterized by cork oak and holm oak trees forming wooded landscapes (occupying 1.22 Mha [1]) mainly found in the south, often associated with grazing livestock (such as cattle or pigs). However, these socio-ecosystems, which are economically important for companies and local communities, face challenges related to declining local knowledge, management transformations and climate change [2]. Given the potential decline of cork oak forests, there is a need for decision-support tools to enhance the management of cork oak forests and improve business competitiveness. In this regard, macronutrients absorbed from soil are crucial for the correct functioning of plants metabolism. Thus, soil and leaf analysis were conducted on cork trees classified as young (never stripped) and adult (previously stripped) across three different moments (February, April and July).

The study was conducted in Évora (GPS coordinates: 38.5493728, -8.0642313), within a geological unit known as "Ediacaran migmatites" (~ 590 Ma), where the soil texture was identified as loamy sand. Soil moist content (assessed with a laboratory stove), ranged from 1.2 to 5.4 %, decreasing as temperatures rose from February and July. Organic matter (measured by using a muffle furnace), varied between 3.2 – 4.0 %, likely influenced by livestock activity. Macronutrients concentrations (phosphorus (P), sulfur (S), potassium (K) and calcium (Ca)) measured via X-ray fluorescence, ranged between 0.02 – 0.04 %, 0.06 – 0.10 %, 0.60 – 1.01 %, and 0.24 – 0.42 %, respectively. Soils near adult trees generally exhibited lower nutrient levels, with the lowest values recorded in April.

In leaf samples, P, S, K and Ca concentrations ranged from 0.06 – 0.18 %, 0.18 – 0.24 %, 1.05 – 2.08 %, and 0.68 – 1.02 %, respectively. Phosphorus and S concentrations were similar between young and adult trees, while adult trees showed higher K and lower Ca levels than young trees. Overall, July presented the lowest leaf macronutrient levels. In conclusion, antagonistic and synergistic interactions may occur in cork oak leaves and macronutrient uptake varies with seasonal patterns, weather conditions and soil nutrient availability.

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EFFECTS OF A WILDFIRE ON CORK POROSITY AND CORK GROWTH

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Keywords: Fiji software, Pixel color analysis, Cork quality, Image analysis.

ABSTRACT

The cork oak (*Quercus suber* L.) is one important forest species of the western Mediterranean basin with a relevant role in the economy as a producer of cork, a valued raw material, especially to produce wine cork stoppers. The industrial value of cork is mainly determined by two features, cork thickness and porosity, which establish the aptitude for cork stoppers and their quality. Factors that may impact on these features e.g. edaphoclimatic, genetic, and silvicultural have been addressed. However, the effect of wildfires has not been addressed although they are gradually more recurrent in the mediterranean ecosystems and increasingly greater threat for forest species, including the cork oak. Due to the lack of information on cork properties from partially burned trees, it is difficult to assess the post-fire consequences on cork development, a relevant information for forest management from an economic and ecological perspective. This study analyses the effects of a wildfire on cork porosity and annual growth by comparing cork samples from partially burnt and unburned trees in the same stand.

A total of 24 samples from partially burned trees and 23 samples from non-burned ones were taken from a cork oak stand located in Santarém county. The wildfire event that affected this stand occurred in 2013. The cork extraction had been in 2008 and was made again in 2021, corresponding to a 13-year cork cycle (2008-2021), meaning that the wildfire occurred during the 5th year of cork growth. Several dendrometric and fire-related variables were measured at the tree level: diameter at breast height; total height; debarking height; Wounds as the area of the three largest wounds on the tree trunk; HminB and HmaxB as the minimum and maximum height of the trunk charred, in percentage relative to the total height of the tree, respectively; Burned coef as the coefficient of total burned area relative to the debarking height of the tree; Severity as percentage of the trunk charred in the first two meters of height; Green crown as volume of green crown, in percentage relative to the total crown.

The cork samples were processed according to the post-harvest industrial practice of water boiling. ImageJ/Fiji image analysing software was used to measure annual growth and porosity. Annual growth rings were marked and measured at least in two positions of the sample. Cork porosity was

detected using the Trainable Weka Segmentation plugin, by training a base classifier on pre-determined regions of interest and adapt it for each sample. The year of the wildfire was marked on the cork sample and the cork area before and post-fire were calculated, along with their respective porosity percentage.

Paired samples t-tests were used to determine if the cork porosity before and after the fire was significantly different. Likewise, independent samples t-test were used to compare the cork porosity of the burned and non-burned trees for two periods: 2008-2012 (before the fire) and 2013-2021 (after the fire). The relationship between fire- and tree-related variables, and cork porosity was inspected using correlation analysis and linear regression.

Preliminary results show that mean cork porosity and mean cork annual growth were significantly higher in samples from trees affected by the fire. The fitted linear model including the Severity variable explained 21.8 % of cork porosity variability of postfire cork samples. This suggests that trees that survive a fire will have a decrease in cork quality. However, these conclusions are only valid for the conditions tested: a dry and hot climate, a cork oak stand with fluvisols and a fire that occurred after on the 5th year of cork growth.

