5

Removing the Dye Kitchen from the Textile Supply Chain

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5.1 Introduction

This chapter focuses on removing the dye kitchen from the textile supply chain; the latter is defined as a sequence of processes necessary to see a garment through from production to distribution (Lambert et al. 2006; Henninger et al. 2015). In the textile supply chain, the dye kitchen is the name given to the place where synthetic dyes and machinery apply colour to textiles. This process can occur in multiple stages, which implies that the textile can have a variety of forms: fibre, yarn, fabric or finished garment. The selection process of the actual dye for the textile is dependent on the fibre chemistry and method of application. Within the textile industry, the two main methods of dyeing are (1) exhaust or batch dyeing, which implies the immersion of textiles or garment into a dye bath containing predominantly water; and (2) padding, which is characterized by colour being padded onto the material through a pad mangle (McLaren 1986; Bird et al. 1975). The dyeing process is complex in nature and

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requires a certain pH (a figure describing the acidity or basicity of water) (e.g. Kobya et al. 2006; Claudio 2007) and temperature, as both can influence the ability of the dye to be attracted to the fibre surface and leave the dye liquor (Ingamells 1993). Both dyeing processes, exhaust or batch and padding, can be applied in a controlled manner, for the dye to diffuse into the textile substrate (Bird et al. 1975). Another method of applying dyes to textiles is by printing onto garments or accessories. This can be performed through using either printing paste via a silk screen method or printing ink via an inkjet printer. The choice of machinery used is dependent on the fibre type and end use of the textile product.

Prior to performing the dyeing process, textiles need to be carefully prepared by impurities being removed from the textiles through processes including, but not limited to:

- Desizing–removes the sizing agent applied to the warp yarns, which is applied in order to reduce friction and reduce yarn breakage on the loom (DuPont 2018)
- Scouring–removes grease and dirt from the fabric and implies a deep clean by boiling the fabric in a soda and water solution (Baxter Packwood 2001)
- Bleaching–removes residual colouring matter, with hydrogen peroxide (H_2O_2) being one of the most commonly used bleaching agents (Liu et al. 2018; Yu et al. 2018)

One of the reasons why materials need to be treated through any of these processes mentioned above is to ensure that the woven or knitted cloth is dyed in a homogeneous manner (Baxter Packwood 2001; DuPont 2018; Yu et al. 2018). Once cleaned and the dying process has been completed, post-treatments are required to fix the dye to the textiles. A majority of these processes require a vast amount of water and chemicals.

As such, it may not be surprising that the fashion and textile industry has received negative spotlight, as the dyeing process, including the pre- and post-treatment of these textiles, can have devastating environmental implications. To explain, in 2011, it was reported that a factory in China leaked dyes, which led to the Jian River turning into a deep red colour (Kaye 2013; Trusted Clothes 2016). A public outcry followed that called for tougher regulations and higher environmental protection standards to be enforced globally.

The chemicals used within the dyeing process as well as the vast amount of water not only have implications for the natural environment but also affect human health by increasing the risk of terminal illnesses (Kant 2012; Akarslan and Demiralay 2015; The True Cost 2015). As a result more attention is paid to the selection process of dyes—natural and/or synthetic dyes, adapting and modifying synthetic dyes, finding new and less harmful auxiliaries, reducing water consumption and implementing measures (in industry and at government level) to reduce harmful effluent released into the local environment (Chhabra 2015; Van Berkel 2017; Irfan et al. 2018). Whilst investigating new processes and solutions is of vital importance, a key question that thus far lacks in investigation is what are the implications of removing the dye kitchen in its entirety from the textile supply chain process, an aspect that has been explored in this chapter.

5.2 Textile Colouration Techniques

Traditional textile colouration techniques involve the object being observed absorbing various wavelengths of visible light through the use of colourants, pigments and dyes. Whilst this is the most common manner in which light interacts with objects and the human eye perceives colour, it is also possible through structural colour (Nassau 2001; Shao et al. 2016). Structural colour works by the microscopic structure of the object scattering or reflecting various wavelengths of light resulting in the observer perceiving colour (Kinoshita 2008). Attempts have been made in the textile industry to mimic structural colour observed in nature, particularly those of certain species of butterfly and beetle (Jones 2017; Yavuz et al. 2018). To explain, in both the creative and scientific worlds, butterflies have fascinated many, due to their aesthetic properties. The *Morphinae* group, which contains the male *Morpho* butterfly, has generated great interest as it exhibits a vibrant iridescent blue on its wings. This genus has been extensively studied during the nineteenth and twentieth centuries (Walter 1895; Ghiradella 1991; Tabata et al. 1996; Vukusic et al. 1999) due to the nature of its complex scale structure and combination of optical processes to achieve an iridescent optical effect. When the wings of the *Morpho* butterfly are examined under a scanning electron microscope, they contain ground and cover scales. Each cover scale overlaps a ground scale, and both scales align in rows with a specific amount of spacing between them (Kinoshita 2008; Saito et al. 2018).

