Received: 6 May 2025 | Revised: 6 May 2025 | Accepted: 24 May 2025

DOI: 10.1111/cote.12836

FULL PAPER

Coloration Technology

A systematic review of natural colourants and trend forecasting practices for the textile and fashion industry

Bintan Titisari | **Pammi Sinha**

School of Design, University of Leeds, Leeds, UK

Correspondence
Bintan Titisari, School of Design, University of Leeds, Leeds, UK.
Email: b.titisari@leeds.ac.uk

Funding information
European Union Horizon 'Research and Innovation Action' Horizon-CL2-2022 HERITAGE-01-04, Grant/Award Number: 101094809

Abstract

Recent global interest in sustainable practices in the textile and fashion industry has inspired stakeholders to readopt natural colourants. However, integrating these practices raises several questions regarding the latest developments in natural colourant and trend forecasting practices in the textile and fashion industry. It also prompts inquiries about how to incorporate the use of natural colourants into current industry, and the role of the trend forecasting industry in this. Colour decisions, first in the fashion design process, are influenced by the designer's creativity, forecasted trends and factory capabilities. A systematic literature review was conducted to examine the latest developments in natural colourants and trend forecasting for the textile and fashion industry. This was compared with a desk-based review of current trend forecasting practices. Five topics emerged from the examination of the literature of natural colourants: natural colourant sources; colouration technology; the application of natural colourants; culture and tradition; and industrialising natural colourants. Meanwhile, four areas arose from the literature of trend forecasting: technology, process, business and society. The in-depth analysis of natural colourant literature focused on "industrialising natural colourants" papers and discovered four key themes: industry scalability; consumer behaviour; economic value; and marketing and promotion. Comparison across these reviews identified opportunities for incorporating natural colourants through technology, marketing and education, supported by trend forecasting practices. Further research and significant adjustments in the industry are crucial, either to facilitate the integration of natural colourants into existing systems or to determine whether parallel standards and tools need to be developed.

1 | INTRODUCTION

Recent increased interest in sustainability has inspired both consumers and manufacturers/designers to readopt natural colourants because they are renewable and biodegradable[1] and thus reduce the fashion industry's chemical impact on waterways and soil.[2] Several established multinational fashion brands such as Nike, Toms, Reebok, Quiksilver, MUD Jeans and Patagonia have produced limited collections of naturally dyed garments and shoes,[2] which shows growing interest in using natural colourants in the fashion industry. This study aims

to explore the use of natural colourants in textiles and fashion, focusing on incorporation and scaling up the production of natural colourants at an industry level, as well as the correlation with trend forecasting practices. This area has been infrequently addressed yet is important because trend forecasting has a strategic role in defining the colours that dominate each season in the textile and fashion industry, via annual and seasonal predictions.

2 | NATURAL COLOURANTS AND THEIR ESTABLISHMENT IN THE TEXTILE AND FASHION INDUSTRY

The term "synthetic dyes" refers to chemically manufactured colourants obtained from organic and inorganic molecules or primarily derived from petrochemicals. Natural pigments are defined as any substances that are synthesised by and accumulated and/or excreted by living cells.[3] Natural dyes are derived from natural sources, such as plants, insects, animals, microorganisms or minerals.[4,5] Other terms are used to describe natural based dyes, including natural colourants,[6–11] bio-colourants,[11–14] bio-based dyes or colourants,[15–17] bio-dyes,[4] bio-mordants[18–23] and biogenic.[24] The terms "natural dyes" and "bio-colourants" are often used interchangeably but differ significantly in their sources, synthesis and applications.

Bio-colourants can be defined as a subset of natural colourants synthesised from pigments[12,25,26] or living cells, such as microorganisms, fungi or algae, and can either be accumulated within or excreted by these organisms.[27,28] Bio-colourants are related to the advances in biotechnology that have enabled the production of bio-colourants through fermentation processes using microorganisms, which were initially used as a food colourant, but as an additive can be used in more broader applications, such as in textiles.[25,28,29] This study uses the term "natural colourants" as used in common parlance and to cover all the terms mentioned above for the purposes of brevity in this paper.