DEVELOPMENTS IN SEMI-AUTOMATED RECOGNITION OF CORK POROSITY USING IMAGE ANALYSIS

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Keywords: Fiji software, Cork Porosity, Pixel color analysis, Cork quality.

ABSTRACT

Cork is one of the most important non-wood forest products produced in Portugal and in several Mediterranean countries. A wide variety of products are made from cork raw materials, with cork stoppers being the most valuable product. The value of cork depends on its physical characteristics for industrial processing, which are evaluated by assessing the thickness and porosity of the cork. High porosity is associated with low quality as the tissue has less insulating capacity, therefore devaluing the product. Cork pores vary considerably making the identification and measurement of cork porosity a complex task. The identification and measurement of cork porosity requires the used of human-based methodologies to ensure the collection of accurate data due to the highly variable morphology of cork samples. However, such methods are time consuming and can become impractical for large sample sizes. Thus, the aim of this study is to test alternative semi-automated techniques that can significantly reduce the data collection time while maintaining its accuracy.

Our methodology consisted in using the image analysis software ImageJ/Fiji to identify and measure cork porosity. A set of ten cork samples processed according to industrial methods, and whose surfaces were sanded were used. Two methods were compared: 1) using the image processing software AnalySIS®; 2) semi-automatic measurement using the Trainable Weka Segmentation plugin from Fiji. First method was the research group's standard method for porosity analysis based on an exhaustive collection of Regions of Interest per sample, so the measurements obtained were considered as control data, while method B was based on using ROIs to train a segmentation model that can be applied and adapted to multiple samples. Linear regression and residual analysis were used to assess the precision and bias of the semi-automated methods.

Preliminar results showed a strong linear relationship of cork porosity values between the two methods (R^2 = 0.8787; unbiased residuals). Semi-automated methods allowed to obtain faster measurements.

According to these results, the tested semi-automated methods show potential to significantly reduce the time required to collect data on physical cork characteristics while maintaining an acceptable level of error. To consolidate these results more samples will be used to verify if the

precision of the semi-automated methods is maintained. Samples from different cork quality classes will be considered to evaluate the adaptability of the semi-automated methods for very different cork samples.

NUTRIENT INTERACTION PATTERNS IN GRÂNDOLA CORK OAK ACROSS DIFFERENT SEASONAL PERIODS: SOIL AND LEAF DYNAMICS

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Keywords: cork oak, climate change, mineral elements, Portugal, X-ray fluorescence analyzer

ABSTRACT

In Portugal, the Montado landscape is characterized by extensive wooded areas predominantly composed of cork oak (Quercus suber) and holm oak (Quercus ilex) trees [1]. Despite their economic significance, these ecosystems face considerable challenges, including transformations in management practices and the impacts of climate change [2]. Tools designed to support decision-making are becoming increasingly essential in optimizing forest management practices. To address these issues, ensuring the availability of mineral elements absorbed from the soil is crucial for the proper metabolic functioning of plants [1].

In this context, a research study was performed in a Montado region of Grândola, Portugal (GPS coordinates: 38.1071851, -8.4419802), within the parent rock formation of "phyllites and quartzites" (Devonian, ~372 Ma). Organic matter content, determined through muffle furnace analysis, ranged between 4.6% and 7.6%, potentially reflecting the influence of livestock activity. Using an X-ray fluorescence analyzer (XRF), the soil concentrations of sulfur (S), potassium (K), calcium (Ca), iron (Fe), and zinc (Zn) were recorded at 0.08%, 0.65–0.73%, 0.09–0.37%, 1.00–1.33 ppm, and 29.08–34.75 ppm, respectively. Additionally, mineral element concentrations in the leaves of young (never subjected to stripping) and adult (previously stripped) cork oak trees were analyzed using the same technique. Higher levels of K, Ca, and S were found in adult trees in February, whereas K and Ca exhibited elevated concentrations in July. In contrast, Zn and Fe levels were higher in young trees compared to adults. The respective concentrations of S, K, Ca, Fe, and Zn ranged from 0.17 to 0.24%, 1.00–1.59%, 0.71–1.06%, 314.55–1129.85 ppm, and 51.75–54.10 ppm. Soils near adult trees showed higher concentrations of Ca and Zn, but lower levels of Fe and K.

These findings showed a mineral element concentrations generally higher in February, likely due to seasonal variations and water availability, which influence nutrient uptake and absorption. Nevertheless, the cork oak's adaptability to the Mediterranean climate results in dynamic nutrient absorption patterns, reflecting its resilience to environmental fluctuations.

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ACCELERATING FIRST CORK HARVEST: FASTEST-GROWING *QUERCUS SUBER* PROVENANCES CAN REDUCE TIME TO INITIAL DEBARKING BY UP TO 15 YEARS

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Keywords: Cork Oak, Provenance trials, Genetic variation, Growth rate, First cork harvest

ABSTRACT

Cork oak (*Quercus suber* L.) is an iconic Mediterranean species facing significant challenges due to climate change and ecosystem decline. Selecting appropriate Forest Reproductive Material (FRM) with enhanced adaptive capacity is crucial for the success of reforestation efforts and the sustainability of cork oak woodlands. This study evaluates the genetic variability in adaptive traits among 35 cork oak provenances originating from Portugal, Spain, France, Italy, Morocco, Tunisia, and Algeria, established in a common garden trial in Southern Portugal (Herdade do Monte Fava) in 1998.

