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THE INTERNATIONAL RESEARCH GROUP ON WOOD PROTECTION

Section Y

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**Sustainable wood products development in a bio-refinery
perspective: case studies in French Guiana**

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Sustainable wood products development in a bio-refinery perspective: case studies in French Guiana

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ABSTRACT

French Guiana, by its belonging to the Amazon region and the Guiana shield, has very specific environmental and social characteristics in the French regional ensemble. In this context, it is thus necessary to find how to reconcile the economic development of the territory, the conservation of biodiversity and the recognition of local knowledge and practices. Bringing together multidisciplinary skills contributes to the discovery of original and applied solutions to local issues and challenges, based on local resources. The research projects presented here aim to develop more integrated approaches regarding the different scientific and technical issues related to endogenous natural resources, notably forest biomass and wood products, and their valorization in the Guianese socio-ecosystem. They exemplify the search for new perspectives based on the bio-refinery concept, through innovative uses of wood, new sustainable construction materials from ligno-cellulosic and plant resources, or functionalities of molecules from durable woods. The objective is to promote the sustainable development of innovative products, and to ensure an optimal diversification of forestry resources. In the longer term, they intend to contribute to the identification of new promising sectors to stimulate in the endogenous economy of French Guiana in the context of a circular economy.

KEYWORDS

French Guiana, timber industry, botanical insecticides, cosmetics, thermic panels, roundwoods, building industry

FRENCH GUIANA: CONTEXT AND CHALLENGES

Tropical Amazonian rainforest is the primary ecosystem in French Guiana, covering 8 million hectares, i.e., around 96% of the emerged lands of this French overseas territory. These forests are renowned for their outstanding biodiversity, but are also used to meet the needs of the population. In particular, several tree species are exploited for timber, with a marked effort to ensure a sustainable exploitation, notably through the implementation of reduced-impact logging practices (Ballère et al., 2021; Hiltner et al., 2018; Piponiot et al., 2018). The exploitable forest area (DFP, or “Domaine Forestier Permanent”) is managed and regulated by the French Office National des Forêts (ONF), and represents 2.4 million hectares, of which only 4 500 hectares are currently in use. The annual volume of harvested logs is around 77 000 m³, with fluctuations depending on the climatic and logistical conditions. A characteristic of the Guianese timber industry is also that it is

very selective. Out of 1 700 tree species recorded in French Guiana, about only 60 are exploited, of which 2 (*Dicorynia guianensis* Amsh., Fabaceae and *Sextonia rubra* (Mez.) Van der Werff, Lauraceae) represent around 75% of the total volume (CRFB (Commission Régionale de la Forêt et du Bois), 2019; Soulères, 2021).

However, the Guianese forest and wood industry intends to strongly increase its production, i.e., up to 210 000 m³/year of logs in 2030, to meet the socio-economic demand. These forecasts are linked to the strong demographic growth (around 2.5% per year between 2009 and 2014) experienced in French Guiana, which causes increasing needs of both the construction and the biomass energy market. In this context, it is thus necessary to conciliate the economic and social development of the territory, the preservation of its biodiversity, alongside with promoting the recognition of local knowledge and practices. Forest industry indeed generates large volumes of residues (currently around 30-50 000 t/year only for sawmill residues), as the average lumber conversion rate is around 40%. Biomass power plants are currently the only built infrastructures that enable to valorize these by-products, and the development of innovative application paths for this resource is strongly at stake. The use of residual bioresources, currently not promoted by the local wood industry, constitutes a unique opportunity to produce sustainable materials and eco-friendly wood products. The valorization of ligno-cellulosic resources for the construction industry as well as the production of bioactive extracts and molecules could moreover stimulate the diversification and resilience of the Guianese wood industry. This responds to the demand of a fast-changing society, and contributes to create new circular models within the local industry, avoiding the need for further impact on the forest.

The research organizations present in French Guiana aim to contribute to the discovery of such original and applied solutions related to local issues and challenges by bringing together multidisciplinary skills. Biorefinery, i.e., the search for optimized and sustainable valorization of all the agro-forestry resources through the development of beneficial by-products, is the corner stone of such research programs. Biorefinery is notably expanding for the production of high value-added products from wood or bark, complementary to novel biomaterials and biomass energy (Cherubini, 2010; Devappa et al., 2015; Hasegawa et al., 2016; Royer et al., 2012a; Verkasalo et al., 2021). Embedded in a bio-based economical context, biorefinery contributes to solve major issues related to the economic valorization of natural resources. These themes will be illustrated in the following examples of ongoing and future research projects in French Guiana. In a wider scope, these perspectives are included in several of the Sustainable Development Goals adopted by the United Nations in 2015, such as the “Industry, Innovation and infrastructure” as well as the “Responsible consumption and production” objectives, but also aim to contribute to the “Climate action” or “Life on land” global goals¹.

