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Global Communities, Biotechnology and Sustainable Design – Natural / Bio Dyes in Textiles

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Abstract

Never before apparel industry has lived such a fast pace period. Brands, collections, colours and styles are increasingly being created every season, changing accordingly to the many trends society generates. People and lifestyle transforms rapidly, and so their expectations. With all the demanding adjustments this sector has to currently face, it seems, though, the concept of clothing remains the same for the past centuries; textiles are still attached to old ways of thinking materials and dated methods of production and application revealing reluctance to dramatic changes and radical innovation within the sector.

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1. Introduction

Sustainable materials integrating technologies, environment, communities, people, language and culture that will inevitably emerge as products are still seen as a challenge. Textiles’ world is vast and varied with many raw materials and techniques employed. It is one of the most pollutants sectors, contributing a great deal to the environmental impact, poor working conditions, energy and water waste, contamination, etc. It is crucial the focus on how to reduce the textile production environmental footprint and the consideration on how materials can allow

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for a more sustainable future, whilst, simultaneously, promoting and enhancing wellbeing and influencing lifestyle [2].

Consumers are increasingly aware of textiles industry’s hazards and demand for quality products, planned accordingly to their function, lifecycle and produced within eco-friendlier methods. The apparel industry is more than style and excitement; consumers expect colour and change allied to quality and function. Not only are they attentive to material’s quality, provenience, production processes and the friendliness of these methods but they also question their function, how these products change over time accordingly to people’s lifestyle, adapting to expected changes as one travels, ages, transforms, experiences, cease to consume, etc.

Sustainable strategies to reduce environmental impact find in biotechnology an infinite number of applications and it has been widely used since a few decades, mainly dealing with clean technologies. The use of bio resources as a technology is millenary but as a scientific subject it took only the usage of new tools to discover different uses and functions of plants, animals, or microorganisms thus allowing for the improvement of this new field of human knowledge [4].

Biotechnology was always applied, since ancient times, in textiles, from fibres production, dyes management or residual waste. From classic to modern biotechnology, its evolution takes place through significant advances in genetic engineering and synthetic biology where the use of living organisms is seen as a biological process that may replace industrial or mechanical systems. Sometimes introducing visionary and radical strategies for improving the performance of objects around, its multiple applications are focused and designed to deal with sustainable development of materials and core industrial issues [5].

Sustainable design seeks innovation within the sector. Science is being introduced as a methodology in the creative process that slowly embraces different technologies, social improvement, environment and wellbeing, while projecting products.

Textiles and fashion industry’s negative impacts on the entire ecosystem are varied: spinning, weaving and industrial production is associated with nonrenewable energy and waste; finishing processes, as dyeing and printing, consume vast amounts of water and chemicals, releasing numerous volatile agents into the environment. Dyeing has always been, throughout the centuries, one of the most important industries with a remarkable evolution. Color was always of a major importance for mankind, playing crucial roles in both the social and economic contexts. Related to different aspects of human behavior, symbolism and aesthetics, color is known to influence people in many levels such as emotional or shape perception; it is known to influence hormones, blood pressure and body temperature [9].

As an influence agent, it is particularly crucial to the commercial success of fashion and textile products. Besides print and pattern, consumers demand for basic characteristics in textiles. These must resist to the agents that cause colours to fade (washing, light, perspiration, etc.). To guarantee these properties, dyes conferring colour to fibres must present high-affinity properties with the latter, allowing for a greater colour fastness and uniformity. They must, simultaneously, allow for a great range of colour shades and be cost effective. The high number of synthetic dyes is justified given the requirements of industry and consumers. However, most of synthetics dyes or dyeing methods are regarded as little sustainable partly due to effluents associated to these finishing processes, which, if not conveniently treated, can be harmful to the environment and human health [10,11,12,13].

1.1 Sustainability in textiles products

Color has always been important in the social and economical context of mankind. It is one of the most important aspects of fashion and textiles, with a long history and remarkable evolution. Dyeing process effectiveness is, therefore, crucial to the textile industry success, attentive on how colors influence consumers. Nevertheless, dyeing methods are often associated with water waste, fossil fuel generated energy, toxicity and contamination, posing a serious threat to the environment and human health. Certain synthetic coloured substances are regarded as toxic and pollutant leading consumers to question textile products’ sustainability. The search for natural coloured substances is increasingly intensifying, as these are perceived as being compatible to nature and less toxic to consumers and the ecosystem. Sophisticated technologies such synthetic biology plays a crucial role in the development of dyes capable of meeting consumer’s demands as well as this new century’s requirements. In this study we explore the dyeing properties of a class of carotenoid - Lycopene - usually used in the food industry as a red colorant that has
been recently synthesized through bacteria. The colouring ability of Lycopene dye has been tested on polyester substrate and found to be suitable for textile dyeing.