At age 23, significant differences ($P<0.05$) were observed among provenances for survival, diameter at breast height (DBH), and overall phytosanitary status. The most striking result was the variation in growth rates. The fastest-growing provenances, predominantly Moroccan, achieved DBH values that could reduce the time to reach the minimum legal diameter (22 cm) for first cork harvest by up to 15.3 years compared to the slowest-growing provenance (Haza de Lino). Mean survival across provenances was 83.6%, ranging from 67% (Corsica) to 93.5% (local Ermidas do Sado and Alcácer do Sal). Most Portuguese provenances also performed above average in growth. Phytosanitary condition varied, with Portuguese and French provenances generally displaying better vitality than the overall average (30% affected trees), while provenances from Italy, Tunisia, and Algeria showed higher susceptibility to pests/diseases or defoliation.

These findings underscore substantial exploitable genetic variation in cork oak for adaptive and growth traits. Selecting the fastest-growing, well-adapted provenances offers a critical pathway to

reduce the extended time to first economic return, a major historical deterrent in cork oak silviculture. Findings also highlight the importance of provenance choice and provide valuable data for guiding FRM deployment strategies, including considering assisted migration, while acknowledging the need for caution regarding site-specificity and potential Genotype x Environment interactions. Further evaluation incorporating cork quality is underway.

MODELLING THE CHEMICAL IMPACT OF ETHANOL-WATER SOLUTIONS ON CORK STRUCTURAL COMPONENTS

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Keywords: cork stoppers, ethanolysis, lignin, suberin, response surface methodology

ABSTRACT

The specific properties of cork, e.g. impermeability, compressibility, mechanical resistance, thermal insulation, and inertia, result from its cellular structure and chemical composition. The structural components of cork, especially suberin and its association with lignin are critical to define the physical behavior of cork and therefore the in-use performance of cork products. Although extensive research has addressed the characterization and variability of cork chemistry and properties, the effect of ethanol-water solutions is still largely unknown. This is particularly important for cork stoppers in wine bottles, especially when in-bottle wine aging is done over extended periods.

This work investigates the effect of ethanol-water solutions on cork structural components using extractive-free cork samples under different reactive conditions e.g. ethanol concentration (0–100%), temperature (135–185 °C), and time (53–187 min) by applying a response surface methodology with a central composite design to model the following responses: solid cork yield and chemical composition, including DCM (dichloromethane) solubles, suberin and lignin contents. The solid cork yield reflects the chemical attack on cork structural components with solubilization of fragments which, given the liquid polarity, should correspond to polysaccharides and lignin degradation products. DCM solubles reflect the depolymerization of suberin with the non-polar fragments remaining attached to the solid.

Overall cork showed considerable stability in ethanol-water thermal processes. Modelling had very good fit for solid mass yield and DCM solubles. The cork yield model had ethanol as main influential variable, increasing with higher ethanol concentrations, lower temperatures, and shorter reaction times. The DCM-soluble model had temperature as the dominant factor, with ethanol concentration playing a smaller role. The suberin content was higher under conditions of increased temperature and extended reaction time, whereas ethanol concentration had less impact. Lignin content decreased with temperature but increased with longer reaction times and lower ethanol concentrations. Suberin proved remarkably strong to ethanolysis while a moderate delignification occurred but not to an extent that could impart the performance properties of cork stoppers.

RESEARCH ON PERFORMANCE OF BAMBOO FIBER REINFORCED CORK SHEET

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Keywords: Cork sheet; Bamboo fiber; Tensile strength; Pliability

ABSTRACT

In China, the thickness of the cork bark form Quercus variabilis is smaller, so the cork cannot be directly used to produce natural cork stoppers. Instead, the cork bark is processed into granulated cork, which are then used to produce agglomerated cork products such as cork sheet. In recent years, the increasing difficulty of cork bark stripping and the rise in labor costs have led to an increase in the price of granulated cork, resulting in a higher cost of cork sheet. Additionally, the low tensile strength of cork sheet restricts its application in broader fields. Therefore, it is necessary to carry out research on reducing the cost and improving the performance of cork sheet.

In this study, bamboo fibers with low cost and high specific strength were used as the reinforcing phase to strengthen cork sheet. The sizes of bamboo fibers were divided into six categories: 24-30 mesh, 30-40 mesh, 40-50 mesh, 50-70 mesh, 70-100 mesh, and above 100 mesh. The sizes of granulated cork were three types: 12-16 mesh, 16-24 mesh, and 24-32 mesh. The cork sheet materials were prepared by plate hot-pressing method with the target thickness of 2 mm, using polyurethane adhesive at the addition amount of 15%, and using the hot-pressing temperature of 120 °C for 6 minutes. Firstly, the influence of different mixing ratios of granulated cork with three mesh numbers on the properties of cork sheet was studied. Secondly, the influence of the size and addition amount of bamboo fibers, as well as the density of composites, on the properties of cork sheet was studied.