FROM WOOD PROTECTION TO HEALTH PROTECTION: DEVELOPMENT OF LARVICIDE PRODUCTS BASED ON *SEXTONIA RUBRA* WOOD EXTRACTS

As a first example, the SextoniAedes European research project² aimed to study *S. rubra* defensive heartwood molecules to inspire economically valuable and environmentally friendly solutions for vector control (Clervil et al., 2020). This tropical tree species presents in the Guyana shield (French Guiana, Suriname, Guyana and Venezuela) and in Amazonian Brazil is characterized by a remarkable long-lasting heartwood naturally resistant to decay, and therefore exploited for carpentry, residential construction and outdoor applications (Detienne et al., 1989; Rodrigues et

¹ <https://www.undp.org/sustainable-development-goals>

² <http://www.ecofog.gf/spip.php?article1177>; <https://youtu.be/Ptkic4MUo6c>

al., 2012; Van der Werff, 1997). The antifungal, termiticidal and larvicidal properties of its heartwood are well known, and the role of the two γ -lactones rubrenolide and rubrynolide in these biological functionalities was widely described (Falkowski et al. 2016, 2020; Houël et al., 2017; Rodrigues et al., 2010, 2011). *S. rubra* wood extract also demonstrated insecticidal activity towards the *Ae. aegypti* mosquito larvae, which has been patented by Falkowski et al (2014). (Falkowski et al., 2014) The SextoniAedes project was conducted from 2017 to 2022 to transform the discovery of a promising ecological larvicidal wood extractives into a valuable product.

Plant-based insecticides appear as a promising alternative for the development of effective and selective control products. However, although numerous botanical extracts have led to encouraging laboratory results in this field, very few of them lead to commercially available products, notably due to economical, technical and regulatory issues (Gerwick & Sparks, 2014; Isman, 2020; Pavela et al., 2019). One of them is to ensure the sustainability and continuous availability of the plant resource. *S. rubra* was thus an excellent candidate, due to the existence of the large and regular locally produced volume of sawmills by-products. In particular, the exploited volume of *S. rubra* represents an average volume of 7.5 % of the total of exploited logs in French Guiana during the last twelve years, i.e., around 5 400 m³/year over the 2010-2021 period. This volume should reach 6 500 m³/year for the 2021-2025 period, i.e., a 20% increase, according to the current analysis of the French National Forestry Office (ONF). Considering a transformation rate of 30 to 40% in sawmills, the available volume of *S. rubra* sawmilling by-products could be estimated to 3 900-4 500 m³/year in the next few years.

Based on these perspectives, our objective was to go further experimental findings and design of a commercially viable formulation based on *S. rubra* wood extract, useable in the aqueous media that constitutes the natural mosquito-breeding environment. We thus took up the challenge to develop a practicable and stable mixture allowing the homogeneous dispersion of a lipophilic botanical extract in water, effective and easy to use, as well as respectful of the environment and non-toxic for users. As regulatory approval remains one of the most important barriers to new botanical insecticide commercialization, this point was also taken into account during the whole formulation process. Our objective was to fulfill the requirements of (EU) 528/2012 and directive 98/8/EC (Directive Biocide), or the regulation (EC) 1107/2009 (plant protection products), as *S. rubra* products should rely on one of these two regulations if commercialized. The testing of non-target organisms was also performed, alongside with the evaluation of acute toxicity and residual activity of the products in semi-field conditions towards *Ae. aegypti* mosquitoes. Promising results were obtained in the perspective of a sustainable and credible use of botanical insecticides obtained from a wood extract.

VALORIZATION OF SAWMILLS BY-PRODUCTS OF NATURALLY DURABLE WOODS FOR THE COSMETICS INDUSTRY: THE VALOREXTR@CT PROJECT

French Guiana tropical forest is characterized by the presence of numerous long-lasting woody species exhibiting remarkable natural durability, i.e., an inherent resistance against various wood-destroying organisms. This property is linked to several factors, one of them being the presence of extractives in the wood tissues. These low molecular weight compounds, also called specialized metabolites, impregnate the xylem cell-walls during heartwood formation process. They belong to a large variety of chemical families, such as polyphenolic compounds, alkaloids, terpenes and terpenoid compounds, or fatty acids. They are easily extracted using usual organic solvents or water, hence their name. If they usually constitute only 1 to 10% of the wood of temperate tree species, their content can reach up to 30% for some tropical species (Amusant et al., 2017). Their role in the tree's passive defense mechanism, and therefore in individual survival rate, is thus

fundamental (Chave et al. 2009). They are also responsible for numerous wood properties, such as color, smell, hygroscopicity, dimensional stability or acoustic properties (Bossu et al., 2016; Gierlinger et al., 2004; Krutul et al., 1992; Bremaud et al., 2011; Prida et al., 2009). The implication of these compounds in the wood natural durability was thoroughly studied in the last ten years for several Guianese species of commercial interest (Basset et al., 2012; Rodrigues et al., 2010; Royer et al., 2012b).

