Investigating the Dyeing Potential of Bacterial Cellulose: Strength and Colorfastness to Perspiration and Laundering

Jennifer Harmon, Ph. D., University of Wyoming

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Literature Review. The primary colors red, yellow and blue, can be combined into a wide range of additional colors. The history of dyeing began with natural dyes, largely derived from plant sources, many of which need a mordant in order to bond with fabric. Historically, dyed fabrics were status symbols due to their expense (Zarkogianni et. al., 2010). The advent of synthetic dyes, which had a wide range of colors, good fastness and often lower cost, resulted in the replacement of natural dyes (Zarkogianni et. al., 2010). Synthetic dyes, however, can cause allergic skin reactions and several rely on petrochemicals for production (Samanta et. al., 2018).

One popular dye choice for cellulose fibers is fiber reactive dye. Introduced a century after the discovery of the first synthetic dye, this type of dye chemically reacts with cellulose to form covalent bonds (Aspland, 1992). These dyes are relatively non toxic, available in a large range of bright colors, have excellent wet fastness and little color loss or staining (Aspland, 1992). With reactive dyes, a main drawback is poor dye fixation which leads to large amounts of colorant in the waste water (Chavan, 2011). This colorant is difficult to remove from the waste water as it soluble in water (Chavan, 2011).

Cellulosic fibers also have a long history of being colored with a variety of natural dyes. Indigo was one of the most important vat dyestuffs in the world until the invention of synthetic dyes (Encyclopædia Britannica, 2019). As a vat dye, indigo is converted to blue after exposure to oxygen (Giannoulis et. al., 2016). This process results in low washing fastness, as only the outsides of the textile are exposed and subsequently dyed (Giannoulis et. al., 2016). Cochineal originated in South America, where the Aztecs used insects to produce vibrantly dyes red cloths, which retained their red coloring (Yoquinto, 2012). As a natural dye requiring a mordant, the color and colorfastness of the cochineal dye relies on the dyestuff, the mordant used and their concentrations (Arroyo-Figueroa, 2011). Weld is a yellow dyestuff from plants cultivated throughout Europe (Maiwa, 2019). Weld produces vibrant, clear yellows with excellent light and wash fastness (Maiwa, 2019). As natural dyes tend to be less efficient in their dye exhaustion, a main concern is the amount of water used in the dyeing process (Barker, 2019).

Consumers expect apparel to have color stability and resist color change, despite end use care conditions (Smith, 1994). Repeated exposure to moisture can lead to color loss and change, particularly with perspiration and laundering. Perspiration is often a sign of discomfort which may inhibit the body from operating at maximum efficiency (Choudhury et. al., 2011). As external environments change, people will perspire in their clothing. Exposure to sweat may cause some apparel change color (AATCC, 2018).

Bacterial cellulose material lacks impurities associated with plant based cellulose, like hemicellulose and lignin (Iguchi et. al., 2000). This material displays increased tensile strength and water absorbing capability (El-Saied et. al., 2008). The micro-fibrils interact through hydrogen bonds. These interactions result in a highly crystalline, absorbent fiber-web (Hsieh et. al., 2008). As impurities are minimal in cotton and are usually removed as much as possible during scouring, cotton was the cellulosic fiber used to guide the following dyeing parameters.

Experiment Methodology. To test dyeing bacterial cellulose, ATCC A. xylinus strain 53524 was cultivated in modified Hestrin Schramm Mannitol (HSM) media. The bacteria were grown for one week and transferred to medium sterilized at 121 degrees C for 25 minutes. Containers were incubated at 32 degrees C for 21 days. Then, mats were harvested and placed in a 1% NaOH soak for 24 hours at room temperature. The mats were treated with a 4% glycerol, 1% germaben solution at room temperature for 24 hours, before being rinsed and drained. Mats where then placed on towels back into the incubator and stretched horizontally and vertically every 24-48 hours. A second soak procedure was performed for 48 hours before bleaching material with 10% commercial bleach and water solution. Mats were rinsed before the last 24 hour soak procedure. One mat for each of the 6 colors was dyed using the respective dye source company's instructions for cotton as a guide. Scouring was performed at 55 degrees Celsius with Synthrapol detergent and soda ash. For the natural dyes, cochineal and weld were treated with mordant before dye application. 8% weight of fiber of tannic acid at 90 degrees Celsius was the first treatment which was followed by 8% weight of fiber of aluminum acetate at 45 degrees Celsius. Cochineal dye used 6% weight of fiber in the dye solution and weld used 40%. Indigo, as a vat dye, does not require a mordant but was reduced with thiourea dioxide. Fiber reactive dyes were used with warm water (37-43 C), salt and soda ash. Excess dye was rinsed off with cool water, washed with Synthrapol detergent and rinsed again with hot water (49 C). 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.