The main research results are as follows:

(1) The different mixing ratios of granulated cork with three mesh numbers had no obvious effect on the tensile strength and pliability properties of cork sheet. When the mixing ratio of granulated cork was 4:4:2(12-16:16-24:24-32), the cork sheet exhibited better performance at 0.27 g/cm³, with the tensile strength of 0.90 MPa and the pliability of 3.6 times.

(2) When the composite density was 0.4 g/cm³ and the bamboo fiber addition amount was 20%, the tensile strength of the composite cork sheet was improved compared with that of pure cork sheet (1.59 MPa) when using 24-70 mesh bamboo fibers. However, when the size of bamboo fibers was 70-100 mesh and above 100 mesh, the tensile strength of the composite was instead decreased. In addition, with the addition of bamboo fiber, the pliability of cork sheet deteriorated. When using 30-40 mesh bamboo fibers, the composite cork sheet had the maximum tensile strength of 1.83 MPa and the pliability of 5.1 times. And when using above 100 mesh bamboo fibers, the composite cork sheet had the minimum tensile strength of 1.53 MPa and the worse pliability of 5.9 times.

(3) Different composite densities and different bamboo fiber addition amounts also affected the properties of cork sheet. When the composite density is lower than 0.30 g/cm³, the addition of bamboo fiber would instead reduce the tensile strength of cork sheet. When the density is 0.30 g/cm³, 0.35 g/cm³, and 0.40 g/cm³, the addition of bamboo fiber promoted the improvement of the tensile strength of cork sheet.

(4) The addition of bamboo fiber improved the dimensional stability of cork sheet, reducing it from a relatively large value of 2.92% (when no bamboo fiber was added) to 1.24%. Meanwhile, the addition of bamboo fiber slightly increased the thermal conductivity of the composite, but it remained below 0.11 W/(m·K), classifying it as a thermal insulation material.

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LONG-TERM EFFECTS OF POST-FIRE MANAGEMENT ON CORK OAK (*QUERCUS SUBER* L.): NATURAL REGENERATION

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Keywords: adaptive management, ecosystem services, fire ecology, mediterranean woodlands, recovery pathways

ABSTRACT

Cork oak (*Quercus suber* L.) regeneration is a cornerstone for the ecological integrity and economic viability of cork oak stands. Despite their recognized importance, these woodlands have experienced areal decline and stand density reduction. Effective natural regeneration is crucial for their long-term sustainability and the continued provision of vital ecosystem services.

The Serra do Caldeirão region has witnessed a documented regression of *Quercus suber* L. [1]. While short-term post-fire regeneration studies offer some insights [2,3], a significant knowledge gap persists regarding medium to long-term recovery dynamics, especially concerning comparative analyses of unmanaged natural regeneration versus areas subjected to post-fire management interventions [4]. This investigation, conducted within the SUDOE REMAS project (SOE3/P4/E0954), aims to elucidate the long-term impacts of conventional post-fire forest management—primarily shrub control, often executed via disc harrowing—on vegetation recovery in *Quercus suber* L. ecosystems.

The study was situated in Serra do Caldeirão (Southern mainland Portugal). In 2022, we assessed four 706 m² plots that burned in 2004: two received conventional post-fire management (shrub control), and two were left to regenerate naturally (n=2 per treatment). Cork oak regeneration was quantified by enumerating individuals and measuring their height along three 10 m transects within each plot. Plot selection ensured homogeneity concerning pre-fire *Q. suber* density, slope aspect, and fundamental edaphic characteristics.

Encouraging cork oak regeneration was recorded in three of the four plots, with west-facing aspects demonstrating superior natural recruitment. Although managed plots (subjected to shrub control) tended to exhibit a numerically higher density of regenerating cork oaks, this difference was not

statistically significant when compared to unmanaged plots, critically, unmanaged plots displayed markedly more consistent regeneration outcomes (i.e., lower standard deviation in recruit numbers).

However, there were no significant differences between managed and unmanaged plots. Contrary to other studies, the slope orientation with the highest natural regeneration was in the South-West and the lowest in the North and South-East plots. This study also indicates that natural regeneration is insufficient to ensure an economically viable tree density (77.68 trees per hectare were obtained in the managed plots and 28.25 trees per hectare in the unmanaged plots). The average tree height per group was 82.36 ± 68.50 cm in the managed plots and 98.75 ± 37.67 cm in the unmanaged plots.

This highlights the imperative for more extensive research into post-fire recovery trajectories in cork oak stands. Critically evaluating the long-term ecological and economic trade-offs associated with different management interventions, such as cork stripping cycles and shrub management strategies. Such research is paramount given the escalating frequency and intensity of wildfires anticipated under Global Change scenarios. A larger replicate number is essential for future investigations to substantiate these initial observations.

