PARSONS SCHOOL OF DESIGN
Advanced Research Seminar

Why are synthetic dyes more promising than the media suggests?

A STUDY ON THE ECOLOGICAL IMPACT OF NATURAL VS. SYNTHETIC DYES

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Written by: Caroline Adamy
Instructor: Nancy Satola

Table of Contents

Introduction

The fashion industry has been criticized by the media for being the second-largest polluter in the world following a 2014 report from the World Bank. However, this landmark report has been repeatedly discredited. To wit: Vanessa Friedman, the fashion director and chief fashion critic for *The New York Times*, traced the origins of so called 'eco-myth' and discovered that influential fashion designers and activists had repeated the claim without identifying any reliable sources.

Labeling the fashion industry as one of the most harmful in the world creates a narrative that prevents customers from making informed decisions. The polarized view that synthetic dyes are catastrophic for the environment and natural dyes are the solution to those problems, hinders the appreciation for incoming technologies. Consequently, demand is likely to shift towards products that aren't as efficient as marketing suggests.

Product versatility and contrasting legal standards around the world, prevent the quantification of pollution to be effectively measured. Two products that look exactly the same could differ in toxicity, durability, or energy efficiency. When environmental statistics are addressed, reports fail to define the stakeholders, and product-lines that make up the fashion industry. The reality is that so many people and industries, such as agriculture and transportation are involved in the making of clothes that quantifying the true-cost, and most importantly avoid counting twice is challenging.

Jason Kibbey, the chief executive of the Sustainable Apparel Coalition (SAC) also recognized that the World Banks claim was flawed.[1] The SAC's measurement is known, in industry parlance, as the Higg Index; this index standardizes the ecologic evaluation of materials and production. The Material Sustainability Index (MSI) is a cradle-to-gate index that was originally created by Nike and later incorporated by the SAC. The MSI captures the comparison between the environmental impact of varying materials. The MSI does not include information on material-use, such as, laundry or durability. There is also no consideration of recyclability at the end of its life[2]. However, the Higg Design and Development Tool, available for SAC members, takes any material use into account.

While the World Bank overstated the environmental damage of the fashion industry, there are elements of the report that have merit. Conventional cotton farming requires vast amounts of water and depend on hazardous fertilizers and pesticides to thrive. These contain a high concentration of nitrogen and phosphorus that are likely to run-off into underground or surface bodies of water and cause eutrophication. Further down the supply chain, dye-houses in countries such as China, India, and Bangladesh are negligent in building water-treatment plants and opt to dump their waste water into rivers. These rivers would otherwise be a source for food, clean water, and leisure activities. During the construction of garments, designers waste between 10-20% of their fabric[3] due to inefficient patternmaking. Any scraps that are generated before selling a product is categorized as pre-consumer waste. The collection of pre-consumer and post-consumer textile waste (used garments) isn't entirely adopted around the world. Surprisingly the top design school

[1] (Friedman 2018)
[2] (Higg MSI 2020)
[3] (Eagan 2014)

in the US, Parsons School of Design, does not count with a fabric recycling system. The lack of a standard recycling or disposal system allows thousands of used garments and textile scraps to go directly to landfills instead of being transformed back into thread. While some energy can be recouped through very efficient incineration processes, textile manufacturers are sourcing virgin plastic again instead of using recycled materials.

After 'The True Cost' directed by Andrew Morgan launched in 2015, and 'River Blue' in 2017, synthetic dyes have been associated with environmental and health atrocities. However, few news outlets explain the differences among synthetic dyes; the innovations that have emerged in the past decade, why they are harmful; and to what extent.

This paper will examine the ecological costs and benefits of synthetic dye application. Attention to water usage and management, energy efficiency, implications on health, and cost efficiency will be prioritized. Additionally, findings on synthetic dyes will be contrasted to the production and application of natural dyes. Identifying the historical background of both dye-techniques and learning about the latest technological advancements are equally important in defining the future of the textile industry.