Honing in even further on the structure of both the cover and ground scales, it becomes apparent that they contain a lamellar structure, which is often referred to as a Christmas tree or shelf-like structure. In the cover scales, these lamellar structures are attached to a thick base, whereas in the ground scale they are attached to a trabeculae, which is a connected series of rows (Kinoshita 2008). The cover scales provide thin-film interference. The combination of the cuticle-rich shelf-like structures and air-rich layers (between the shelf-like structures and the gap between the ground and cover scales) provides multilayer interference (Kinoshita 2008; Saito et al. 2018).

Between each shelf structure there is a random height distribution. This is allegedly responsible for cancelling out any interference between neighbouring ridges and enables each structure to scatter the light independently. The distance between each ridge also provides diffraction grating, which is partly attributed to generating the iridescent effect observed in this species of butterfly (Kinoshita 2008; Saito et al. 2018). The ground scale contains melanin, which is responsible for the absorption of the complementary colours and enhances the contrast of the blue colouring (Kinoshita 2008). A key question that emerges here is whether it would be possible to reproduce these naturally occurring optical processes in textiles, and thus be able to remove the dye kitchen from the textile supply chain.

One of the first companies that has managed to imitate the microstructure of the Morpho butterfly is the Japanese company Tejin (2010), naming their invention the Morphotex® fibre (Tejin 2010; Das et al. 2017). As previously indicated, the optical processes, such as thin-film and multilayer interferences, generated from the interaction of light with the lamellar structure on the surface of the wings of the butterfly, are responsible for generating the vibrant iridescent blue observed. The core of the Morphotex® fibre contains 61 alternate layers of nylon 6 and poly (ethylene terephthalate) (thereafter referred to as polyester) surrounded by a polyester sheath. This creates a fibre with a multilayer interference core, responsible for the iridescence created by the fibre. By manipulating accurately the thickness of the nylon 6 and polyester layers in the fibre core, Teijin fibres have managed to successfully create these fibres to give a red, blue and green iridescence (Tejin 2010).

Kinoshita (2008) highlights that the polymers selected to create the Morphotex® fibre have relatively close refractive indices (1.60 for nylon 6 and 1.55 for polyester) and the lack of vibrant iridescence can be attributed to this closeness. A cross section of the Morphotex® fibre was observed under a scanning electron microscope (shown in Fig. 5.1).

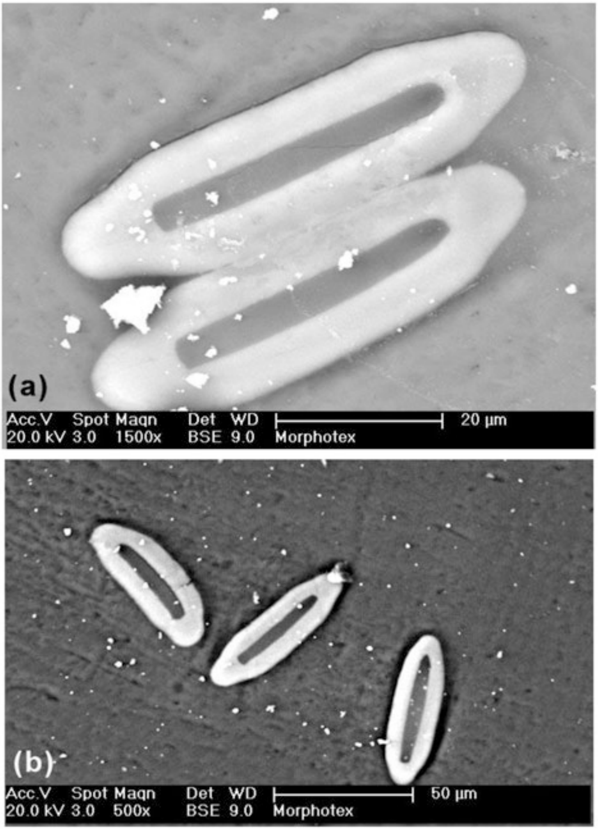

Fig. 5.1 (**a**) and (**b**) Scanning electron microscope images of Morphotex® fibre cross section

A melt-spinning process, similar to that used in the formation of bicomponent fibres, could have been used to create the fibre.

