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RESEARCH

UNLOCKING NATURAL RESOURCES FOR COST-EFFECTIVE SUSTAINABILITY

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The "Safe-by-design" concept is crucial for the sustainable use of resources and has significant economic implications. Bio-based compounds that feature unique color profiles and antimicrobial properties hold great value for large-scale industrial applications. Our ongoing projects ***BioColour, Colour4CRAFTS,*** and ***BioAnti***, are grounded in natural resource management and adhere to sustainable chemistry principles [1]. We are developing strategies based on green chemistry to extract natural compounds and pigments from renewable sources, including plants, fungi, and insects. Our approach offers a sustainable and non-toxic alternative to petroleum-based hydrocarbons, which helps reduce environmental impact and conserve resources, as shown in **figure 1**. Given that synthetic dyes account for nearly 60% of global water pollution, the *BioColour* project serves as a solution-driven research initiative. The BioColour project involves research teams from three continents (Europe, North America, and South America) and aims to build an interdisciplinary research network to tackle these pressing issues. While the synthetic dyes market is projected to reach USD 3.26 billion by 2034, harnessing natural colorants as a replacement presents a viable and environmentally sound solution, highlighting the future potential of the BioColour project and its appeal to these markets. However, natural colorants face challenges, such as average color stability and durability. The collaborative research with Petri Heinonen's groups at Kumpula Campus focuses on developing semisynthetic versions of promising biocolorants to enhance their fixation properties towards natural fibers (cellulose and protein fibers) as part of the *Colour4CRAFTS* project. The group is also exploring the potential of natural product chemistry, which has led to the discovery of interesting compounds with potent broad-spectrum antimicrobial properties. Some of these compounds are already used in the commercial food industry to extend product shelf life. Integrating these effective antimicrobial natural compounds into textiles can be especially beneficial for medical textiles and sports apparel, aligning with the goals of the *BioAnti* project.

Figure 1. General experimental setup combining all three projects.