Historical Context

How it all began

Before 1856, textiles were dyed using natural pigments derived from plants, insects, and some animals. Among the viable options, cochineal was greatly used in Oaxaca Mexico and was traded with Peru's Pre-Inca civilizations such as Moche, Paracas and Nazca. The Japanese mastered the

craft of blue indigo dyeing. Tyrian red[4] was predominantly used during the ruling days of King Cyrus in Persia, the Roman Empire, and followed into the Byzantine Empire.[5]

Tyrian red originated in Tyron & Sidon, now Lebanon, and its production expanded to Crete, Sicily, and Anatolia.[6] Purple mucus found in carnivorous sea snails, *BOLINUS BRANDARIS,* was extracted, sun dried and used to create a vibrant dye. Emperors such as Augustus, Nero, Marcus Aurelius, Commodus, Heliogabalus, and Severus Alexander where the only ones allowed to use the blood resembling color which had divine connotations. King Cyrus described it as an exclusive royal symbol.[7] Emperor Nero, in a rather abrupt approach, ordered his stewards to drag out a female member of the audience, during a performance, and strip her for using Tyrian Red[8].

The amount of time and money invested in creating purple tones naturally, as well as the status that came with wearing it, made it possible for William Perkin to gain popularity in 1856 with his synthetic innovation. Approximately 250,000 mollusks were used to create 1 ounce of Tyrian Red dye and most people wouldn't make enough in a year to cover the cost of a dyed toga. During William Perkin's time, natural dyers predominantly living in France, depended on foreign pigments to create their colors while Perkin could produce year around in a lab. Unfortunately for business, natural dyers had to manage transportation delays that were likely to slow the production

[4] Also known as Phoenician purple, royal purple, or imperial purple
[5] (Matthews 1970)
[6] (Mark 2009)
[7] (Elliott 2008)
[8] (Matthews 1970)

of dyed materials. Dye quality was also affected by the whims of nature and the dye maker's skills[9] whereas synthetic dyes provided good textile fastness and color consistency.

Initially, the young chemist was trying to convert an artificial base into the natural alkaloid quinine, which comes from Cinchona bark. Currently, quinine is used to treat malaria and serves as an ingredient for tonic water. However, his experiment created some unexpected results. Instead of getting a colorless quinine, he ended up with a reddish powder. Intrigued by his findings he proceeded to add aniline which had been linked with colorants for 30 years. After creating a perfectly black product that after purification, and drying and washing with alcohol, no other aniline dye had attracted the public's eye like Mauvine.

Rise to fame

Fascinated at the age of 19, William Henry Perkin, with the economic support of his father, proceeded to patent the product labeled Tyrian Purple in August of 1856.[10] The dye was expensive to produce at first but finding the right suppliers allowed him to source alanine for less. Moreover, Mauvine dye only worked on silk and wool but not on cotton which was very popular at the time. Fortunately, he found that Tannin helped mordant (prepare) the fabric to absorb his dye. Soon after, it became the color of the season. Perkin also called Mauvine, Tyrian Purple as a marketing tool. Associating the dye to a color that could only be used by Kings and Emperors generated an aspirational effect. Not too different to the fashion world today, influential women such as Princess

[9] (Stothers and Abrahart n.d.)
[10] (Bernard 2018)

Victoria and Empress Eúgenie, a Spanish aristocrat and the wife of Napoleón III Bonaparte played a major role in its propagation. (See Figure 1)

The French mastered and dominated the market with natural dyeing techniques, but Perkins triggered curiosity around Europe to create new colors derived from coal-tar. Still, French dye-houses didn't lose significant business until the early 1900's. *The Oxford Encyclopedia of Economic History* reveals that naturual pigments were still a very significant part of the economy. The rising popularity of purple may help explain why European and some American textile indusutries were devouring 305,000 tons of logwood yearly in 1895 to dye their fabric purple.

Companies such as Geigy, Bayer, Hoechst, Actien-Gesellschaft fur Anilin-Fabrication (AGFA), Badische Anllin-und Soda-Fabric (BASF), Gesellchaft Fur Chemische Industrie im Basel (CIBA), and Kern & Sandoz emerged at the time. Perkins had a strong patent in Britain, forcing many dyers to develop their products in Switzerland and Germany, where patent laws weren't as strict or established. Emmanuel Verguin was accredited with the creation of fuchsine or "magenta" and became more popular than Perkin's Mauvine. Lyon based producers "La fuchsine" secured the rights and began production. They also kept prices high and chased patent infringers.

