Biotechnology Design

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ChromoBC: Designing colour and responsiveness in bacterial cellulose

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Abstract

Colour is usually added to materials after fabrication. ChromoBC presents a different approach using bacterial cellulose (BC) that has exceptional mechanical properties and can be microbially produced from low-cost carbon sources. ChromoBC encodes colour and responsiveness into a material that is grown by microbes and whose properties can be genetically programmed. In this work, we demonstrate four colouring modes. In the first approach, the cellulose-producing bacterium, *Komagataeibacter rhaeticus*, expresses visible proteins that paint the growing cellulose. In the second, *K. rhaeticus* synthesises eumelanin via an engineered biopathway that forms tuneable grey-to-black materials. As a responsive material, anthocyanin-loaded BC reports environmental pH through instant colour changes. The fourth mode uses a synthetic symbiotic co-culture of bacteria and yeast (Syn-SCOBY) to develop a living, responsive cellulose-based material. The engineered baker's yeast, *Saccharomyces cerevisiae*, functionalises cellulose with a secreted enzyme, allowing a chemical input to trigger a colour change. Together, these prototypes demonstrate different forms of BC-based colour-changing materials that can be permanent, tuneable, reversible and responsive. At BioDesign 2026, visitors encountered ChromoBC as a hands-on BC-based material palette, testing pH-responsive material and activating enzyme-based colour changes. This demo positions biologically designed BC as a sustainable and tuneable interface in which biological processes become visible and interactive.

Impact statement

ChromoBC offers designers biologically made, sustainable material options in which colour can be expressed, tuned, reversibly changed or biochemically triggered. It demonstrates how synthetic biology can be translated from an invisible, molecular-level laboratory process into a direct, hands-on material interaction.

Description

ChromoBC brings together four strategies for programming colour into BC. Each strategy uses a different relationship between biology, chemistry and the material matrix: genetically encoded colour, metabolically tuned colour, pH-responsive colour and enzyme-triggered colour (Malcı et al. 2024). The demo explores how these distinct biological mechanisms can become tangible forms of material interaction. In this way, designers can compare colour as a fixed material property, a tuneable biosynthetic output, an environmental response and a triggered biochemical event.

Visible protein-based colours

In the first mode, colour is produced by the cellulose-producing bacterium itself. We engineered *K. rhaeticus* to express visible chromoproteins, including AmilCP, red fluorescent protein RFP and gfasPurple (Ba and Sun 2026). As the cells grow within a cellulose network, the pellicle takes on the colour of the expressed protein (Figure 1A, B). Swapping the coding sequence therefore changes the material palette without changing the fabrication process. RFP also provides a glowing material under blue light (Figure 1C). The colours remain visible after pressing at 30 °C, allowing the wet hydrogels to be converted into thin coloured sheets (Figure 1D). This approach uses genetic sequence as the sole variable for the material colouring.

Self-produced tuneable black BC

Permanent colour can also be generated using pigments synthesised through engineered metabolic pathways. We expressed tyrosinase enzyme in *K. rhaeticus* to produce eumelanin during BC growth (Walker *et al.* 2025). By tuning tyrosinase expression level, we obtained materials ranging from light brown/grey to deep black (Figure 2A, B). The pigmented pellicles could also be heat-pressed into thin, leather-like sheets, as shown with the black pellicle samples (Figure 2C). This prototype shows how pigmentation can be generated and tuned via genetic manipulations in biochemical pathways.

Demo: Biodesign Conference

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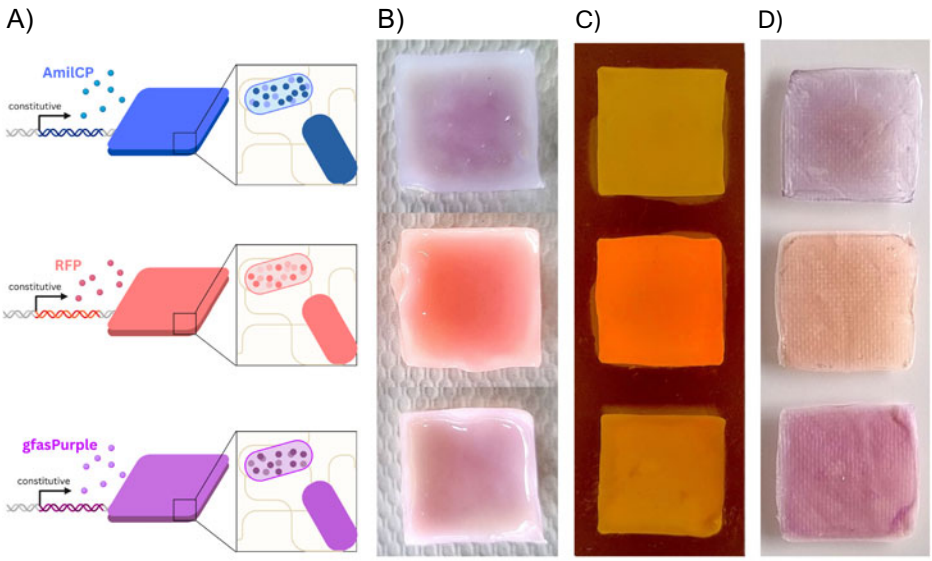


Figure 1. Self-grown coloured BC through visible protein expression. **(A)** Changing the encoded protein changes the colour of the *K. rhaeticus* cells and BC pellicles. **(B)** BC pellicles containing AmilCP, RFP or gfasPurple. **(C)** RFP provides an additional fluorescent state under blue light. **(D)** Pigmented hydrogels retain visible colour after pressing into thin sheets.