Bicomponent and microfibres are made from two different polymers, which either are extruded separately and then combined to make one fibre or are extruded together and combined as the fibres leave the spinneret. The most common of these structures are side-side and core-sheath. The purpose of manufacturing these types of fibres is due to the range of properties they can provide, aesthetically and/or functionally. The aforementioned butterflies are not the only creatures that exhibit structural colour; the bodies and wings of various beetles showcase similar attributes (Saito et al. 2018). However, the mechanisms responsible for causing the observer to perceive colour, differ from that of the wings of the male *Morpho* butterfly (e.g. Kinoshita 2008; Saito et al. 2018). To reiterate this finding, the exoskeleton of the *Chrysina gloriosa* beetle (see Fig. 5.2) contains regularly spaced cells with a siloxane oligomer-based cholesteric liquid crystal. This enables the exocuticle to reflect left (anticlockwise) circularly polarized light (Sharma et al. 2009). The orientation of the molecules inside the liquid crystals is responsible for manipulating light and creating the phenomenon viewed by the observer.

Researchers have successfully coated textile fibres with cholesteric liquid crystals (Lagerwall and Scalia 2012; Picot et al. 2013; Kang et al. 2017). In the research conducted by Picot et al. (2013) a solution containing cholesteric liquid crystals was spray-coated onto polyamide fibres, and then UV cured.

Picot et al. (2013) stated that cholesteric liquid crystals produce a fibre with intense and bright colours, due to the properties of these materials. These liquid crystals are independent of temperature as they are cross linked by free radical polymerisation. This implies that their colour cannot change (Picot et al. 2013). Textile designers have explored ways of applying microencapsulated cholesteric liquid crystals onto garments and other textiles; however, the outcome from these explorations has been that their (textile design) colour *is* dictated by a change in temperature. Typically, these types of cholesteric liquid crystals have been used on batteries and for medical applications. Textile designer Sara Robertson (2011) explored the use of heat as a design tool, silk screen printing these microcapsules onto textile substrates.

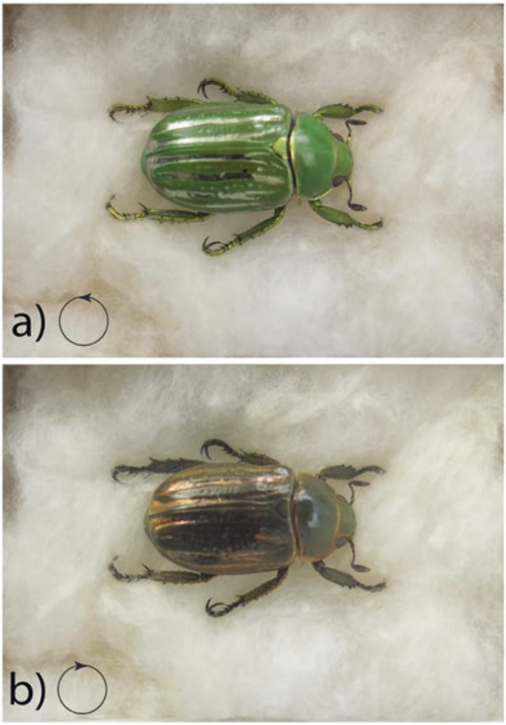

Fig. 5.2 Photograph of the beetle *Chrysina gloriosa*. (**a**) The bright green colour, with silver stripes, seen with a left circular polarizer. (**b**) The green colour is mostly lost when seen with a right circular polarizer

Along with beetles and butterflies, inspiration for incorporating structural colour into textiles has also come from observing opal stones, using self-assembled colloidal photonic crystals. In a recent study, Yavuz et al. (2018) applied these materials to woven cotton fabric, with the result displaying different iridescence at different viewing angles. This work used monodisperse and spherically uniform nanospheres of poly (styrene-methyl methacrylate-acrylic acid) synthesized by soap-free emulsion polymerization and deposited by an electrostatic self-assembly technique onto a chitosan-cationized woven cotton fabric (Yavuz et al. 2018). A further study conducted by Pursiainen et al. (2008) has managed to produce a stretchy material also inspired by structural colour in opals, with the colour of the material changing upon being stretched. Typically, previous films were susceptible to cracking; however, the aim of this research was to overcome this setback.