Up until WWI, Germany was supplying 95% of global synthetic dyes. American clothing companies stopped receiving supplies and therefore had to build their own industry. Swiss dyers soon took over the German market. Swiss engineers, who also had enormous experience in the field were also sought out by businessmen to develop facilities in New Jersey.

Public Perception

Synthetic vs. Natural

180 people participated in a poll that asked 3 simple questions. Do you have any naturally dyed products and how many? If the answer was no, the participants would be asked why they didn't have any. It is important to highlight that only some have a background in textiles, fashion, chemistry, or environmental sciences, so the responses are meant to inform public perception rather than actual medical or environmental facts concerning dyes and materials.

Out of 180 people who participated in the poll, 22 had at least 1-2 naturally dyed products in their closet, but five times as many (151) had none. These results suggest that synthetic dyes dominate the market. Although alarming, clarification must be made that the poll doesn't take into account the range of colors in their closet. Secondly, the participants were not asked about low-impact dyes, or other conscientious choices such as buying second hand, or upcycled clothing. Non-the less it highlights that synthetic dyes dominate the market. Only two people reported they had 10+ naturally dyed pieces. Both cases were Parsons students making their own.

22 claimed they had never seen a naturally dyed product for sale, are rare to find, or did not know where that information was displayed. Typically, clothing brands will include a label listing all the materials, but dyes aren't a requirement. According to Greta Eagan companies that use natural dyes and are certified, will market the achievement as a trophy. Companies that aren't disclosing the information are less likely to engage in those practices.[11]

[11] (Eagan 2014)

Naturally dyed clothes are priced as luxury items but aren't at the level of luxury competitors. Getting a return on your investment is always important. Therefore, if a product is expensive but the color washes away, or won't sustain wear and tear, it's not worth it. Fast fashion has flooded the market with cheap products. Customers have become accustomed to spending a certain amount of money on essential clothing. Convincing customers to choose a more expensive, yet naturally dyed alternative will heavily rely on ecological consciousness or some fascinating design feature. Also, protecting the environment, taking as many hazardous chemicals out of our systems, and protecting our health are all major concerns in today's day and age and can create immediate intrinsic satisfactions that wouldn't otherwise be gained by purchasing a synthetically dyed product, even if it were more energy efficient to produce.

The responses are shocking considering that several participants are from Peru. Peruvian pre-Inca and Inca civilizations (primarily the Paracas culture) once had the most sophisticated textiles in the world. They used a range of natural fibers and dyes, and even though some are still used today, almost none of the Peruvian participants owned naturally dyed products. This is to show that even authentic 'artisanal' products are hard to come by as the souvenir and touristic industry now mass-produce knock-offs or are not fabricated into clothing. In other words, they are used as matts, or centerpieces.

Traditional dyers, many who are a part of indigenous communities and are true experts in the field are confronted with low sales. Their geographical exclusion, limited tech knowledge or appropriate contacts, shipping limitations and access to high quality textiles, or the dependency on tourists can all be attributed to the struggle. However, another explanation is that naturally dyed

products aren't everyone's 'style'. Responses indicated that this technique is highly associated with ethnic designs which many can't relate to. Only being able to dye natural fibers limits choice, i.e. athletic wear, which is typically made from Nylon, Polyester or Spandex and can only be dyed with synthetic dyes.

Moreover, natural dyes can be manipulated by the dyer to create customized and unique pieces that can pull in customers on a more personal level, but having too many variables and inconsistent results can stagnate customer loyalty. A two-faced challenge that will always come up with craftsmanship is cultural appropriation or plagiarism. Artisans struggle to compete with cheaper synthetic imitations of their original designs. Several designs include family stories, history and belief systems. On the other hand, the intense and sometimes irrational shaming of people expressing their culture or that of others under the 'cultural appropriation' tagline has put immense pressure on the demand for artisanal products. Many times, the accuser fails to consider the background of such individual, whether they are multiracial and identify with multiple cultures, have a deep connection with a particular country, or simply believe in the values of a community and want to show support by purchasing a product they truthfully like. The hypersensitivity that is being encouraged and the fear of being criticized has caused people to take a step back from purchasing local products. Artisans are limited to the number of sales they can achieve, where instead the concept of cultural appropriation should arguably be a reminder to be respectful and show genuine interest for other cultures.