1.2 Sustainable materials: dyes

Consumer’s expectations and inevitable issues related to sustainability within this industry such as energy waste, contamination, climate, environment and lifecycle of a product have triggered a preference for organic materials. This has also led to the gradual interest and reintroduction of natural dyes (generally used in ancient times, mostly derived from plants) in the market. These bioresource dyes possess a biodegradable nature and are, generally, considered safer. They possess a higher level of affinity with the environment causing less impact. Depending on the natural dye, some are known to possess great colourfastness properties (applied with or without mordents), fair range of colours, protection properties against UVR8 as well as medical properties as antimicrobial [19,10] and anti-inflammatory advantages [11].

Despite the vast array of coloured compounds found in nature, only a small parcel of it is applied to textiles. An extensive amount of data got lost at the time of the introduction of synthetic dyes in the market and most knowledge on resources, extraction techniques and applying methods is limited. Deeper understanding on materials - dyes and fibres – and the biodiversity yet to be explored is required. Dyeing with natural dyes tends to be, simultaneously, expensive due to their rather complex processes of extraction and application and the very limited amount of dyestuff provided. Knowledge on bio sources, and their different properties, is vital to push boundaries on applicable research within the sector.

Technologies using bio resources are not new but their evolution is rapidly transforming the world with their infinite number of possibilities. Furthermore, the scope of science allows, currently, for a completely new radical way of rethink materials that will emerge as products around us.

Regarding dyes, state of the art technologies consist in the production of coloured compounds by microorganisms. Dyes produced by this type of biosources are created through a mechanism that uses living bacteria, often found in different plants’ microsystems (rhizosphere), manipulating at times their environment. This living machine might be considered as a sustainable design strategy for mass manufacture. Its effectiveness finds in synthetic biology a way to enable the production of specific dyes designed to meet the industry’s demands and consumer’s expectation. Microorganisms can, not only grow fast but also, be programmed to provide varied dyes with different properties and different colours, being simultaneously cost effective.

Some pigments created through bio machines were already isolated in lab. “E-chromi” is one of such projects, born from the collaboration of scientists and designers who genetically engineered bacteria to secrete a variety of coloured pigments, visible to the naked eye. Standardised sequences of DNA (biobricks) were designed and inserted into E. coli bacteria enabling for the production of colours such as red, yellow, green, blue or violet, possibly allowing for its application on textiles. One of the isolated pigments is Lycopene, a red shade compound found in tomato fruit. To understand if this type of dye can be scaled up for industry, experiments onto different substrates must be conducted.

Lycopene (Figure 1), extracted from fruits of Solanumlycopersium plants, is a known carotenoid pigment representing something around 65% to 98% of its content. It is found in tomatoes and applied, commonly, as a natural red food colorant and a nutraceutical [13]. Its beneficial and therapeutic properties are well documented and established. It is a powerful antioxidant - the stronger amongst all class of carotenoids – and studies suggest Lycopene is effective in varied medical preventive treatments. Its varied medicinal properties are analysed and documented in many recent studies [15,16,17,18].

Although many studies were conducted on the advantages and properties of natural dyes regarding dyeing procedures, colour shades and fastness properties, no information is found on Lycopene and its interaction with textiles. For the first time, this project considers the application of Lycopene dye to textiles. We conducted the present study to investigate the dyeing and fastness properties of polyester using Lycopene pigment. Dyeing conditions such as the concentration of the dye, dye bath pH, dyeing temperature, dyeing time and the overall fastness properties were investigated.
2. Materials

2.1. Dye material

*Lycopene* natural food colorant, obtained from LYCORED COLORS (Fig. 1).

![Chemical structure of Lycopene](image)

Fig.1. Chemical structure of Lycopene

2.2 Fabric

Polyester fabric (Polyester Sateen Glacier White) was obtained from Whaley’s (Bradford) LTD. Harris Court, Great Horton, Bradford, West Yorkshire, BD7 4EQ England.

3. Method

3.1 Dyeing procedure

*Lycopene* was tested to understand its dyeing properties in Polyester fabric. *Lycopene* dye is a non-water-soluble dye therefore oxidising and levelling agents were used (2g dm⁻³ Ludigol AR + 1g dm⁻³ Levagol DLP) in the dye bath.

Fabric was cut into 5g square samples that were dyed with 0.5%, 1%, 2%, 5% omf. These samples were dyed at a liquor ratio of 30:1, with the dye bath being maintained at pH value 4.5 (sodium acetate C₂H₂NaO₂ and acetic acid C₂H₄O₂ solution). The temperature was raised up to 140 °C and held at this level for 60min. Fabrics were removed and rinsed with water and put to dry at room temperature. Reduction clearing to remove any surface deposited dyestuff followed in a Sodium carbonate (1.5g dm⁻³ Na₂CO₃) and Sodium dithionite (2g dm⁻³ Na₂S₂O₄) solution, at a liquor ratio of 20:1, for 15min. at 60°C.