Although natural colourant markets have significantly diminished over the past 150 years, many societies worldwide continue to uphold textile craft traditions that have been passed down through generations.[30] More consumers are increasingly drawn to the visual comfort and psychological quality offered by natural colourants, which are making naturally dyed fabrics more desirable, high-value products compared with those produced using synthetic dyes.[31] This preference is further supported by the eco-friendly, low-toxic and anti-bacterial properties of natural colourants, as well as their rising cultural and economic significance.[31,32]

The growing interest in natural colourants is a positive development, but integrating these practices into the current fashion industry poses challenges. Using natural dyes in global apparel production for sustainability is complex, from dyestuff production, wet processing steps, colour consistency and fastness, effluent water, to scalability.[2] The scalability of natural colourant production also encounters various challenges, such as the lack of collection and availability of natural colourants in standard ready-to-use forms, limited and non-reproducible colour options, an inability to meet large demands, high purification costs, a lack of technical expertise, time-consuming processes and the necessity to prevent overexploitation of resources when obtaining natural colourants.[33–35]

The development of natural colourant processes has fallen significantly behind since the introduction of synthetic colourants. In the fashion industry, natural colourants remain a renewable alternative to synthetics,[2] and for the success of the commercial use of natural colourants, it is essential to produce new shades with acceptable fastness behaviour.[36] Historically, plants and insects have been primary sources of natural colourants, although modern researchers are increasingly exploring microorganisms to make production more sustainable and cost-effective compared with traditional extraction methods,[28] which can lead to more diverse applications, alongside ongoing efforts to refine production processes and reduce costs.

3 | TREND FORECASTING IN THE TEXTILE AND FASHION INDUSTRY

Colour technology revolutions in synthetic colourants transformed the visual culture of fashion in the nineteenth century, and the emergence of forecasting colour trends was a result of the industrialisation of synthetic colourants.[37] Contrary to popular belief, synthetic colourants did not entirely replace natural colourants in the late nineteenth century, particularly in British dyeing.[38] The shift from natural to synthetic colourants was gradual, driven not only by the supposed fading of natural colourants, but also by popular tastes or trends and cultural expectations (eg, the Victorian desire for novelty)[38] combined with trend forecasting practices.

Trend forecasting is a mechanism for analysing current knowledge and past trends to anticipate future directions to guide business decisions; thus it is dual natured because it both determines and is determined by society.[39] A strategically important part of the product development process, trend forecasting enables a deep understanding of the alignment of the design process with company strategy, and the design process has been

calculated to add 50% to the entire value of the chain for the fashion and textiles sector.[40] All companies undertake their own trend forecasting, predicting between 4 months and 1 year in advance of the new season, with the larger mass market companies making their forecasts 1 year in advance.[41] Companies providing trend forecasting services prepare forecasts to support business decision making; for example, the high-level forecasts 2-5 years in advance of a season announce general trends in colour, texture and fabrics, accompanied by colour of the year. Colour-matching services provide appropriate colour numbers to enable dyers to develop recipes and yarn producers to produce yarns for textile mills to make into fabric.[42–46] Trend forecasting plays a pivotal role in the textiles and fashion industry; however, little is known about what role the trend forecasting industry has in supporting or encouraging the adoption of natural colourants into the existing textile and fashion industry.

4 | RESEARCH METHOD

As discussed above, this study aims to answer two research questions: (i) What are the latest developments in natural colourants in the textile and fashion industry and trend forecasting practice? (ii) What prevents the use of natural colourants in the current industry, and what is the role of the trend forecasting industry in this? To address these questions, this study conducted a systematic literature review (SLR) adopting the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 guidelines[47] to facilitate transparent and complete reporting and to reflect recent advances in systematic review methodology and terminology. PRISMA 2020 has three phases, namely (i) identification (keywords searching); (ii) screening (records excluded, eligibility, retrieval); and (iii) included: studies included in the review. Two databases, Scopus and Web of Science, were used to conduct the SLR (Table 1).