Rising Popularity of Natural Pigments

Natural dyeing is one of the most ancient forms of art, but the increasing concerns for climate change have put natural dyeing back on the map. Indigenous communities around the world have continued practicing these techniques but now thousands of books are available on the market. There has also been an increase in textile/ artisanal tourism. There are workshops offered all around the globe. Thread Caravan, for instance, offers workshops in Mexico, Guatemala, Panama, Colombia Japan and Morocco to learn from artisans.[12]

Audrey Louise Reynolds is a Brooklyn based natural dyer who sources her pigments from squid ink, flowers, shells, plankton, soil, among others. Her customers range from indie brands such as Kaelen and The Elder Statesman, to big clients like Nike and J. Crew.[13] As a matter of fact, Nike's research team has turned the idea of using plants to dye products in small quantities into something that could be done at full scale for thousands of pairs[14] to finally launch their plant-color-collection. (See figure 2 & 2.1)

Studio Maira Jimena and Kinua Yarns are big promoters and educators in Peru. They recently released naturally dyed organic certified cotton thread that might be very good for weaving and sewing. Natural dyeing courses are also offered at Parsons school of design and a range of other institutions.

[12] (Thread Caravan 2020)
[13] (Reynolds 2020)
[14] (Nike n.d.)

Calling synthetic dyes to the stand

Understanding the environmental costs and benefits of a product can be puzzling. While fashion brands are required to include fiber content; country of origin; manufacturer/dealer identity; and care instructions, they are not required to disclose information on the dye-house or type of dye being used. These regulations are enforced by the U.S. Federal Trade Commission (FTC) and U.S. Customs and Border Protection (CPS). If a product was made in another country, the origin of materials may not be the same as the manufacturing site. "Made in USA", however, means that clothes were manufactured and materials were sourced in the United States. Otherwise, the label must state "Made in the USA of Imported Materials."[15] Certified products by Bluesign® or STANDARD 100 by OEKO-TEX® provide additional labels and can be useful tools for customers.

Water Usage

Although naturally dyed products are thought of as a cradle-to-cradle system where fabric can be composted back into the ground, they are not the only closed-loop system available to designers. Natural dyes demand large amounts of water, whereas technologies engineered by the synthetic dye industry have reduced water consumption by employing efficient water treatment and recycling plants. These technologies allow textile manufacturers to cycle water repeatedly without demanding more from the public reserve. Water has been used to dye fabric for centuries, and textile firms have generally been reluctant to embrace change.[16]

[15] (Hodakel 2020)
[16] (Heida 2014)

ColorZen is a dye-house that modifies cotton's molecular structure and allows dye to settle within the fibers without requiring the massive discharge of water. After treatment, the dyeing process uses 90 percent less water, 95 percent fewer chemicals, 75 percent less energy, and half as much dye as conventional processes, according to the company.[17] They have also eliminated the need for fixing agents that keep the fabric's color consistent. *ColorZen* is proof that dyeing can be more efficient, though it is not the only company that deserves recognition.

A 2013 article published by *The Guardian* stated that waterless dyeing should be the textile industry's holy grail, but widespread adoption was years away.[18] The Dutch company *DyeCoo Textile Systems BV* launched the world's first ever industrial dyeing machines that use super carbon dioxide (CO_2) as a replacement for water.[19] *DyeCoo* claims that only half the industry's standard is needed in dyes. They have also managed to reduce their energy use by having a closed-loop production. Carbon dioxide is kept as a liquid by controlling the temperature and pressure conditions. At atmospheric pressure, CO_2 becomes gaseous and travels through the dye container and into the dyeing vessel where a fabric bolt has been inserted. At this stage, the dye impregnates the fabric evenly, allowing a better color distribution. Finally, carbon dioxide and the dye matter are filtered through a separator. The CO_2 and dye return to their original valves respectively waiting for the next round.