Other sets of samples followed in order to understand their quality regarding colour depth and shades of the dyeing. To determine colour uniformity different parameters were applied to the speed rotation and to the temperature rising speed while increasing up to 140°C as shown in Table 1.

| Samples  | Dyeing temperature                  | Dyeing speed rotation |
|----------|-------------------------------------|-----------------------|
| Set I    | 2°C/min. up to 60°C - 4°C/min. up to 140°C | 35                    |
| Set II   | 7°C/min. up to 140°C                | 20                    |
| Set III  | 7°C/min. up to 140°C                | 10                    |
4. Results and Discussion

4.1 Effect of dye concentration

Experiments were carried out to find the effect of the amount of dye used onto the polyester fibre. As shown in Figures 2, 3, and 4, the K/S values rise with the increase in dye concentration. Set of dyeing I presents higher K/S values when compared to sets II and III.

4.2 Effect of speed rotation and temperature

The experiments carried out onto polyester substrate show the potentiality of Lycopene application as a natural textile dye. By observing the different shades of orange provided and results in table 1, colour intensity is higher at 5% concentration of dye when the dyeing temperature was increased at a slower rate (2°C/min. up to 60°C and 4°C/min. until 140°C) and rotating at a higher speed (35), with shades differing exponentially in colour, when compared to other parameters (7°C/min. increasing up to 140°C at rotation speed of 10 and 20), displaying weaker colour intensities as shown in Table 2, and after light exposure in Table 3.

Table 2. K/S values.

| Samples | Set I | Set II | Set III |
|---------|------|--------|---------|
| % on mass of fibre | λ Max | K/S | λ Max | K/S | λ Max | K/S |
| 0.5%    | 460  | 1.069 | 460    | 2.937 | 460    | 2.057 |
| 1%      | 460  | 3.190 | 460    | 3.065 | 460    | 2.819 |
| 2%      | 460  | 6.698 | 460    | 4.568 | 460    | 4.867 |
| 5%      | 460  | 6.868 | 460    | 5.846 | 460    | 5.427 |

Table 3. K/S values after light exposure.

| Samples | Set I | Set II | Set III |
|---------|------|--------|---------|
| % on mass of fibre | λ Max | K/S | λ Max | K/S | λ Max | K/S |
| 0.5%    | 460  | 1.024 | 460    | 2.259 | 460    | 1.748 |
| 1%      | 460  | 3.067 | 460    | 2.077 | 460    | 2.068 |
| 2%      | 460  | 3.896 | 460    | 2.562 | 460    | 2.873 |
| 5%      | 460  | 6.323 | 460    | 2.991 | 460    | 3.507 |
Fig. 2. K/S values of different percentages of on mass of fibre, set of dyeing I.

Fig. 3. K/S values of different percentages of on mass of fibre, set of dyeing II.

Fig. 4. K/S values of different percentages of on mass of fibre, set of dyeing III.
5. Conclusions

It is a challenging period for the textile industry, with the economic downturn threatening sales and a growing awareness of real social and environmental challenges, such as climate change, wars over resources and increasing consumer’s expectations of brands.

Biotechnology’s evolution takes place through significant advances in genetic engineering and synthetic biology discovering uncommon uses and functions of plants, animals or microorganisms, sometimes even replacing old industrial mechanical systems to biological ones.

The appropriation of biotechnologies exerts increasing influence in our daily lives. Technological innovation and breakthroughs in textiles are establish to meet a variety of objectives as improvement of varied species of plants used in the manufacture of fibres or their properties, production of new types of fibres, different types of dyes, effluents’ management, amongst others. The recent trend of extensive use of biomaterials in product and fashion garments is growing exponentially and offers perspectives on sustainable design that assimilates science and technology, sustainable strategy and wellbeing and social innovation. Textile and fashion designers are looking at science as a tool to be used as part of the creative process allying, simultaneously, cut edge and complex technologies to serve better apparel industry in terms of quality innovative garments, increasingly trying to create textiles which lifecycle enable to adapt accordingly to the consumer’s characteristics and inevitable changes - age, shape, taste, needs, etc.

Natural dyes obtained through engineered bacteria may contribute to a more ecological process to produce natural dyes and may fill the gap regarding their limited quantity providing feasibility and application on an industrial level. On the other hand, natural dyeing compounds, as Lycopene, are more biodegradable and safer.

This is the first report where Lycopene was applied to textiles. In our study, Lycopene was used to dye polyester. The obtained results suggest that the colorant extracted from fruits of Solanum lycopersicum plants can be considered a potential source of natural textile dye.

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