- **Step 1: Searches in databases**. A search was conducted in the Scopus and Web of Science databases of all available peer-reviewed journal articles on 21 February 2024. Restricting to double peer-reviewed journal articles assumed that they were reliable due to the rigorous review process.
- **Step 2: Deleting duplicates and documents written in a language other than English**. All duplicate documents were deleted, as well as the ones not written in English.
- **Step 3: Checking the type of article**. All documents' sources were checked and only articles from scientific journals remained.
- **Step 4: Reading the title and keywords**. All titles and keywords were read with a question that guided either inclusion or exclusion for documents.
- **Step 5: Reading abstracts**. All abstracts were read with a question that guided either inclusion or exclusion for documents.
- **Step 6: Retrieval of records**. The full texts of all records remaining from Step 5 were searched for and retrieved.
- **Step 7: Reading full texts**. The full texts of the documents were read, with a question that guided either inclusion or exclusion for documents, thus determining the final portfolio to be used in the content analysis.
- **Step 8**: **Validation of themes**. From the documents in Step 7, emerging themes were identified and then validated.

4.1 | Desk-based research about trend forecasting practices

Trend forecasting websites and trend forecasting reports were examined from September to December 2024. The websites provide publicly available information for unsubscribed viewers; trend reports provide more in-depth information for subscribed clients (commercial entities and higher education). The aim of examining the websites was to understand what services they provide and what publicly available information they present about natural colourants. The aim of the reports examination was to understand their engagement with natural colourants through (i) reporting use and developments in natural colourants; and (ii) their communication of natural colourant knowledge and understanding to the fashion and textile industry. An example of this is major European trend forecasting companies, as the Colour4-CRAFT study focuses on European natural colour industry.[48]

5 | FINDINGS

From the SLR and desk-based research, the findings are presented in three sections: (i) development of natural colourant practices based on articles and focusing on industrialising natural colourants; (ii) developments in trend forecasting practices; and (iii) discussion comparing the SLR and current practices. The focus was on scaling up the production of natural colourants to an industry level and any correlation with trend forecasting practices in the textile and fashion industry.

TABLE 1 The structured literature review process as it was applied and the resulting papers that were analysed and validated

Step	Action	Bio-colourants and natural dyes in the textile and fashion industry	Trend forecasting literature
1	Searches in databases	Query used: (TITLE-ABS-KEY (natural AND dye* OR bio AND colo?rant)) AND (textile OR fashion) AND (craft OR design) AND (LIMIT-TO (DOCTYPE, 'ar')). The searches returned 551 documents throughout two datasets	Query used in the searches: (TITLE-ABS-KEY (trend AND forecast*)) AND (colour) AND (textile OR fashion) AND (craft OR design) AND (LIMIT-TO (DOCTYPE, 'ar')). The searches returned 87 documents
2	Removing records	Deleting duplicates and documents written in a language other than English: 525 documents in English	Deleting duplicates and documents written in a language other than English: 76 documents in English
3	Checking the type of article	Only peer-reviewed scientific journal papers: 520 documents remained	Only articles from peer-reviewed scientific journal papers were kept for analysis: 46 documents remained
4	Reading title and keywords	Question guiding inclusion or exclusion: "Do the title and keywords refer to a study that refers to natural dyes/bio-colourants practices in textile design or fashion design?" Papers related to wastewater treatment, dyes removal and other topics unrelated to textile and fashion design were removed: 265 documents remained	Question for inclusion or exclusion: "Do the title and keywords refer to a study that refers to trend forecasting practices in textile and fashion design?": 35 documents remained after this step
5	Reading abstracts	Question guiding inclusion or exclusion: "Does the abstract refer to a study that explains the developing of natural dyes/bio-colourants in textile and fashion design?": 247 documents remained	Question for inclusion or exclusion: "Does the abstract refer to a study that specifically accounts for the trend forecasting process and/or practices in textile and fashion design?" Studies that sought to address specific problems (eg, difficulties in analysing outfits and styling details correctly for digitising purposes): 30 documents were left
6	Retrieval of records	The full texts of all 247 records were searched for and retrieved. Full texts for all records were found	Full texts of all 30 records were searched for and retrieved. Full texts for all records were found
7	Reading full texts	44 papers were identified that discussed the upscaling of natural dyes for the fashion and textiles industries, which was the focus of this study; therefore 44 documents were used in content analysis determining the final portfolio. Question guiding inclusion or exclusion: "Does this research contribute to identifying the opportunities, challenges and/or barriers for natural dyes/bio-colourant to be incorporated into the textile and fashion industry related to the trend forecasting practice?"	The question guiding inclusion or exclusion of the documents was "Does this research contribute to identifying the opportunities, challenges and/or barriers for natural dyes to be incorporated into the textile and fashion industry related to the trend forecasting practice?"
8	Validation of themes	Emerging themes identified were validated by discussion between both authors and experts in this area helped to refine and amend the themes	From the 30 documents, emerging themes were identified, first by one author, followed by a similar exercise by the other author and then validated through discussion between both authors.