[17] (Heida 2014)
[18] (Kaye 2013)
[19] (Dye Coo 2010)

The *Yeh group* in Thailand is already using *DyeCoo's* machines to produce clothes for *Adidas.*[20] The brand claims using CO_2 is a safe and environmentally-friendly option because the gas is contained and can be used repeatedly without the risk of any emissions.[21] *Far Eastern New Century* in Taiwan also utilizes these machines to manufacture clothes for *Nike.*[22] The American company *Airdrye* is a close competitor. According to Rita Kant, assistant professor at the Institute of *Fashion Technology at Panjab University* in India, *AirDye's* process embeds dye within textile fibers instead of merely on them. Thus, color lasts longer and is more resilient to chemicals and washings."[23] R.S Blackburn in the book *Sustainable textiles – Life cycle and environmental impact*, highlights the importance of getting colors right the first time. He explains that if the shade of the fabric is not accurate and a shading addition is required, this will add on average 20% to the cost of dyeing. Not only are shading additions and re-dyes bad for profit, they are also bad for productivity, meaning delivery dates may be missed resulting in the loss of business; they are also bad for the environment as they contribute disproportionately to water and energy consumption.[24]

The informal conditions in which natural dyeing occurs, makes it possible to hide the real ecological-impact. While natural dyeing occurs in small batches, large amounts of water are used to dye small pieces. Overtime or across a geographical area, multiple individuals dyeing small batches of textiles with a lot of water can significantly add strain to the water supply. Water consumption would therefore be traced back to a domestic source rather than an industrial one. Most importantly households are not obligated and are highly unlikely to have water treatment

[20] (Heida 2014)
[21] (Kaye 2013)
[22] (Heida 2014)
[23] (Kaye 2013)
[24] (Blackburn 2009)

tools. If the dyer decides not to add heavy metals, pH modifiers, or mordents to improve dye fastness, the chances of creating toxic water wastewater is very low. Hence, it can be used for watering plants or flushing a toilet. However, water recycling would depend on the dyers initiative and can easily become a problem.

Additionally, natural dyes are limited to dyeing natural materials and this can elevate water consumption significantly.[25] Cotton is the second largest fiber consumed after polyester and is particularly water thirsty. However, changes in production, such as transitioning into organic farming, can reduce the environmental impact. A report by the *Textile Exchange* stated that a number of brands and retailers are signing commitments to increase the use of organic cotton. Countries such as Tanzania, Uganda, Benin, Turkey, and the USA have contributed significantly to this transition. In 2016/17, global organic cotton production reached 117,525 MT fiber, representing a ten percent growth. Yet as promising as the transition may seem, only 0.5% of cotton is grown organically.

New organic materials and processes are entering the market. Thus, a strong relationship with suppliers and a keen understanding of organic certifications is fundamental to reduce the environmental impact along the supply chain. Synthetic dyes can add color to a broader range of materials, many which require less water than natural fibers. In other words, the success of natural dyes depends on reducing the ecological impact, most importantly thee demand for fresh water. According to the Higg Index, conventional cotton as a raw material and without undergoing

[25] Protein fibers such as wool, leather, and silk; and cellulose fibers like cotton, hemp, bamboo, modal, etc.

additional treatments has an impact benchmark of 74. Conventional cotton is better than 18% of the textiles registered in the MSI. Organic Cotton, on the other hand, has an impact benchmark of 18 and is better than 81.52% of the textiles listed in the MSI.[26]

Natural dyes will not be as competitive as synthetic dyes unless technologies made to reduce and reuse water are implemented. The perishability of organic materials prevents dyers from saving dye vats. Having containers filled with liquid dye is also an inefficient use of space. In some rural places, holding on to containers with water can be an imposition on health. Natural dyers from the Shipibo Community in the Peruvian Amazon Rainforests cannot leave water containers out, as it can propagate the spread of dengue. Therefore, only a few pieces of fabric are dyed before the water is dumped and another vat is prepared a few days later. Natural Dyers should consider methods that can conserve, and salvage the organic material before and after dyeing fabric. This will help reduce waste, the overall cost of raw materials and allow dyers to produce colors year around, regardless of the season.

