Investigating the Dyeing Potential of Bacterial Cellulose: Colorfastness to Crocking and Artificial Light

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Literature Review. Before synthetic dyes, natural dyestuffs derived from plants, insects, mollusks and minerals dyed textiles (Yusuf et. al., 2017). Dyed textiles were historically status symbols due to their expense (Zarkogianni et. al., 2010). The invention in the mid 1800s of the first synthetic dye, mauveine, transformed vibrant purple dyed fabrics from status symbols to common items (Schultz, 2013). Soon, synthetic dyes gained prominence by providing good colorfastness at a lower cost.(Zarkogianni et. al., 2010). Many synthetic dyes rely on petrochemicals for production and may cause allergic skin reactions (Samanta et. al., 2018).

For cellulosic fibers, the synthetic dye most common is reactive dye. These dyes form a strong covalent bond with the cellulose, resulting in excellent color fastness (Gopalakrishnan et. al., 2018). The bonds of these dyes to fibers makes them less damaging to the environment than other dyes (Gopalakrishnan et. al., 2018). However, these water-soluble dyes react in dye water, making dye exhaustion lower and waste dye difficult to remove (Gopalakrishnan et. al., 2018).

Natural dyes are largely plant based and can vary in hue and intensity (Ziarani et. al., 2018). Despite this, dyestuffs like indigo, cochineal and weld were frequently used. Indigo was an important dyestuff of the ancient world and remained so until the invention of synthetic dyes (Encyclopædia Britannica, 2019).The process of removing oxygen from the dye vat and exposure after fabric being dipped provides indigo its blue color (Giannoulis et. al., 2016). Often, natural dyestuffs exhibit lower colorfastness properties than synthetics. In comparison to fiber reactive dyes, indigo has poorer crocking performance (Giannoulis et. al., 2016).

Natural red colorants are prone to fading more quickly, except cochineal (Greenfeild, 2016). Cochineal relies on a mordant to bond with cellulosic fabrics. Colorfastness relies on the dyestuff, the mordant used and their concentrations (Arroyo-Figueroa, 2011). Weld, a yellow dyestuff, was widely used historically, with evidence as early as the third century (Petroviciu et. al., 2014). This bright yellow colorant has shown superior light and dry rubbing (crocking) fastness to several natural dyes, including indigo (Dogan & Akan, 2018). Mordant type and concentration can also affect the colorfastness performance of weld (Haar et. al., 2013).

Bacterial cellulose (BC) is extruded by acetic-acid bacterium to produce a biodegradable cellulosic product (Iguchi et. al., 2000). BC displays increased water absorbing capability and tensile strength, while lacking impurities (El-Saied et. al., 2008; Iguchi et. al., 2000). The micro-fibrils interact through hydrogen bonds, resulting in a crystalline, absorbent fiber-web (Hsieh et. al., 2008). This study investigated the dye-ability of BC with natural and fiber reactive dyes.

Experiment Methodology. ATCC A. xylinus strain 53524 was cultivated in modified Hestrin Schramm Mannitol (HSM) media. Bacteria grew for one week and was placed into medium sterilized at 121 degrees C for 25 minutes. Containers were incubated at 32 degrees C for 21 days. Then, mats were placed in a 1% NaOH soak for 24 hours at 70 degrees F. The mats were treated with a 4% glycerol, 1% germaben solution soak at 70 degrees F for 24 hours, before being rinsed and drained. Mats where placed on towels in the incubator and stretched every 24-48 hours. A second soak was performed for 48 hours before bleaching with 10% commercial bleach and water solution. Mats were rinsed before the final 24 hour soak and rinse.

All dyeing procedures were guided by the dye source company's instructions for cotton. Mats were scoured before dyeing at 55 degrees C with Synthrapol detergent and soda ash. Cochineal and weld mats mordanted before dyeing. The first utilized 8% weight of fiber of tannic acid at 90 degrees C. The second used 8% weight of fiber of aluminum acetate at 45 degrees C. Weld dyeing utilized 40% weight of fiber while cochineal used 6%. Indigo, as a vat dye, did not require mordanting but was reduced with thiourea dioxide. Warm (37-43 C) water, salt and soda ash were used with the fiber reactive dyes. Dyed mats had excess dye rinsed off with cool water, washed with Synthrapol detergent and rinsed again with hot water (49 C).

Results. As can be seen in the pictures below, all dyes were absorbed by the bacterial cellulose.

Control *Blue: FR* *Natural* *Red: FR* *Natural* *Yellow: FR* *Natural*

Colorfastness to Crocking: Dry and wet crocking colorfastness evaluation was done in accordance to AATCC 8-2016. BC samples were cut to 30mm by 100mm. 50mm by 50mm cotton crocking squares rubbed the surface for 10 turns at 1 turn per second. Water was dropped onto wet testing squares until moisture regain of 65 +/- 5% was achieved. Change in color as a result of crocking was evaluated with AATCC EP-1 for color change or EP-2 for staining using .5 rating gradations. Wet crocked samples were evaluated against non-crocked cotton plain weave cloth. At least two evaluators analyzed each sample in a light box using the daylight setting. 3 samples in each group were evaluated. Ratings reported scored within .5 of one another on the change scale. The average color change ratings for dry crocking in all fiber reactive and natural dyes were 4.5 or higher, indicating little to no color change from the dry rubbing the surfaces of the samples. With red fiber reactive and cochineal dyes, averages ranged from 4.86 to 5.00. This result indicated little to no color change from the wet rubbing of sample surfaces. With yellow fiber reactive dyeing, sample averages ranged from 2.00 to 3.00, indicating substantial color change. With the weld dye, averages ranged from 3.00 to 5.00, indicating moderate to no color change. *Colorfastness to Artificial Light*: AATCC 16.3 was used as an evaluation guide with a custom built light exposure device modeled after Australian test method 2001.4.21. BC was cut 35mm by 35mm with an exposure area of 30mm by 30mm. Samples were mounted in the circular lamp and exposed to continuous light for 72 hours before being cooled and conditioned. All samples were then compared to unexposed samples in a light box using the daylight setting. Average color change ratings for the indigo samples were 5.00 while fiber reactive blue samples ranged from 2.25 to 2.75. Fiber reactive average color change ratings ranged from 3.00 to 3.75 with the cochineal ratings ranging from 2.75 to 3.33. Weld average color change ratings ranged from 3.00 to 3.75 with yellow fiber reactive dye ratings ranging from 2.00 to 3.25.

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