6 | DEVELOPMENT OF NATURAL COLOURANTS IN THE TEXTILE AND FASHION INDUSTRY

The SLR findings on natural colourant practices in textiles and fashion highlight the growing interest in natural colourants. The number of publications in Scopus and Web of Science shows a significant increase from 2010 to 2024 (Figure 1), with a total publication of 265 journal articles. This number of publications was finalised after removing duplicates, articles not in English and articles with a different focus, as outlined in Table 1. After reading the abstracts in the first screening process, 246 articles remained from both datasets. The articles show trends in five themes: (i) natural sources; (ii) coloration technology; (iii) the application of natural colourants; (iv) preserving culture and tradition; and (v) industrialising natural colourant practices. Some

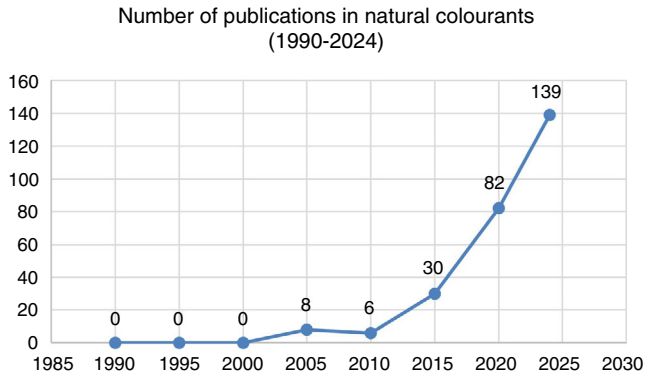

FIGURE 1 Number of publications on natural colourants in textile/fashion in Scopus and Web of Sciences

initial themes and codes were identified from reading the abstracts (Table 2). The technology advancement theme appears to be the highest, with most articles concerned in improving the coloration process and advancing testing methods. Conversely, the theme of industrialising natural colourants occurs 45 times, and is analysed later based on the relevant full papers. An overview of each initial theme is described in this section.

Abbreviations: 3D, three-dimensional; UV, ultraviolet.

6.1 | A wide spectrum of natural colourant sources

Natural colourant sources span a wide range, traditionally derived from plants (eg, madder, woad, logwood, indigo, henna), animals (eg, cochineals, kermes, lac, lichens) and minerals (eg, limonite, lazurite).[49] While traditional colourants such as madder,[15,22,23,50–59] indigo,[33,60–64] lac,[9,17,65] cochineal,[50,66] orchil,[67] safflower,[68,69] turnsole,[70] weld[71] and woad[72] are still being studied, there is significant interest in expanding these sources and discovering new ones (Table 3). Plant-based colourants continue to dominate, with research expanding beyond leaves to include seeds,[73] pods,[74,75] bark,[76–84] wood,[81,85] fruits,[86,87] roots,[62] rhizomes,[18,88–91] peels[92,93] and flowers.[35,94,95] Increasing attention is being given to medicinal plants around the world,[96–104] and some of them are linked to Ayurveda practices,[6,35,74,75,105–119] traditional Chinese medicine,[120–124] or both practices.[75,107,125,126] Industrial waste and by-products also show high potential, with 51 studies exploring their possible use and many reporting good colour fastness. Among 33 different waste sources, almond shells,[21,127–129] pomegranate rind and leaves,[130–133] grape pomace,[134–136] orange peel[137–139] and *prina* (crude olive pomace)[20,140] are frequently discussed. Most studies are increasingly focused on finding sustainable sources that are locally abundant, cost-effective, time-efficient and less toxic. The advances in biotechnology offer new opportunities to use fungi[14,16,141–145] and bacteria[34,146] as natural colourant resources, which were later called bio-colourants. Some articles highlight the use of lichen for its versatility and eco-friendly properties.[147,148]