The agriculture industry has a history of deforestation, and abusive use of fertilizers and pesticides. The increasing demand for farmland designated to the production of food could become a concern if natural dyes were to show significant increases in demand. However, similar to the fashion industry, knowledge and technology are more advanced than ever. If natural dyes were to scale up, some farmers would be able to produce responsibly. Additionally, natural dyes could be obtained from agricultural waste. One of the most famous materials to work with are onion skins. A more controlled alternative is to grow flowers or herbs that contain strong color pigments on

[26] (Higg MSI 2020)

rooftops. This is an interesting alternative for urban landscapes as the materials can be grown and monitored locally. This idea however will depend heavily on city regulations and the existing infrastructure. The *Fashion Institute of Technology* in NYC has a dye garden that uses cotton as their main compost ingredient.[27] Food waste is also effective. Nonetheless, despite the varied options, natural dye matter is likely to be sourced from multiple areas as none of these alternatives provide the full color spectrum that synthetic dyes can offer.

A world without synthetic dyes is hard to imagine, but before 1856, natural dyes dominated the market. Opposite to popular belief, natural dyes weren't as ecologically pristine. After Columbus's discovery of the Americas, Europeans deeply depended on extracting resources from these lands. According to *The Oxford Encyclopedia of Economic History,*

> *"(…) the development of textile industries in various parts of the world gave dye sources a strategic importance in international policies and made the large-scale cultivation of selected dye plants necessary to ensure a regular supply (…)Following the discovery of America and sub-Saharan Africa by the Europeans such dye woods as old fustic from North America, brazil-wood from Brazil, and bar-wood and camwood from Africa brought a mass of new, cheap coloring matters mostly procured by careless exploitation of natural forests. Especially after the industrial Revolution, the huge textile industries in Europe and North America relied more and more on these imports: around 1895, they were devouring 305,000 tons of logwood yearly."* [28]

[27] (FIT 2014)
[28] (Oxford University 2003)

Water Pollution

A 2014 World Bank report about the Bangladesh Responsible Sourcing initiative claimed that textile production was responsible for up to one-fifth of industrial water pollution globally, with the emission of as many as 72 toxic chemicals reaching the water supply.[29] A pollution assessment carried out by IWM (2007) found that industrial sources, notably the textile industry, tanneries, and the pharmaceutical industry, were the largest contributors to pollution in the Dhaka watershed. Over 1.3 million cubic meters of heavily polluted industrial wastewater entered the drainage and river system without treatment on a daily basis in Dhaka alone.[30]

From the 1960s to the 1990s, El Paso Texas was the blue jeans capital of the world producing 2 million pair of jeans a week.[31] Cheaper production available in Mexico, China, Bangladesh, and Indonesia due to low wages and weak environmental regulations incentivized business to shift to offshore production sites. According to a publication by FASHIONISTA "An inky blue discharge, indigo, bleeds into the South China Sea from the denim mills in Xingtang. Xingtang makes roughly two-thirds of the world's denim clothing annually and local plants employ up to 220,000 people but many are refusing to work under these conditions.[32] The irresponsible and scot-free dumping of hazardous waste water has made it nearly impossible to source potable water in affected regions. The district of Tiruppur in India is home to 700 dyeing units, but is also one of the biggest generators of hazardous waste. Failure to enforce the appropriate regulations to all industries in

[29] (World Bank 2014)
[30] (ibid.)
[31] (Jackson 2005)
[32] (Brannigan 2017)

the area, have allowed water used for human consumption, industrial purposes, land irrigation and fish production to be greatly contaminated by toxic substances.[33]

The Dhaka Water Supply and Sewerage Authority relies on the treatment of surface water sources to complement groundwater supplies. However, during the dry season, river water can become so polluted that it cannot be effectively treated to drinking water standards. If the situation worsens, the Dhaka Water Supply and Sewerage Authority may have to obtain water from the Padma and Meghna Rivers, with estimated investment costs of $430 million and $285 million, respectively[34]

Poor water management is a critical issue in the fashion industry, but some synthetic dyes meet high environmental standards. *Mara Hoffman*, a New York based designer, and leader in sustainable fashion assures her customers that her suppliers use high quality dyes by brands such as *Hunstman* (See Figure 3). When onboarding a new supplier, she looks for partnerships that are *Oeko-Tex® 100 Standard,* meaning that raw materials will undergo testing to ensure that no harmful chemicals are used. Her team tests materials against a '*Restricted Substances List'* (RSL) based on the '*Zero Discharge of Hazardous Chemicals'* list.