A better understanding of heartwood formation and the role of wood extractives in natural durability represents a great inspiration source for innovative applications and products for mankind, in the agricultural, pharmaceutical or cosmetics sectors. In the latter field notably, if extractives can allow the tree to cope with biotic and abiotic stress, these properties could also be exploited for the protection and care of the human skin, in a bio-inspiration perspective. Wood extractives which protect the tree life could also protect human skin, as it plays a barrier role against biotic and abiotic aggressions. In this field also, the valorization of sawmills by-products from durable bio-resources offers the possibility to add a new step to the value chain between forest industry and biomass energy sector. Bio-inspiration and bio-refinery approaches bring the potential to strive for a development model that is fair, and respectful of people and natural resources.

The ValorExtr@ct European research project³ was developed in this context, with the aim of investigating the antioxidant and antimicrobial properties of wood extractives to develop novel cosmetic products in a circular economy approach. Durable wood species from the exploited wood species, including the major commercial species *D. guianensis*, *S. rubra* and *Quaera rosea* Aubl. (Vochysiaceae), were thus particularly targeted, to ensure a stable supply of renewable raw material. Woodchips and sawdusts were collected from various sawmills in French Guiana, grounded and dried. Wood powders were then extracted using suitable eco-solvents. The aims were both to allow an efficient extraction of polyphenolic compounds, and to solve green technologies and innovation issues at each level of the process. Polyphenols can be found in large amount in various tree tissues. They are characterized by a large structural diversity, and include for example flavonoids, tannins, phenolic acids, coumarin or lignans. Generally speaking, their high chemical reactivity lead to interesting biological activities, notably radical scavenging activity, enzymatic activity or fungicidal properties (Royer et al., 2012a ; 2013). The functionalities of the wood extractives were eventually studied, to evaluate the potential of the extracts for skin protection (pollution, ageing...).

At the end of this project, conducted from Amusant and Partners from 2017 to 2021, the screening performed on the selected extracts allowed to propose novel natural ingredients to be used in the cosmetics sector. More precisely, the physico-chemical composition of the selected species was analyzed, notably to identify chemical biomarkers linked to their biological properties, to progress towards the identification of the conditions allowing the production of standardized extracts of sustained quality. In this field, Near Infra-Red Spectroscopy, which is a rapid, powerful, non-destructive and cost-effective prediction technic was used. This technique can be used both qualitatively and quantitatively in the forestry industry, to predict essential oil or extractive yields and natural durability, but also to discriminate wood samples according to geographical origins (Alves et al., 2012; Amusant et al., 2016; Karlinasari et al., 2021; Niamké et al., 2014). The extracts were biologically evaluated both *in tubo* and *in vitro*. On the two best performing extracts, complementary *in vitro* analyses were performed to evaluate their antioxidant effect alongside with a booster effect of hyaluronic acid and collagen production. The anti-inflammatory properties on dermis cells were also investigated, and the *in vitro* and *in vivo* ocular and cutaneous irritant

³ <https://www.cirad.fr/en/worldwide/cirad-worldwide/projets/valorextr-ct-project>; https://youtu.be/q8gJx_ExlX8

potential measured. Eventually, the extraction process was validated on a semi-pilot scale. Future prospects for the project are now to pursue the clinical and regulatory studies on the 2 most effective extracts, in order to recommend them as skin care active ingredients obtained from the sawmill co-products of a sustainably exploited forest (PEFC certification). A technical and economic study will help to ensure the transfer towards an industrial production of these extracts.

THERMAL INSULATION BOARDS FROM THE VALORIZATION OF RESIDUAL WOOD RESOURCES IN FRENCH GUIANA: FROM WOOD BY-PRODUCTS TO INNOVATIVE BIOMATERIALS

Besides extractives, other wood components, such as fibers, also present a major interest to meet technological challenges in the context of a circular economy. Decarbonization and improved energy efficiency of buildings are for example long-term objectives of the EU. Research must contribute to tackle this challenge, by promoting the emergence of new bioeconomic models ensuring that both socio-economically and environmentally requirements are met. One of the possibilities is to promote the development of efficient biomaterials for insulation. Due to French Guiana strong demographic growth, about 120 000 private and social housing will be constructed by 2040 according to INSEE (French National Institute of Statistics and Economic Studies). The use of wood fiber-based insulation materials constitutes a promising solution for improving hygrothermal comfort in homes in humid tropical zones, and could substantially reduce energy consumption related to air conditioning (Montrose and Soubdhan, 2021). In particular, the volume of insulation materials installed in French Guiana has already increased from 20 000 to 350 000 m² between 2016 and 2019, evidencing an attractive global growth for this new sector in the local building market. Up to date, the market relies on the importation of non-bio-based products (mainly rock wool and thin reflective insulation, with very high transport costs and bad ageing performances reported in tropical conditions).