5.3 Concluding Remarks

This chapter was set out to explore whether it is possible to remove the dye kitchen from the textile supply chain, by looking at alternative modes of colouring fabrics. As indicated, mimicking nature and structures present in the wings of male *Morpho* butterflies or beetle provides a new way of applying dyes to fabrics. Yet, some of the more traditional dyeing techniques are still needed, as some of these examples mentioned previously required the use of a dark pigment or dye to absorb the remaining wavelengths of light that are not reflected. Thus, corresponding fibres or ground fabrics must be dyed either by exhaust/batch dyeing or padding. Therefore some may argue the use of synthetic dyestuffs to achieve these optical effects does not completely remove the use of the dye kitchen from the production process but rather alters it slightly whilst further providing new opportunities to researching colouring processes in nature. Although research in this area continues to grow, the benefits of combining this research with that exploring the adaptation and modification of synthetic dyes, and finding new and less harmful auxiliaries, cannot be overlooked. As trend forecasting shows, the need for brands to have the 'right' colour for the right season ensures that fashion products are in trend and will only sell if customers are satisfied. Textile colour is therefore an important property and is required by the consumer; consequently if current production methods have a detrimental impact on the environment, alternatives methods must be considered.

References

Akarslan, F., & Demiralay, H. (2015). Effects of textile materials harmful to human health. *Acta Physica Polonica A, 128*, 402–408.

Baxter Packwood, K. (2001). *Getting started with natural dying*. Ames, IA: Packwood.

Bird, C. L., Boston, W. S., & Society of Dyers Colourists. (1975). *The theory of coloration of textiles*. Bradford: Society of Colourists for Dyers Company Publications Trust.

Chhabra, E. (2015). Natural dyes versus synthetic: Which is more sustainable? *The Guardian* (online). Retrieved November 24, 2018, from https://www.theguardian.com/sustainable-business/sustainable-fashion-blog/2015/mar/31/natural-dyes-v-synthetic-which-is-more-sustainable.

Claudio, L. (2007). Waste Couture: Environmental impact of the clothing industry. *Environmental Health Perspectives, 115*(9), 449–454.

Das, S., Shanmugam, N., Kumar, A., & Jose, S. (2017). Review: Potential of biomimicry in the field of textile technology. *Bioinspired, Biomimetic and Nanobiomaterials Review*, 1–12.

DuPont. (2018). What is textile desizing? *DuPont* (online). Retrieved November 24, 2018, from http://www.dupont.com/products-and-services/industrial-biotechnology/industrial-enzymes-bioactives/articles/what-is-desizing.html.

Ghiradella, H. (1991). Light and color on the wing: Structural colors in butterflies and moths. *Applied Optics, 30*(24), 3492–3500.

Henninger, C. E., Alevizou, P. J., Oates, C. J., & Cheng, R. (2015). Sustainable supply chain management in the slow-fashion industry. In T. M. Choi & T. C. E. Cheng (Eds.), *Sustainable fashion supply chain management: From sourcing to retailing*. Heidelberg: Springer.

Ingamells, W. (1993). *Colour for textiles*. West Yorkshire.

Irfan, M., Zhang, H., Syed, U., & Hou, A. (2018). Low liquor dying of cotton fabric with reactive dye by an eco-friendly technique. *Journal of Cleaner Production, 197*, 1480–1487.

Jones, C. (2017). *Textile materials inspired by structural colour in nature*. PhD thesis, University of Manchester.

Kang, J. H., Kim, S. H., Fernandez-Nieves, A., & Reichmanis, E. (2017). Amplified photon upconversion by photonic shell of cholesteric liquid crystals. *Journal of the American Chemical Society, 139*(16), 5708–5711.

Kant, R. (2012). Textile dyeing industry an environmental hazard. *Nature Science, 4*(1), 17027–17032.

Kaye, L. (2013). Clothing to dye for: The textile sector must confront water risks. *The Guardian* (online). Retrieved November 24, 2018, from https://www.theguardian.com/sustainable-business/dyeing-textile-sector-water-risks-adidas.