STANDARD 100 by OEKO-TEX® is one of the world's best-known labels for textiles tested for harmful substances. It stands for customer confidence and high product safety. The strict tests for harmful substances and the comprehensive catalog of measures include Important legal regulations such as banned azo colorants, chromium (VI), PFOS, lead (US-CPSIA), etc.

[33] (Rabbani and Sarker n.d.)
[34] (IWM 2007)

Most fiber-reactive shades are classified as low-impact dyes because they meet the requirements of the Oeko-Tex Standard 100, an international textile certification program. To meet this standard, low-impact dyes cannot contain toxic substances, must have an absorption rate in which 70% or more of the dye is absorbed by the fabric and require relatively little rinse water.[35] These are produced from petrochemicals, molecularly bond with fabric, creating colorfast, long-lasting shades. They're used on cellulosic fabrics such as cotton, linen, hemp, rayon and Tencel. They can also be used with wool and some synthetic fibers including nylon.

The evaluation of the textile industry must be holistic in its approach, therefore requiring a comparison with natural dyes. Given that natural dyes only work with natural fibers it is important that natural dyers work with organic certified products to cut their footprint. Natural fibers such as cotton, bamboo, modal, corn (PLA) and milk/ protein fiber, require pesticides or other chemicals to grow.[36] Fertilizers for example tend to have high concentrations of nitrogen and phosphorus. These substances can leach into the soil and into sources of ground water, as well as streams and rivers. As a result, bodies of water experience eutrophication, i.e. nutrients trigger the excessive growth of algae, which can deplete the levels of oxygen. Species can no longer sustain themselves under these circumstances.

[35] https://www.sympaticoclothing.com/why-i-use-earth-friendly-low-impact-vs-natural-dyes/
[36] (Eagan 2014)

Energy

Dye Coo, Airdry, and ColorZen have proven that energy can be saved by simply recycling materials, and finding ways to reduce the drying time of fabric. However, true energy efficiency relies heavily on fiber manufacturing. Cotton fabric, among other natural fibers, have already been addressed. In short, an organic certification can reduce the amount of water, chemicals, and energy required to grow. This should effectively reduce the impact of naturally dyed products. Synthetic dyes and textiles cannot be composted but they can be recycled. Natural fibers that have been dyed synthetically are included in this claim. Companies such as **ECONYL®** have managed to create 100% repurposed nylon by reusing waste like fishing nets, scrap fabric, carpet flooring, and industrial plastic from landfills and the ocean. They sort it, clean it, convert it back to its virgin-like form and create yarn.[37] As long as the material is not blended, it can be regenerated infinitely. Polyester on the other hand, which is the most used fabric in the world, and can only be dyed with synthetic dyes, relies heavily on virgin petro-chemicals. Fortunately, polyester can be created by upcycling PET bottles, or recycling used polyester fabric. The issue with getting these materials to the appropriate facility continues to be a challenge. Patagonia launched their Common Thread initiative to recycle used or worn-out Patagonia Capilene. After running the numbers, they found that 72% of the energy used to produce virgin fibers was saved by recycling used textiles into new yarns and fabrics.[38] Zara and H&M also collect fabric waste.

[37] (ECONYL® n.d.)
[38] (Eagan 2014)

Other Color alternatives

Bio-Technology

Colorfix

Colorfix uses synthetic biology to remove the need for harsh chemistry in the creation and application of dyes. The first step is to find a color that is created by a living thing such as an animal, plant or microbe. Via DNA sequencing, bio-engineers work out what encodes the instructions to make a pigment and translate the message into engineered microorganisms, which are used both to grow and transfer the color."[39]

Pili

French company, *Pili* approaches dyes through a fermentation process. The incoming technology claims to use approximately five times less water and ten times less energy because microbes work at room temperature. Additionally, the creative director Marie-Sarah Adenis explains that instead of using petroleum as the raw material, the process uses renewable carbon such as agricultural waste that is transformed by micro-organisms instead of destructive chemicals. One hundred tones of petroleum and ten tones of toxic chemicals per tone of product are therefore saved in the process.[40]

[39] (Colorfix 2020)
[40] (Woollacott 2020)

Fermentation allows micro-organisms to break down renewable plant-based matter like sugar or wood, to reshape it into dyes. This process has a reduced energy balance since the enzymes in these microorganisms work at room temperature, without toxic solvents, and using far less water and energy than petrochemical processes.[41]

Peruvian Colored Cotton

Peru is historically known to be a land packed with natural resources and has been the source of many edible and non-edible agricultural products, including potatoes, blueberries, asparagus, and cotton. However, post 1990, President Alberto Fujimori[42], Alejandro Toledo[43], and Alan Garcia promoted the diversification of crops (assigned for exports). The diversification of agricultural crops also came with the prohibition of growing a cotton species called Gossypium barbadense, which was cultivated in Pre-Incan times by the Moche Culture to make intricate textiles. Its most evident trait is its ability to grow naturally in colors.