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STF-REINFORCED CORK COMPOSITES FOR ENHANCED MITIGATION OF CONCENTRATED IMPACT FORCES

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ABSTRACT

Cork composites are well known for their excellent energy absorption, making them attractive materials for impact mitigation. However, their mechanical performance under concentrated impact forces—such as those caused by penetrating objects—remains a significant limitation [1]. While previous studies have explored shear thickening fluid (STF) reinforcements at the interface of cork composites [2–3], the improvements in impact mitigation have generally been marginal. To overcome this challenge, we present a novel reinforcement strategy incorporating 3D STF reinforcements within cork composite structures [4]. The hybrid composites consist of two adhesively bonded cork layers, one of which is machined to house STF reservoirs of varying depth, area, and shape (circular and hexagonal). Thirteen configurations were tested under low-energy drop-weight impacts with a 20 mm hemispherical impactor. Compared to neat cork, STF-reinforced samples showed a significant reduction in maximum impact force—even for shallow (2 mm) STF volumes, yielding an average 20.3% improvement. The best-performing configuration—a 30 mm diameter, 5 mm deep cylindrical reservoir—achieved a 59.7% reduction, while a hexagonal design with a 16.5 mm side length reached 57.5%. An optimal reinforcement-to-sample thickness ratio of 25% was identified. Exceeding this threshold did not improve and could even impair performance. These findings demonstrate that 3D STF reinforcements can substantially enhance cork's resistance to localized impacts, supporting its application in advanced protective applications, including defence systems, where both energy absorption and penetration resistance are critical.

Keywords: Shear thickening fluid (STF); Cork; Reinforcement; Impact; Hybrid composite.

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VALUING CARBON SEQUESTRATION IN POST-FIRE CORK OAK FORESTS: A CASE STUDY FROM MONCHIQUE, PORTUGAL

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Keywords: Agroforestry, Carbon storage, Ecosystem Services Certification, Payment for Ecosystem Services, Quercus suber

One of the biggest challenges in managing non-productive forest areas is the development of viable economic models that recognize and reward non-provisioning Ecosystem Services (ES). In Mediterranean agroforestry systems, these services — ranging from carbon sequestration to biodiversity conservation — are often undervalued or excluded from traditional markets. This is particularly evident in Portugal's Monchique region, where cork oak (*Quercus suber*) forests play a vital role in the economy and culture of the region but are increasingly vulnerable to climate-driven disturbances, such as wildfires.

In 2018, Monchique experienced one of the most devastating wildfires in recent Portuguese history, burning over 26 800 hectares and severely impacting cork production. A private landowner in the parish of Alferce, whose property was heavily affected, faced the loss of productive cork trees and the degradation of forest structure. With limited options for immediate economic recovery, the landowner, already a member of the 2BForest's Forest Stewardship Council® certification group (FSC-C135716), turned to alternative ways of valuing the forest's ecological functions.

The property received an FSC® certification for both Forest Management (FM) and verification of ES impacts (M105) in 2024, specifically targeting the restoration of forest carbon stocks (ES2.2). This certified area, part of the Natura 2000 Network (PTCON0037), encompasses 97.13 hectares and is managed under a plan to increase of the density of forested areas, through natural regeneration and replanting of cork oak and strawberry tree (*Arbutus unedo*), protect the landscape against wildfires and preserve protected species, such as the endangered Monchique oak (*Quercus canariensis*). The certification process, supported by the Ecosystem Services Sponsorship project (ES_SPONSOR) – a 2BForest programme to find and engage sponsors in forest restoration and conservation – involved rigorous field assessments and ecological modeling, resulting in an increase from 5 037.18 to 6 637.38 tonnes of carbon stock between 2018 and 2024.

Today, the landowner continues to extract cork from surviving trees and integrates complementary land uses such as sheep grazing and the production of *aguardente de medronho* (*Arbutus unedo* brandy), demonstrating the multifunctionality and resilience of agroforestry systems. This ES_SPONSOR project also contributes to wildfire risk reduction, soil stabilization, and biodiversity enhancement, aligning with national and EU-level goals for climate adaptation and rural development. The FSC certification not only provides visibility and recognition in ES markets but also enhances the credibility of sustainable forest management practices.

This case study illustrates the potential of ES certification to transform post-fire recovery into an opportunity for innovation in cork oak landscapes. By quantifying and monetizing carbon sequestration, landowners can diversify income streams, reduce vulnerability to climate risks, and

contribute to broader environmental goals. The Monchique example underscores the importance of integrating ecological restoration with market-based instruments, offering a replicable model for other fire-prone Mediterranean cork oak forests seeking to balance conservation and economic viability.

INFLUENCE OF THE STORAGE CONDITIONS AND TYPE OF CORK STOPPER ON THE QUALITY OF BOTTLED RED WINES

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Keywords: anthocyanins, red wine, micro-agglomerated cork, natural cork, technical cork.