6.2 | Expanding the application of natural colourants

Extensive research has been conducted on the use of natural colourants, with a primary focus on their interactions with natural protein and cellulosic fibres. However, recent studies have shown that the application of natural colourants has been expanded to include a variety of fibres beyond cellulosic and protein fibres, such as synthetic fibres, regenerated cellulose fibres and other materials (eg, bacterial cellulose[110,149] and mycelium[150]). There are 116 research articles on natural protein fibres that primarily focus on wool (67 articles), silk (45 articles), leather (three articles) and mohair (one article). Among cellulosic fibres, cotton remains the most studied (73 articles), followed by linen (three articles), jute (two articles) and one article each on hemp, flax, pineapple and Napier grass. Natural colourants have generally been found to be unsuitable for synthetic fibres such as polyester and polypropylene due to their hydrophobic nature and low dyeability.[151] Nonetheless, there has been an increasing number of research papers experimenting with the use of natural colourants on synthetic fibres, primarily polyester (20 articles), polyamide (eight articles), nylon (five articles), acrylic (three articles) and regenerated cellulose fibres (10 articles). The studies show good colour fastness on synthetic fibres, providing a potential area for exploration in the future.

Apart from application in dyeing processes, natural colourants have been explored for various applications, including their use in silkscreen printing as a thickening agent[61,152–154] or a pigment,[102,105,155–157] in three-dimensional printing with thermoplastic polyurethane,[88] camouflage fabric for protective clothing[156] and bio design applications.[150] In the past decade, many designers have been using the bio design approach to create fashion products, such as the Future of Living Materials project, which uses microorganisms and bacteria in its designs.[150]

TABLE 2 Overview of key themes and codes of the natural colourant systematic literature review

Key themes and sub-key themes		No. of occurrences
A wide spectrum of natural colourant sources		**278**
Plant-based colourant	Natural colourants from plant	121
Traditional colourant	Natural colourants that have been used for a long history	35
Medicinal plant	Natural colourants from plants previously known for medicine (herbal plants)	35
Insect-based colourant	Natural colourants from insect	3
Natural derivative	The colouring compound of natural colourant	11
Fungal-based colourant	Natural colourants from fungi	13
Waste products, by-products	Natural colourants from waste or industrial waste	51
Bacteria	Natural colourants from bacteria	3
Lichen	Natural colourants from algae	3
Other sources	Other sources of natural colourants	3
Advancements in coloration technology		**553**
Process optimisation	Improve the dyeability, streamlined procedures for efficiency, pretreatment methods (eg, chemical modification), enhanced colour uptake, improved extraction techniques	184
Advanced dye quality testing method	Better accuracy in dye quality testing method (colour and rubbing fastness properties, colouring compounds and characteristics, colour matching)	194
Sustainable and environmentally safe process	Eco-friendly processes and materials (bio-mordant), reduction of environmental impact (less waste)	128
Multifunctionality of finishing treatments	Anti-bacterial, antimicrobial, UV protection and anti-oxidant properties	29
Health and safety	Reduced toxic exposure and mitigated health risks	10
Biotechnology integration	Use of enzymes and bacteria for better colour application and processing	8
Expanding natural colour application		**158**
Natural fibre	Application of natural colourants on different types of natural fibre (cellulosic and protein fibres)	109
Synthetic fibre	Application of natural colourants on different types of synthetic fibre	31
Printing	Natural plant for printing binder	14
Bio-design	Bacterial cellulose and mycelium	1
3D printing	3D printing	1
Protective clothing	Application of natural colourants to create camouflage fabric	1
Culture and preservation of natural colourants		**51**
Culture	Attempts to maintain natural colourant practices in different cultures	25
Historical	Studies on different natural colourants from ancient history	18
Traditional craft process	Preserving traditional craft processes using natural colourants	8
Industrialising natural colourants		**45**
Economic value	The economic value of natural colourants to society	20
Marketing and promotion	Strategies to make natural colourants accepted by the market	10
Industrial mechanism	Advancement to scale up natural colourants on an industry scale	7
Consumer behaviour	Characteristic of existing and potential market of natural colourant products	12