Aside from its colorful properties, Native Peruvian cotton grows in extreme climates. Research published by Universidad Agraria in Peru found that colored cotton requires significantly less water and fertilizers to grow and can be 100% organic. Overtime, the crop has adapted to strive in extreme saline soils with low water levels in comparison to commercial species.

[41] (Pili 2020)
[42]
[43]

Lambayeque a region along the coast of Peru, is the top producer at the moment. This specie can survive altitudes ranging from 1900 meters above sea level in the Andes and 1600 along the coast allowing for the crop to potentially be grown in more regions. Its colorful features could prevent the need for dyes, or its efficient growing qualities could help reduce the footprint of both natural and synthetic dyes to decrease. With consumers demanding a variety of colors, it is important to highlight that the tone of the fibers can be slightly modified based on the pH levels of the water, therefore allowing for color alterations. In many cases the color of fabric works as an optical illusion that may be created by weaving together two different colors such as blue and yellow to make vivid green fabric. By using these virgin colors and in some cases organic dyes, the creative possibilities are infinite. In Peru for example, traditional textiles from the Andes already implement red dyes from an insect called cochineal, indigo to make blue and muelle to make yellow. In the Amazon, women from Shipibo communities use dyes from achiote for red, Almond for green, Turmeric for yellow, and many other colored plants to design lively textiles and patterns called Kene.

Conclusion

In conclusion, natural dyes are less toxic than synthetic dyes but not necessarily less impactful. The controlled environment of synthetic dyes has allowed engineers to quantify and evaluate their efficiency with precision, contrary to natural dyes. The information acquired has been incredibly useful in engineering technologies that improve the overall ecological impact. Companies such as Dye Coo and Air dry are proof that fabric can be dyed without water, hazardous chemicals, and less energy. Although their fabric choice is still limited to polyester. ColorZen, on the other hand,

managed to use low-impact-dyes on cotton, meaning that water and energy have also been reduced significantly. Hopefully organic cotton or native Peruvian cotton is used more often than not. Certifications and regulations have improved overtime, especially in the US, assuring that waste water from textile facilities aren't dumped into rivers or public water treatment facilities. Nonetheless, facilities in South East Asia need to continue adopting new technologies in order to stay competitive and avoid depleting entire rivers. There are elevated life and monetary costs involved in polluting rivers. These involve loss of water and food supplies, migration, and costly projects to import water from other regions. Natural dyeing techniques are not currently a viable substitute given that synthetic dyes are versatile, can been produced year around and have become water and energy efficient. However, the success of synthetic dyes can be accredited to the scientific approach and technological advancements rather than the formula itself. In wit: bio-technology has experienced major increases in demand and curiosity. Companies such as Colorfix have identified ways to generate dyes from isolating parts of DNA found in nature. Similarly, Pili utilizes microbes and fermentation processes to create color. These innovations are still finding ways to scale up, but have demonstrated that color can be achieved in a new way.

Even though there are an array of options, it is important to highlight that each and every one of them provide a different end-product. For example, Dye Coo and Airdry, which are synthetic, are good alternatives for athletic wear, and the ecological impact can be minimized if recycled polyester were to be used. Natural dyes on the other hand are wonderful for customized, and unique pieces.

Images:

(Figure 1) A close copy of a painting by Franz Xaver Winterhalter (1806–1873), the portrait depicts Eugénie de Montijo de Guzmán (1826–1920), wife of Emperor Napoleon III and mother of the prince imperial.

(Figure 2)

(Figure 2.1)

(Figure 3) Mara Hoffman – Freya Dress made from TENCEL, soft rayon made from beechwood.

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