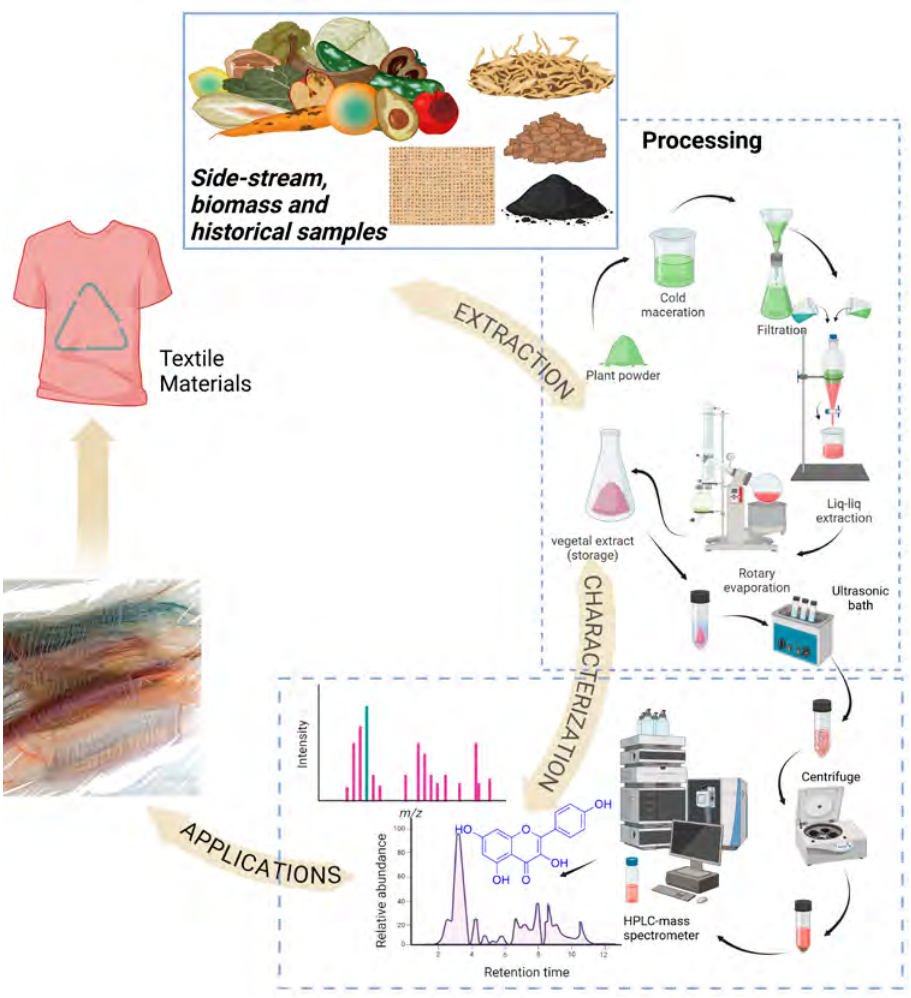

Figure 2. Collaborators of the BioColour project.

The BioColour project

The *BioColour* consortium (biocolour.fi) is funded by the Strategic Research Council at the Research Council of Finland (from 2019-2025). This interdisciplinary project brings together partners from different countries (as illustrated in **figure 2**) with a focus on expanding the use of natural pigments and dyes derived from various Finnish sources for bulk industrial applications. The research partners in the *BioColour* consortium aim to utilize and process biomass from forestry and agricultural streams as well as compounds from fungi to create more sustainable biodyes [2]. Since its inception, the consortium has raised awareness about natural dyes and their properties in the textile and packaging industries. Key aims include promoting the integration of bio-based colorants into value-added supply chains for the food industry, achieving sustainable dyeing of textile materials, and enhancing coating and packaging materials. At the University of Helsinki (Chemistry, Kumpula Campus), our focus is on bio-based sources, which involve collection, processing, extraction, and studying the specific structures of these colorants in the extracts [3]. Understanding the structural characteristics of bio-based colorants enhances our knowledge of natural compounds. By classifying these compounds based on their structures, we can make informed decisions to target specific applications. For instance, if a biocolorant possesses a molecular structure that is non-acidic and has low water solubility, it may be ideal for use in dyeing synthetic fibers like polyester, polyamide, or cellulose acetate. In contrast, more acidic colorants may have different applicability (such as wool dyeing). The dissemination of our findings through scientific articles and conference presentations has fostered collaborations with multiple research groups, allowing *BioColour* to expand its efforts. Beyond the study of dyes and pigments, the project also delves into the cultural, social, and ethical aspects of biocolorants, sparking discussions on "novel aesthetics" through product experiments and art exhibitions, challenging the norms associated with synthetic colorants.

The Colour4CRAFTS project

The *Colour4CRAFTS* project, led by the University of Helsinki and involving several European universities, the research institute KIK-IRPA and the PILI-Bio company, brings together a multidisciplinary team of researchers and R&D companies (showcased in **figure 3**). The project explores bio-based textile coloration from both historical and modern technological perspectives. It aims to transform traditional dyeing processes into sustainable and innovative practices through actions represented by the acronym CRAFTS: Combining, Re-engineering, Applying, Futuring, Transforming, and Stretching. Research areas include historical dyeing practices, the cultural significance of color, the scientific analysis of natural colorants, and the development of sustainable dyeing methods. By examining the history and traditions of dyeing in the northeastern Baltic region, *Colour4CRAFTS* seeks to fill knowledge gaps and inspire new sustainable dyeing techniques. The project aims to reconnect individuals with their cultural heritage and promote green practices in the textile industry. By transforming traditional processes into sustainable and cutting-edge practices, *Colour4CRAFTS* supports creative industries and aligns with future green deal objectives.