Results. *Perspiration*. Colorfastness evaluation was done in accordance to AATCC 15-2013. This test is used to evaluate the fastness of colored textiles to acidic perspiration. Fabric specimens were cut to 50mm by 50mm. Artificial perspiration pH for these samples was 6.0. Samples were wetted for 15 minutes, wrung and wetted again for 15 minutes. Samples were then weighed to ensure a weight 2.25 +/- .05 times original weight. Samples were stacked on plexiglass plates, evenly distributed in a horizontal perspiration tester and heated to 38 +/- 1 degree Celsius for 6 hours. Average ratings for color change from perspiration in indigo dyed samples ranged from 3.33 to 4.67 while blue fiber reactive ratings ranged from 4.75 to 4.83. Average ratings for cochineal dye samples ranged from 3.00 to 4.17 with red fiber reactive sample ranging from 4.17 to 4.5. Average ratings for weld dyed samples ranged from 1.50 to 3.00 with yellow fiber reactive dyed sample ranging from 1.00 to 1.50. *Laundering*. To evaluate laundering, AATCC 61-2013 Test No. 1A was used. This test simulates five careful hand launderings at 40 degrees +/- 3 Celsius. Fabric specimens were cut to 30 mm by 100mm and added to preheated canisters with 10 steel balls, .37% AATCC standard reference detergent without brightener and 200 ml deionized water. The laundrometer was run for 45 minutes which was followed by 3 individual rinses with water heated to 40 +/- 3 degrees Celsius. Samples were air dried. Average ratings for color change from laundering in indigo and blue fiber reactive dyes were over 4.50. Average ratings for cochineal dye samples ranged from 1.38 to 1.63 with red fiber reactive sample averages rated 4.5 or higher. Average ratings for weld dyed samples ranged from 1.17 to 2.75 with yellow fiber reactive dyed samples rated below 2.00. *Strength.* Impact of the dyes and dyeing process on strength was tested with ASTM D 2256, using 3, 12.5 mm by 80 mm strips in each group as compared to a control group. The control sample registered an average breaking strength of 231.57 N, which was only higher than the average breaking strength for yellow natural dye and blue fiber reactive only. The breaking elongation for the control was 7.23mm, which was only higher than the average breaking elongation for yellow fiber reactive dye. These preliminary results indicate that the dyeing and processing procedure used for BC did not detrimentally impact the materials' strength.

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References.

AATCC, American Association of Textile Chemists and Colorists. (2018). AATCC Technical Manual. Research Triangle Park, NC: American Association of Textile Chemists and Colorists.

Arroyo-Figueroa, G., Ruiz-Aguilar, G. M., Cuevas-Rodriguez, G., & Sanchez, G. G. (2011). Cotton fabric dyeing with cochineal extract: influence of mordant concentration. *Coloration Technology*, *127*(1), 39-46.

Aspland, J. R. (1992). Reactive dyes and their application. *Textile Chemist and Colorist*, *24*(5), 31-36.

Barker, L., Wietocha, P., Ekstrom, E., Winters, A., & Yu, U. J. (2017). Colorfastness of naturally-dyed fabrics using contact dyeing method.*Journal of Textile Science and Fashion Technology, 2*(5), 1-5.

Chavan, R. B. (2011). Environmentally friendly dyes. In *Handbook of textile and industrial dyeing* (pp. 515-561). Cambridge, England: Woodhead Publishing.

Choudhury, A. K., Majamdar, P. K. &Datta, C. (2011). Factors affecting comfort: human physiology and the role of clothing. In *Improving comfort in clothing*(pp.3-60). Cambridge, England: Woodhead Publishing.

Encyclopædia Britannica (2019). *Indigo*. Retrieved from: https://www.britannica.com/ technology/indigo-dye

El-Saied, H., El-Diwany, A. I., Basta, A. H., Atwa, N. A., & El-Ghwas, D. E. (2008). Production and characterization of economical bacterial cellulose. *Bioresources, 3*(4), 1196-1217.

Giannoulis, A.,Karanikas, E., Eleftheriadis, I.,Nikolaidis, N., Tsatsaroni, E. (2016). Color fastness to crocking improvement of indigo and sulphur dyed cellulosic fibres. *International Journal of Advanced Research in Chemical Science, 3*(10), 44-52.4

Hsieh, Y., Yano, H., Nogi, M., &Eichhorn, S. J. (2008). An estimation of the Young's modulus of bacterial cellulose filaments. *Cellulose, 15*(4), 507-513.

Iguchi, M., Yamanaka, S. &Budhiono, A. *Journal of Materials Science* (2000) 35: 261.

Maiwa, (2019). *Weld.* Retrieved from: https://maiwa.com/collections/weld.

Samanta, P., Singhee, D. &Samanta, A.K. (2018). Fundamentals of natural dyeing of textiles: pros and cons.*Fundamentals of Natural Dyeing of Textiles: Pros and Cons, 2*(4), 1-7.

Smith, P. J. (1994). Colour fastness testing methods and equipment. *Review of Progress in Coloration and Related Topics, 24,* 31-31.

Yoquinto, L. (2012). The Truth About Red Food Dye Made from Bugs. Retrieved from: https://www.livescience.com/36292-red-food-dye-bugs-cochineal-carmine.html

Zarkogianni, M., Mikropoulou, E., Varella, E., &Tsatsaroni, E. (2011). Colour and fastness of natural dyes: revival of traditional dyeing techniques. *Coloration Technology*, *127*(1), 18-27.