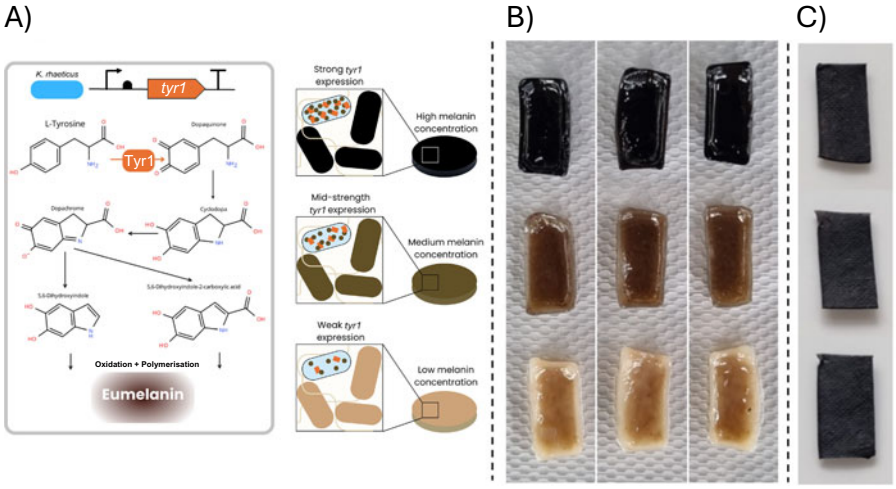


Figure 2. Metabolically tuned eumelanin pigmentation. **(A)** Tyrosinase expression enables eumelanin production in *K. rhaeticus*. **(B)** Different expression levels generate a light brown/grey-to-black material palette. **(C)** Melanised BC can be heat-pressed into thin, leather-like sheets.

pH indicator BC as a reversible and responsive material

The third mode moves from permanent colour to environmental response. BC loaded with red-cabbage anthocyanins changes colour as local pH changes, producing red-pink tones under acidic conditions, blue-purple around neutral pH and green-yellow tones under basic conditions (Figure 3). The response is instant and visible, allowing the material to be painted with acidic or basic liquids. Here, the colour change is chemical rather than living, but it demonstrates how a bio-derived pigment can translate an environmental condition into immediate visual feedback. pH-responsive colour may also be relevant to future skin or wound interfaces, where local pH can vary with physiological state (Costa and Horswill 2022); in the present demo, however, it is used as a material interaction rather than a validated diagnostic.

Engineered living material & enzyme-functionalised cellulose

The fourth mode introduces biological functionalisation through Syn-SCOBY, a synthetic co-culture of cellulose-producing *K. rhaeticus* and engineered *S. cerevisiae* (Gilbert *et al.* 2021). The yeast secretes a fusion protein containing a cellulose-binding module (CBM) and beta-lactamase (BLA). The CBM anchors the enzyme to cellulose fibres as the material forms (Figure 4A). When nitrocefin is added, immobilised BLA converts the pale-yellow substrate to red, creating a local colour change within minutes (Figure 4B). Changing the enzyme–substrate pair can generate alternative colour outputs. The yeast-expressed alpha-galactosidase similarly converts colourless X-alpha-Gal into a blue-green product as shown in Figure 4C. This establishes a general design principle: a biochemical function can be positioned on cellulose and coupled to a visible output. The same functionalisation can also be created using purified CBM-enzyme, producing a non-living format that retains the chemical response (Figure 4D), which was used as a non-living analogue in the demo.

These mechanisms demonstrate alternative approaches for biologically painted and/or responsive textiles and wearable interfaces in which a material communicates local chemical conditions through colour. Such applications would require additional

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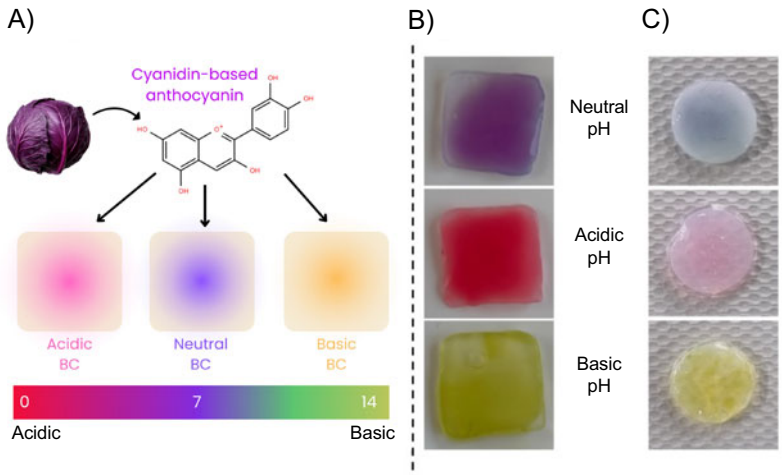