Kinoshita, S. (2008). *Structural colors in the realm of nature*. Singapore: World Scientific.

Kobya, M., Demirbas, E., Can, O. T., & Bayramoglu, M. (2006). Treatment of levafix orange textile dye solution by electrocoagulation. *Journal of Hazardous Materials, 132*(2/3), 183–188.

Lagerwall, J. P. F., & Scalia, G. (2012). A new era for liquid crystal research: Applications for liquid crystals in soft matter nano-, bio- and microtechnology. *Current Applied Physics, 12*, 1387–1412.

Lambert, D. M., Croxton, K. L., Garcıa-Dastugue, S. J., Knemeyer, M., & Rogers, D. S. (2006). *Supply chain management processes, partnerships, performance* (2nd ed.). Jacksonville, FL: Hart-ley Press.

Liu, K., Zhang, X., & Yan, K. (2018). Bleaching of cotton fabric with tetraacetylhydrazine as bleach activator for H_2O_2. *Carbohydrate Polymers, 188*, 221–227.

McLaren, K. (1986). *The colour science of dyes and pigments* (2nd ed.). Bristol: Hilger.

Nassau, K. (2001). *The physics and chemistry of color*. New York: John Wiley & Sons Inc.

Picot, O. T., Dai, M., Broer, D. J., Peijs, T., & Bastiaansen, C. W. M. (2013). New approach toward reflective films and fibers using cholesteric liquid-crystal coatings. *ACS Applied Materials & Interfaces, 5*(15), 7117–7121.

Pursiainen, O. L. J., Baumberg, J. J., Winkler, H., VIel, B., Spahn, P., & Ruhl, T. (2008). Shear-induced organization in flexible polymer opals. *Advanced Materials, 20*(8), 1484–1487.

Robertson, S. (2011). *An investigation of the design potential of thermochromic textiles used with electronic heat-profiling circuitry*. Doctoral dissertation, Heriot-Watt University.

Saito, A., Ishibashi, K., Ohga, J., Hirai, Y., & Kuwahara, Y. (2018). Fabrication process of large-are *Morpho*-colour flexible film via flexible nano-imprint mold. *Journal of Photopolymer Science and Technology, 31*(1), 113–119.

Shao, J., Liu, G., & Zhou, L. (2016). Biomimetic nanocoatings for structural coloration of textiles. In J. Hu (Ed.), *Active coatings for smart textiles* (pp. 269–299). Duxford: Woodhead Publishing.

Sharma, V., Crne, M., Park, J. O., & Srinivasarao, M. (2009). Structural origin of circularly polarized iridescence in jeweled beetles. *Science, 325*(5939), 449.

Tabata, H., Kumazawa, K., Funakawa, M., Jun-ichi, T., & Akimoto, M. (1996). Microstructures and optical properties of scales of butterfly wings. *Optical Review, 3*(2), 139–145.

Tejin. (2010). *Chomagenic fibre*. Transmaterial (online). Retrieved November 24, 2018, from http://transmaterial.net/morphotex/.

The True Cost. (2015). *The true cost*, 26th May 2015.

Trusted Clothes. (2016). *Impact of dyes*. Trusted Clothes (online). Retrieved November 24, 2018, from https://www.trustedclothes.com/blog/2016/06/23/impact-of-dyes/.

Van Berkel, R. (2017). *Water efficiency in textile processing*. UN (online). Retrieved November 24, 2018, from http://kms.recpnet.org/uploads/resource/2845a5b02cca6a6ba7cd90735a9e1575.pdf.

Vukusic, P., Sambles, J. R., Lawrence, C. R., & Wootton, R. J. (1999). Quantified interference and diffraction in single morpho buttery scales. *Proceedings of the Royal Society of London B: Biological Sciences, 266*(1427), 1403–1411.

Walter, B. (1895). Die Oberachen-oder Schillerfarben. F. Vieweg and son.

Yavuz, G., Zille, A., Seventekin, N., & Souto, A. P. (2018). Structural coloration of chitosan cellulose fabrics by electrostatic self-assembled poly (styrene-methyl methacrylate-acrylic acid) photonic crystals. *Carbohydrate Polymers, 193*, 343–352.

Yu, D., Wu, M., Lin, J., & Zhu, J. (2018). Economical low-temperature bleaching of cotton fabric using an activated peroxide system coupling cupric ions with bicarbonate. *Fibres & Polymers, 19*(9), 1898–1907.

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