The use of residual bioresources, unvalorized biomass resulting from the local wood industry, constitutes a unique opportunity to produce efficient eco-materials for society, by creating new circularity models within the local industry (Esparon, 2021). The objective of the PANTHER project is therefore to study the potential of a new local bioeconomy based on the production of high-performance bio-insulation boards from the use of residual wood resources. The project is based on the hypothesis that the exceptional intrinsic properties of tropical woods (in terms of mechanical and thermal stability as well as durability) can allow the development of high-performance materials adapted to tropical areas (Bossu et al., 2018; Schulte et al., 2021; Vignon, 2020). Such development would both help to promote the diversification of the Guianese wood sector industries and create collaborations and common ambitions between research and industry in a new field of application of great potential. Within this project, two residual bioresources, which are residues from harvesting and sawmill processing operations, are mainly targeted: (1) sawmill by-products (bark and fibers) of two main commercial species (*D. guianensis* and *Qualea* sp.); and (2) bark residues from two fast-growing species that are very common and that currently have no valorization pathway (*Cecropia obtusa* Trécul, Urticaceae, and *Jacaranda copaia* (Aubl.) D. Don, Bignoniaceae).

The adequacy with the challenges met by the local forestry sectors will be taken into account through bioeconomic approaches. A technology and innovation transfer step will also be included. The aim is to (i) synthesize and promote the results that can be transferred to the Guianese wood industry through conferences and workshops, (ii) identify the technical innovations resulting from the project that can be implemented in other companies in the national bio-insulation industry, (iii) and to establish a roadmap for the development of a future industrial pilot project on the Guianese

territory. We strongly hope that the research carried out will allow the emergence of a new way of valorization of Guianese bioresources that will be able to fit into a circular bioeconomy model.

IDENTIFYING NEW CONSTRUCTIVE SOLUTIONS TO INCREASE THE SHARE OF USEABLE WOOD MATERIALS IN A FOREST PLOT: THE CASE OF ROUNDWOOD

If circular economy in the forestry sector mainly aims at creating new products from wood wastes, this concept can also be expanded with the objective to implement integrated approaches taking into account the ecological environment (management, quality and availability of the resource), the industrial environment (balance of technical performance and environmental footprint), and the socio-economic environment (to promote the re-appropriation of a technical-cultural heritage). Complementary to bio-inspiration, techno-inspiration can lead to technical innovations in a sustainable perspective, by relying on the recognition and valorization of knowledge and practices.

The use of roundwood in traditional construction in French Guiana was in particular documented by Ogeron et al. (2018). A total of 960 roundwood pieces were inventoried, corresponding to 27 vernacular names cited by this Amerindian population living in the eastern part of French Guiana. This folk species corresponded to 263 botanical species, e.g., *Minquartia guianensis* Aubl. (Olacaceae), *Vouacapoua americana* Aubl. (Fabaceae), *Oxandra asbeckii* (Pulle) R.E.Fr. (Annonaceae), *Pseudoxandra cuspidata* Maas (Annonaceae), *Xylopia nitida* Dunal or *Xylopia cayennensis* Maas (Annonaceae), from 25 families. These results highlighted both a wide knowledge and use of this type of woods by the Palikur population. Their choice of the tree species to be harvested for this specific use have been partially explained by the technological characterization conducted on correspondent wood specimens.

The current objective, within the framework of a thesis beginning this year, is now to move forward the selection of promising roundwood species for the development of new architectural design to build light wood constructions in tropical regions. Based on their high abundance, and straight and homogeneous trunk conformation, 8 interesting small-sized tree species have been selected. Their mechanical properties and resistance to decay will be analyzed at sample scale using classical methods but also at macro-scale, by developing new experimental setups adapted to roundwood specimens. Finite-element analysis will be used to model the mechanical performances and ageing of the designed roundwood structures, depending on the species used, jointing techniques and environmental conditions.

We expect that the produced knowledge from this study will stimulate the emergence of new selective logging methods to optimize the valorization of the forest resource in French Guiana and diversify wood constructive solutions.

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The ValorExtr@ct project (Functional research of bark extracts from forest biomass and recovery in the cosmetics sector) was funded by the European Regional Development Funds (FEDER) for French Guiana (ERDF OP, agreement n° FEDER/2017/N°30).

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