The quality of red wine is closely related to its chemical composition and sensory properties before bottling. However, after bottling, its composition changes continuously during the storage period, mainly due to factors such as temperature, light exposure, bottle position, oxygen content or oxygen transmitted through cork stoppers. Thus, the aim of this study was to assess the effect of light exposure, temperature and type of cork stoppers on the quality of a bottled red wine over three months under different storage conditions. Red wine made with Touriga Nacional and Aragonês grapevine varieties (*Vitis vinifera* L.) from 2020 vintage was bottled (amber glass bottles, 750 mL) in 2025 using three different cork stoppers [natural cork (naturity®); micro-agglomerated cork (neutrocork®); technical cork (twin top®) from Amorim Cork, Portugal]. Two storage conditions were chosen: one in hypermarket (light exposure and temperature), and another in optimal cellar conditions (darkness and 16°C). The wines stored under commercial conditions showed significant decrease in total monomeric anthocyanins and total pigments, being the higher decline in wine bottled with neutrocork stopper. The decrease is consistent with the involvement of these compounds in numerous condensation reactions and degradations during the storage period. The monomeric anthocyanins in red wine are not particularly stable, and their concentration in wine usually drops quickly during storage in bottle because the exposure to light. The natural cork stopper better preserved the quality of the red wines in terms colour intensity and colour tonality. These findings highlighted that temperature and light exposure conditions in commercial retail considerably decrease the quality of bottled red wines and, consequently, their shelf life.

ULTRAFILTRATION AND NANOFILTRATION FOR THE RECOVERY OF PHENOLIC/TANNIC COMPOUNDS AND WATER FROM THE CORK PROCESSING WASTEWATERS

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Keywords: Cork Processing Wastewaters; Recovery of Water and Phenolic/Tannic Compounds; Ultrafiltration/Nanofiltration

ABSTRACT

Cork processing wastewaters are generated in large volumes in the operation of immersion of the cork planks in boiling water for softening and disinfection. These wastewaters are a complex mixture of vegetal extracts with a very high fraction of phenolic/tannic colloidal matter that is responsible for severe environmental problems. The present work investigates:

1- The water reuse through an integrated process of flocculation/ flotation/ ultrafiltration (UF);

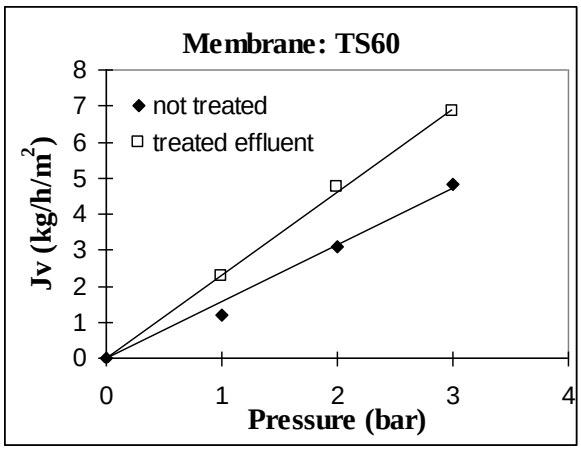

FIG. 1 – PERMEATION FLUX AS A FUNCTION OF THE APPLIED TRANSMEMBRANE PRESSURE.

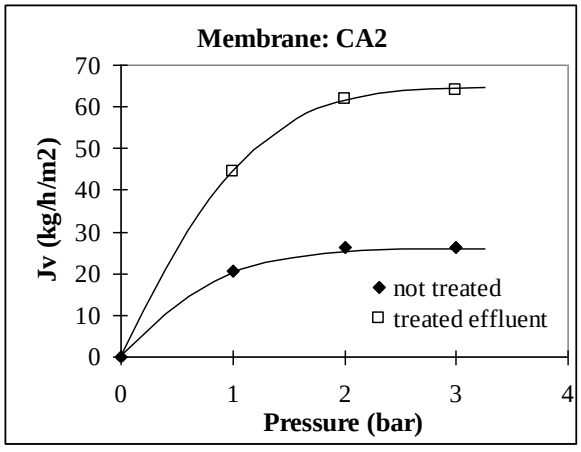

FIG. 2 – PERMEATION FLUX AS A FUNCTION OF THE APPLIED TRANSMEMBRANE PRESSURE.

Fig1 and Fig2 display the ultrafiltration performance before and after the pretreatment of flocculation/ flotation with the commercial membrane TS60 (molecular weight cut-off of 4000 Da) and the

laboratory made CA2 membrane (molecular weight cut-off of 98 kDa), respectively. The removal of the colloidal matter with fouling characteristics [1] leads to a significant enhancement of the permeation fluxes.

2 - The recovery of phenolic/tannic compounds by nanofiltration (NF).

The nanofiltration of 100 liter of wastewater is carried out with a Filmtec NF200-2540 spiral-wound module in concentration mode [2]. The NF concentrates are used in the leather industry for the vegetable tanning of the skins.

References:[1] **"**Tannic-membrane interactions on ultrafiltration of cork processing wastewaters**",**Miguel Minhalma, Maria Norberta de Pinho, Separation and Purification Technology, 22-23 (2001), 479-488 .

[2] "Nanofiltration of Cork Wastewaters and Their Possible Use in Leather Industry as Tanning Agents",Vitor Geraldes, Miguel Minhalma, Maria Norberta de Pinho, A.Anil, H.Ozgunay, B.O.Bitlisli, O.Sari, Polish J.of Environ.Stud.,18(3) (2009),353-357.