TABLE 3 The sources of natural colourants

Plants	Plants	Plants	Traditional colourants	Medicinal plants	Waste products and by-products
Leaves or shrubs:	**Fruits and seeds:**	**Flowers:**	Indigo	*Acacia auriculiformis*	Onion (*Allium cepa*) skin extract
Aegle marmelos leaves	*Allium cepa* cv. Settonia	African tulip	Lac	*Achillea biebersteinii*	Almond shell waste
Averrhoa bilimbi leaves	Annatto seeds	*Buddleja officinalis*	Madder (*Rubia tinctorum* L.)	Annatto seeds	Banana peels
Barberry (*Berberis vulgaris* L.)	Aronia (*Aronia melanocarpa)* fruits	Chinese rose	Orchil	*Arnebia euchroma*	Beetroot peels
Berberis thunbergii	*Artocarpus lacucha*	Clove (*Yzygium aromaticum*)	Safflower	Barberry (*Berberis vulgaris* L.)	*Camellia oleifera* Abel shells
Coconut leaves	Avocado (*Persea americana*) seeds	*Eichhornia crassipes* flowers	Tumeric	*Buddleja officinalis* flowers	Orange peels
Corchorus olitorius leaves	Black pepper (*Piper nigrum* L.)	Gardenia	Turnsole (Dyer's Litmus)	*Cassia fistula* pods	Chestnut shells
Daphne mucronata	Coffee	*Hibiscus rosa-sinensis*	Weld	*Casuarina equisetifolia* L. leaves	Chickpea husk
Embelia schimperi	Common poppy (*Papaver rhoeas* L)	*Hibiscus sabdariffa* L	Woad (*Isatis tinctoria* L.)	Chinese gall	*Citrus aurantium* peels
Eucalyptus	*Gardeniae fructus* seeds	Marigold (*Tagetes erecta*)		*Chromolaena odorata*	Coffee grounds
Euclea divinorum	Gunda Gundo orange fruits	*Prangos ferulacea*	**Insects**	*Clitoria ternatea* L	*Copaifera langsdorffii* Desf. Bark
Euclea racemosa	Harmal seeds	Rose	Cochineal	*Conocarpus erectus* L. leaves	Corn distillers' dry grain
Fennel (*Foeniculum vulgare*)	Hops (*Humulus lupulus* L.)	Safflower red	Lac	*Coreopsis tinctoria*	Date pits
Grape leaves	Lotus seed pods	*Spartium junceum* L. flowers		*Cortex phellodendri*	Faba bean husk
Gulzuba (*Hibiscus mutabilis*)	Persimmon	*Thespesia populnea* flowers	**Natural derivatives**	Curcumin	Grape pomace
Green tea leaves	*Pinus nigra*		Alizarin	Dyer's alkanet (*Alkanna tinctoria*)	Groundnut testa
Henna (*Lawsonia inermis*)	Purple corncob	**Barks and woods:**	Alizarin Red S (ARS)	*Erythrina abyssinica* plant	*Inula graveolens* essential oil wastewater
Macaranga peltata	Purple sweet potato	Acacia trees (*Acacia catechu*)	Anthocyanin	Gallnut (*Quercus infectoria* Olivier)	*Juglans regia* bark residues
Madhuca longifolia leaves	Saffron	Amur cork (*Phellodendron amurense*)	Emodin	*Garcinia dulcis* Roxb.	Mango seed kernel waste
Nettle leaves	*Sesbania culeata* plant	*Araucaria columnaris* barks	Indigoidine	*Glycyrrhiza glabra* L. roots	Olive tree leaves
Quercus infectoria Olivier	Strawberry	*Croton urucurana* Baill. bark	Indigotin	Halela zard (*Terminalia chebula*) fruit	Orange peels

(Continues)

TABLE 3 (Continued)

