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Pattern 2.1: co-culturing self-pigmenting bacterial cellulose

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Abstract

With rising awareness of environmental costs in manufacturing, the textile and fashion industries are gradually adopting bio-based materials and biofabrication as emerging alternatives. Among a great range of living materials, bacterial cellulose provides significant plasticity and scalability. Recent studies in engineered living materials indicates that pigment biosynthesis can possibly be integrated into cellulose formation, creating self-pigmenting systems. Yet, design-oriented knowledge about how these systems generate specific pigment distributions and spatial patterns remains incomplete, especially regarding controllable patterning capabilities.

In response, this research focuses on building a systematic pigment- and pattern-oriented understanding of co-culture self-organisation. It investigates how pigment-producing and cellulose-producing microbes can co-produce diverse and aesthetically visible patterns, and how these biological tendencies can be harnessed as a design tool. The objective is to develop a co-culture design framework and corresponding fabrication methods that employ engineered *Escherichia coli* and Komagataeibacter xylinus, extending recent advances in bacterial cellulose biofabrication. Addressing the lack of transferable co-culture design methods in existing living materials research, this research treats self-pigmenting bacterial cellulose as a duo-species design system and organises parameters such as strain combinations, inducer and cofactor regimes and vessel geometries into an adaptive toolkit.

This research via experiment probes how microbial tendencies – such as edge accumulation, layer thickening or gradient following – can be mapped onto pigment distribution and emerging pattern types, by systematically varying chemical inputs and spatial arrangements. Thus, co-culture is positioned as a responsive material medium in which pigment expression and cellulose assembly are mutually conditioned. Instead of seeking absolute control of microbial behaviour, it explores how reproducible interactions between microbial growth tendencies and design parameters, informing the framework for coordinating pigmentation, cellulose formation and material performance, while extending discussions in bacterial-cellulose and bio-synthetic materials research.

Description

By integrating pigment biosynthesis with cellulose production in a designed co-culture system, pigment emerges during growth rather than being added in a post-dyeing stage (Figure 1), reconfiguring the traditional workflow of first making a textile and then applying colour. This approach builds on wider developments in bio-based textiles and bacterial-cellulose material innovation (Biofabricate and Fashion for Good 2020; Burnstine and Camargo 2025; Vuruşkan and Özbengi Uslu 2025; Guan *et al.* 2022).

The work further examines how spatial repetition emerges when these parameter sets are repeated across vessels, revealing reproducible relations between microbial growth tendencies and design configurations. The demo (Figure 2) translates this framework into an illuminated, multi-sample installation that scales up microbial biomaterials. It is built from self-pigmented bacterial cellulose samples cultivated in a variable co-culture system, where chemical ratios and vessel geometry shape pigment localisation, blending and fading. The co-culture approach draws on engineered living-material research in which programmable functions and bacterial-cellulose fabrication are developed through microbial systems (Gilbert *et al.* 2021; Gilmour *et al.* 2023).

Illuminated from below, the samples highlight links between colour and structure, inviting close observation (Figure 3). Each piece functions as both a prototype for scaled-up material assembly and a material record of its designed composition within the biofabrication

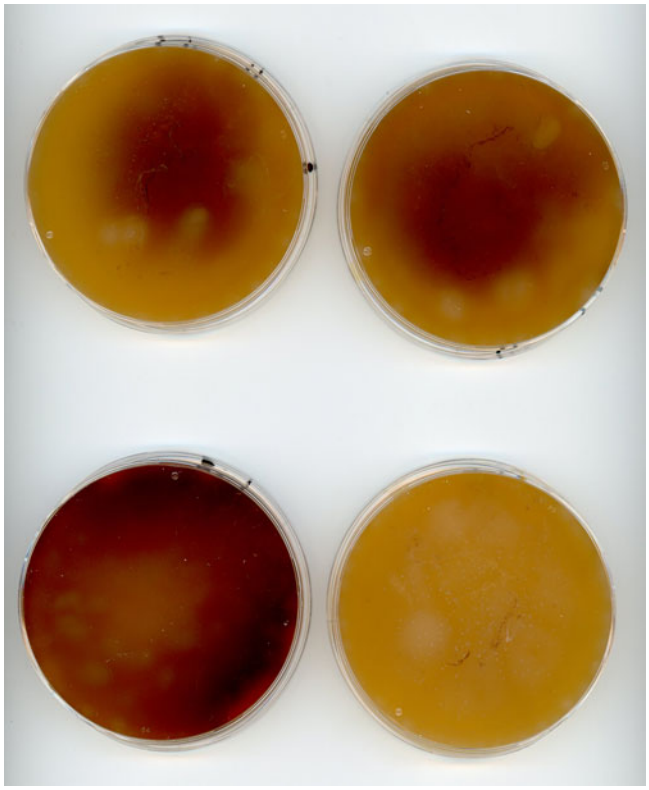


Figure 1. By integrating pigment biosynthesis with cellulose production in a designed co-culture system, pigmentation occurs during growth instead of being applied afterwards.



Figure 3. Along with the descriptions that explain more details on how changes in parameters shape the resulting patterns, visitors are invited to engage by closely observing the demo.



Figure 2. The demo was built by multiple self-pigmented bacterial cellulose samples cultivated within a variable co-culture cultivation system.

framework. This positions bacterial cellulose as a potentially scalable material platform for bio-based and naturally coloured textile applications (Galdino Jr. *et al.* 2021).

Technical details

Dimension 15 × 15 × 18 cm.

Technical requirements

Electrical access for the bottom illumination.

A dim environment is recommended if possible.

Data availability statement. The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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Author contributions. H.L.T. conceived and developed the overall research concept, designed and conducted the experiments, analysed the data and drafted and revised the manuscript.

T.A. (Thora Arnardottir), M.Z. (Meng Zhang) and M.D.-R. (Martyn Dade-Robertson) supervised the research process, contributed to the development and refinement of the research design and provided critical feedback on the analysis and manuscript.

K.G. (Katie Gilmour) provided major technical support for the experimental design and laboratory procedures and contributed to the interpretation of the results and revision of the manuscript.

All authors read and agree to be accountable for all aspects of the work.

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