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Day 1 October 13th, Monday

Time	
8h30	Registration
9h00	**Opening and welcoming speeches** Ricardo Sousa, *University of Aveiro* Helena Pereira, *University of Lisbon* Luís Ferreira, *Rector of the University of Lisbon*
9h30	**Keynote lecture** Designing smart cork oak management and cork production modelling tools in the context of climate and territorial challenges Margarida Tomé *(CEF, ISA-Ulisboa, PT)*
10h00	**Presentations** Cork oak forests and sustainability Chair: Joana Amaral Paulo *(CEF, LA TERRA, ISA-Ulisboa, PT)*

10h00: Identifying the drivers of canopy greenness trends in the cork oak woodlands of Portugal Danielle Rudley *(CEF, LA TERRA, ISA-ULisboa, PT)*
10h15: FSC® Ecosystem Services Procedure - the role of certification in enhancing the value of forests Miguel Soares *(FSC Portugal, PT)*
10h30: Forest certification in Mediterranean oak woodlands: drivers, challenges and management impacts Marco Marques *(CEABN-InBIO, ISA-ULisboa, PT)*
10h45: Fertigation in the last years of a cork production cycle – a cellular approach Ana Poeiras *(CREATE, UÉ, PT)*

11h00	Break
11h30	**Interview** José Ramon Gonzalez-Adrados *(UPM, ES)* Interviewed by Helena Pereira *(CEF, ISA-Ulisboa, PT)*
12h00	**Presentations** Cork oak forests and sustainability Chair: Ricardo Sousa *(TEMA, UA, PT)*

12h00: Advances in intensive monitoring plots of *Quercus suber* Nuno Almeida Ribeiro *(CREATE, ECT-UÉ, PT)*
12h15: Use of a resistance drill to study the internal structure of cork oak trunks José Gonzalez-Adrados *(ETSI de Montes, Forestal y del Medio Natural, UPM, ES)*
12h30: Corkclass: a mobile application to enhance the valuation and commercialization of cork batches in the field María del Cuvillo García, *(ICIFOR-INIA, CSIC, ES)*
12h45: The rationale behind cork's thermal properties: a comprehensive review Tiago Santos *(TEMA, UA, PT)*

13h00 Lunch

14h00 **Keynote lecture**

R&D drivers for cork industrial success: the case of Amorim Cork
Miguel Cabral *(Amorim Cork, PT)*

14h30 **Presentations**

Cork and wine

Chair: Thomas Karbowiak *(Institut Agro Dijon, FR)*

14h30:
Phenolic compounds able to pass from cork to wine: reactivity and sensory implications
Joana Azevedo *(LAQV-REQUIMTE, FCUP, PT)*

14h45:
Is wine bottle overcapping wax an effective oxygen barrier or just an aesthetic element?
Ghadi Abi Fadel *(Institut Agro Dijon, FR)*

15h00:
Vocus cork analyzer: real-time technology for industrial quality control of natural corks and discs for still and sparkling wines, and for monitoring contamination in cork harvesting areas.
Luigi Ciotti *(Tofwerk AG, CH)*

15h15:
Impact of storage conditions on oxygen transfer during wine bottle aging
Julie Chanut *(Institut Agro Dijon, FR)*

15h30 **Roundtable**

Towards more resilient cork oak agroforestry in the context of global changes
Panel: Luís Bonifácio (*INIAV, PT*), Maria Conceição Caldeira *(CEF, LA TERRA, ISA-Ulisboa, PT),* Helena Machado *(INIAV, PT*), Nuno Oliveira (*Amorim Agro-Florestal, PT*)
Moderator: Manuela Branco *(CEF, LA TERRA, ISA-Ulisboa, PT)*

16h00 Break

16h30 **Presentations**

Cork oak forests and sustainability

Chair: Ofélia Anjos *(IPCB, PT)*

16h30:
Mitigating *Coraebus undatus* damage: the role of mixed stands
Manuela Branco *(CEF, LA TERRA, ISA-Ulisboa, PT)*

16h45:
Cork oak proteins as markers of the biological pattern of decline induced by interacting with *P. cinnamoni*
Ana Cristina Coelho *(CISCA, Ualg, PT)*

17h00:
RNA-based biopesticides for cork oak protection
Pedro Ferreira *(CBMA, Uminho, PT)*

17h15:
Sustainability of the montado: challenges, strategies and future perspectives
José Carlos Pinto da Silva *(FEUC*; *INFEIRA, PT)*

17h45 **Poster session**

20h00 **Conference Dinner** at Restaurante Museu da Cerveja (Praça do Comércio)