Figure 3. pH-responsive colour as a direct material interaction. **(A)** Anthocyanins change molecular state and colour with pH. **(B)** Anthocyanin-loaded BC produces vivid colour states across acidic, neutral and basic conditions. **(C)** Anthocyanin-containing red cabbage extract can also be applied to acidic or basic BC pellicles to promote colour shift.

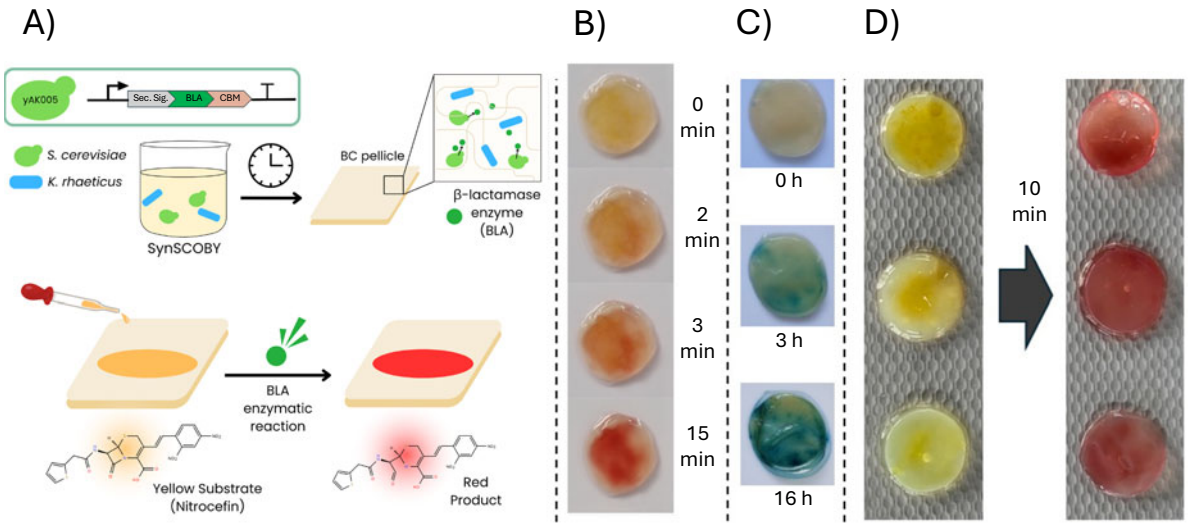


Figure 4. Enzyme-triggered colour formation in a cellulose material. **(A)** In Syn-SCOBY, engineered yeast secretes CBM-BLA, which binds to the BC matrix produced by *K. rhaeticus*. **(B)** Adding the nitrocefin substrate triggers a yellow-to-red colour transition by BLA activity within minutes. **(C)** Blue-green colour formation can be obtained when the enzyme-substrate pair is changed to alpha-galactosidase – X-alpha-Gal. **(D)** Purified CBM-enzyme can functionalise BC without living engineered cells in the material.

validation for their intended context; here, ChromoBC is presented as a material and interaction platform that can inspire future biodesign applications for biologically coloured and responsive materials.

The demo as interaction

At BioDesign 2026 in Delft, visitors encountered ChromoBC through three stages of participation:

1. **Permanent colour:** visitors inspected protein-pigmented and eumelanin-pigmented BC hydrogels and pressed sheets, comparing how colour can be grown into the material.
2. **pH painting:** visitors applied anthocyanin-containing solutions into acidic, neutral and basic BC pellicles, creating reversible colouring through pH changes.
3. **Enzymatic trigger:** visitors added substrate droplets to CBM-BLA-functionalised BC and watched local red colour emerge within the material.

The aim was not only to explain the underlying biotechnology, but to make the differences between static, responsive and biologically functionalised material behaviours tangible through handling and interaction.

Design implications

ChromoBC shows that colour can be encoded, tuned, reversibly shifted or locally triggered. The prototypes show how bacterial cellulose can act simultaneously as material and interface, making biological and chemical processes visible and interactive. ChromoBC is presented as a material palette through which designers can explore how biologically grown materials can support different forms of visual interaction.

Technical setup & requirements: The demo used display plates for material samples, table space, micropipettes, tips, tweezers and a screen for video playback.

Interactivity: Visitors applied pH buffers and enzyme substrate directly to designated BC samples to generate visible colour changes.

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Data availability statement. This demo presents physical tools and materials; no new datasets or code were generated for this work.

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Ethical standards. Ethical approval and consent are not applicable for this work.

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