The work done at the Department of Chemistry approaches natural dyes from two different angles: analysis of natural colorants and other natural products, along with synthetic modification of natural dyes. The analytical side focuses on different types of phenolic compounds found in nature, such as tannins, flavonoids and anthraquinones that are widely spread throughout the plant kingdom. In nature, these compounds have versatile tasks in plants, but in textile dyeing they either function as colorants or they are believed to act as mordants that help colorants bind to textiles. The key objective of the project is the identification and quantitation of natural products not only in dye plants, but also in actual historical textile samples. Analytical method development is at the very core of this research. Novel methods are needed in screening large number of dye plants and in recognizing which compounds are truly active in textile dyeing.

The synthetic modification of natural dyes aims to improve the properties of these abundant molecules. The natural dyes can suffer from poor wash or light fastness, but through simple synthetic modifications the interactions between the dye molecule and the textile fibers can be improved. By adding different functional groups to the dye molecules, the dyes can be tailored to match various fibers, such as cotton, wool or polyester. The improved fastness could help eliminate the use of mordants, which are commonly metal salts used to fix the natural dye into the fabric. The dyeing experiments made with the modified natural dyes have been successful: not only is the fastness better compared to the unmodified natural dye, but we are also able to affect the shade of the color by varying the functional group attached to the dye molecule.

Overall, *Colour4CRAFTS* seeks to transform traditional dyeing processes, preserve cultural heritage, and foster innovative solutions for the future of bio-based practices in creative industries and industrial-scale textile production.

Figure 3. Collaborators of the Colour4CRAFTS project

Figure 4. Collaborators of the BioAnti project.

The BioAnti project

The *BioAnti* consortium project is a three-year initiative (2022-2025), funded by the Jane and Aatos Erkko Foundation, involving research teams from the University of Helsinki (PI), the VTT Technical Research Centre of Finland, and LUT University, as shown in **figure 4**. This consortium is known for its infrastructure and expertise in textile applications of natural compounds, the production and utilization of antimicrobial extracts, as well as separation technology and plant design. Antimicrobials derived from biomass processing offer a sustainable alternative to synthetic antimicrobials. Plant-based antimicrobials, sourced through various means, primarily contain phenolic compounds that exhibit strong antibacterial, antifungal, and antiviral activities. These natural compounds are known to disrupt the cellular machinery essential for the survival and proliferation of microbes. In contrast, natural textile materials can retain moisture, which may promote microbial growth. This situation necessitates new technologies or processes that incorporate antimicrobial finishing. With our project vision, we advocate for a greener approach that utilizes natural antimicrobials instead of synthetic ones. The BioAnti project emphasizes sustainability, aiming to create a waste-free process where energy and materials flow and circulate efficiently. Our goal is to develop a sustainable and cost-effective method to isolate valuable compounds from biomass and refine them into antimicrobial products for textiles, using modern technologies such as membrane technology [4]. Antimicrobial compounds from plants, including flavonoids, tannins, and saponins, have shown synergistic effects when used in combination. This enhances their efficacy and reduces the potential for the development of resistance. Furthermore, the growing interest in natural antimicrobials is driven by increasing consumer demand for clean-label products and the necessity for sustainable solutions across various material industries. In this project, we are exploring various sources and innovative, chemical-free methods to maximize extraction. The integration of natural antimicrobials into the textile industry not only addresses the challenges of microbial contamination and resistance but also aligns with the global shift towards more sustainable and environmentally friendly practices.

Research Teams (Ongoing Projects)
Members of Riikka Räisänen Research Group: Riikka Räisänen (Professor, Principal Investigator of BioColour, Colour4CRAFTS and BioAnti): Arvind Negi (BioColour), Julie Gaitán Tabares (BioAnti), Peppi Toukola (BioColour and Colour4CRAFTS).
Members of Petri Heinonen Research Group: Petri Heinonen (Colour4CRAFTS), Juuso Laitila (Colour4CRAFTS), Otto Seppänen (Colour4CRAFTS).

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