Day 2 October 14th, Tuesday

Time	
9h00	**Keynote lecture** Update on the structure and regulated biosynthesis of the apoplastic polymer suberin Dylan Kosma (*UNR, USA)*
9h30	**Interview** António Rios Amorim *(CEO Amorim Cork, PT)* Interviewed by Helena Pereira *(CEF, ISA-Ulisboa, PT)*
10h00	**Presentations** Cork science and properties Chair: Ofélia Anjos *(IPCB, PT)*
	10h00: Understanding deformation mechanisms of cork under compression loading using digital image correlation François Villette *(SUPMICROTECH, FR)*
	10h15: Unraveling the role of pectins in the accumulation of trichloroanisole in cork Rocío Arce *(CRAG, ES)*
	10h30: Study of the compressive behaviour of natural cork under exposure to water and ethanol vapours during ageing Massimiliano Gerometta *(Institut Agro Dijon & SUPMICROTECH, FR)*
	10h45: Dynamic compressive behavior of cork agglomerates combined with shear thickening fluids: experimental and computational approaches Guilherme Sousa *(TEMA, UA, PT)*
11h00	Break
11h30	**Presentations** Cork science and properties Chair: Solange Araújo *(CEF, LA TERRA, ISA-Ulisboa, PT)*
	11h30: Mitigating visual perception of photodegradation through mixtures of untreated and heat-treated cork granules: an image-based analysis Byeongho Kim *(KNU, ROK)*
	11h45: Valorization of winter cork through nirs-based characterization Clara Esteban Álvarez *(ICIFOR-INIA, CSIC, ES)*
	12h00: Comparison of vocus cork analyzer and iso 20752:2023 as quality control methods in the cork industry Monica Tiana *(UNISS, IT)*
	12h15: Biotechnological upcycling of cork powder Lara Campos *(BCBT, DUT, DK)*
	12h30: Does forest certification contribute to cork oak woodland conservation? Miguel Bugalho *(CEABN-InBIO, ISA-Ulisboa, PT)*

12h45 Lunch

14h00 **Keynote lecture**

Cork: New trends in Architecture

Cristina Veríssimo *(DAL, CAN)*

14h30 **Presentations**

Cork in construction and engineering

Chair: Gabriel Serra *(TEMA, UA, PT)*

14h30: Use of cork in construction: professional perceptions and challenges to its adoption Conceição Colaço *(CEABN-InBIO, ISA-Ulisboa, PT)*
14h45: End-of-life of cork products – myths, limitations and sustainable opportunities João Jesus *(CTCOR, PT)*
15h00: Green twin: self-supporting interior partition wall from recycled agglomerated cork components with integrated greenery and plant energy system Ricardo Mayor-Luque *(IAAC, ES)*
15h15: A sustainable approach to aerospace through cork José Martinho Oliveira *(CICECO, UA, PT)*

15h30 **Roundtable**

Cork applications: from design to engineering, from health to space

Panel: Martinho Oliveira *(ESAN, UA, PT),* José Graça *(CEF, ISA-Ulisboa, PT)*, Lisete Moutinho (Amorim Cork Solutions), Tomáš Fíla (*FTS-CTU, CZ),* João Campos (*IST, PT*)

Moderator: Ricardo Sousa *(TEMA, UA, PT)*

16h15 Break

16h45 **Presentations-**

Innovative cork products

Chair: Duarte Neiva *(CEF, LA TERRA, ISA-Ulisboa, PT)*

16h45: Development of cork composites for eco-friendly shoe insoles using biobased polyurethane prepolymers Gabilton Adão *(CIMO, LA SusTEC, IPB, PT)*
17h00: Dynamic mechanical properties of cork and cork-shear thickening fluid composites Tomáš Fíla *(FTS-CTU, CZ)*
17h15: Variable viscosity in cork-based biocomposite extrusions through robotic 3D printing Ricardo Mayor-Luque *(IAAC, ES)*
17h30: Use of Amadia and unmatured cork mixtures to cork-polypropylene composites for contact with food. Safety aspects Tiago Monteiro Vieira *(CBQF, ESB-UCP, PT)*
17h45: Estimation of above-ground biomass in a cork oak forest using geospatial techniques Veronica Mercado-Vázquez *(ETSI Agronómica, Alimentaria y de Biosistemas, UPM, ES)*

18h00 **Conclusions**

Field Visit October 15th, Wednesday

Time	
8h00	Departure by bus from Lisbon to Coruche (ca. 80 km) Meeting point: Rectory of the University of Lisbon Coordinates: 38° 45' 10.4" N, 9° 09' 27.6" W
9h45	Field visit to the cork oak forest Herdade da Quinta Grande (Coruche) Coordinates: 38° 56' 3.25" N, 8° 31' 3.31" W Presentations: *Joana Amaral Paulo (ISA/CEF), Helena Pereira (ISA/CEF) and José Ribeiro da Cunha (Herdade da Quinta Grande)*
11h15	Arrival at Observatório do Sobreiro e da Cortiça Coordinates: 38° 56' 10.3" N, 8° 29' 10.0" W
11h30	Visit to the Observatório do Sobreiro e da Cortiça building and exhibition Presentations: *Joana Faria (FSC), António Gonçalves Ferrreira (UNAC), Francisco Oliveira (Câmara Municipal de Coruche)*
13h15	Arrival at Fábrica Amorim Florestal - Coruche Reception: *Carlos Abreu* (Amorim)
13h30	Lunch at the factory's cantine
14h30	Cork industry Visit to the Amorim factory
16h30	Departure to Lisbon by bus
18h00	Arrival in Lisbon