Plants	Plants	Plants	Traditional colourants	Medicinal plants	Waste products and by-products
Rhamnus petiolaris Boiss	Tamarind hull	Jackfruit wood	Indirubin	Harmal seeds	Peanut skin
Salix phylicifolia	*Vicia faba* L.	*Juglans regia* bark	Purpurin	*Helichrysum arenarium* subsp. aucheri	*Pelargonium graveolens* L'Her.
Salvia officinalis	Wild taro corm	Mahogany (*Swietenia macrophylla)*	Rutin	*Impatiens glandulifera* Royle petals	Pomegranate peels industry waste
Thymus Serpyllum		Mangrove bark	Sodium copper chlorophyllin (SCC)	Jungle geranium (*Ixora coccinea* L.)	Pomegranate tree leaves waste
Vine leaves	**Roots and Rhizomes:**	*Quercus ithaburensis* Decaisne		*Justicia schimperiana* leaf extract	Prina (crude olive pomace)
Yellow-bud tea	Amba Haldi	Red sandalwood	**Fungi**	*Madhuca longifolia* leaves	Sorghum husk
	Beetroot (*Beta vulgaris* L)		*Chlorociboria aeruginosa*	Marzanjosh (*Origanum vulgare*)	Tea waste
Shells and Pods:	Kuntunkuni tree root	**Bacteria**	*Dermocybe sanguinea*	*Nyctanthes arbor-tristis*	Teak leaves
Almond shells	*Macaranga peltata*	*Chromobacterium violaceum* UTM5	*Talaromyces australis*	*Prosopis juliflora*	Tomato waste
Cotton pods	Madder dye (*Rubia tinctorum* L.)	*Spirulina platensis*	*Talaromyces purpurogenus*	*Scrophularia striata*	Watermelon rind
Date palm	Marzanjosh (*Origanum vulgare*)		*Cortinarius semisanguineus*	*Swietenia mahagoni*	
Pomegranate peels	*Pinus nigra*	**Lichen**	*Scytalidium cuboideum*	*Terminalia arjuna*	**Other sources**
Red onion (*Allium cepa*) skins	Tumeric	*Parmotrema perlatum*	*Penicillium murcianum*	*Terminalia chebula* Retzius	Mud
Wild pomegranate peels		*Candelariella reflexa*	*Tapinella atrotomentosa*	Yarrow (*Achillea millefolium* L.)	Marine's life

Note: This table displays various sources of natural colourants studied in the literature review, and then categorised into 7 groups (indicated with grey headings): plants, bacteria, lichen, traditional colourants, insects, natural derivatives, fungi, medicinal plants, waste products and by-products, and other sources. The plant category is further divided into 6 groups (in bold) based on the parts of the plants used, which include leaves or shrubs, shells and pods, fruits and seeds, roots and rhizomes, flowers, and barks and wood.

6.3 | Advances in colouration technology

The technology theme appears most frequently in the dataset, with 553 occurrences, as presented in Table 2. The dataset primarily focuses on technology in textile dyeing, aiming to achieve better colour quality through sustainable and environmentally friendly procedures that are cost, time and energy effective.[35,109,158] Sustainable manufacturing processes are being explored by applying eco-friendly processes and using sustainable materials, such as bio-mordants,[20–22,128,159–162] reducing environmental impact by utilising waste,[105,127,135,136,155,160,163,164] minimising toxic exposure[84,165,166] and mitigating health risks.[14,61,94,115,165,167]

Advances in the coloration process aim to improve the interaction between dyes and fibres to enhance colour performance. Various experiments have been conducted, including pretreatment methods such as plasma treatment,[75,123,127,168–170] chemical modification,[171–173] chitosan[87,90,154,158] and ultrasonic applications.[18,111,128,131,174,175] Microwave treatment is also being explored to reduce costs and make coloration and extraction processes more sustainable.[11,70,85,107,118,173,176–178] Efforts are also underway to enhance the extraction

process,[11,76,85,118,125,135,136,161,174,176,177,179–182] reducing time and costs to align with current dyeing facilities. Biotechnology integration through the use of enzymes[179] and bacteria[87] is being explored for improved colour application and processing.

More accurate testing equipment for colour fastness, colour properties and colour-matching tests on dyed fabric are now widely used. The *K/S* value, representing a dye's colour depth and strength, is a critical parameter in textile dyeing. Higher *K/S* values indicate deeper achievable colours. Some studies use a spectrophotometer to measure colour characteristics using CIELab colour coordinates.

Some natural colourants have been found to have multifunctional finishing treatments, such as antibacterial, antimicrobial, ultraviolet protection and antioxidant properties. These features are believed to add more value to natural colourant products, serving as a marketing tool to appeal to a wider consumer group.

6.4 | Culture and preservation of natural colourant practices

The market for natural colourant products has declined in the last 150 years, despite textile practices remaining highly valued both socially and politically, serving as important symbols of national identity or community.[30,64,183] Some communities preserve the textile craft traditions that continue to thrive in their societies and that have been handed down across generations.[30]

Efforts to document these historical practices have been undertaken in regions such as the UK,[67] Dubrovnik,[184] China,[33,68,185] Japan,[69] Indonesia,[186] northern Chile[187] and Sudan.[188] Studies on ancient dyeing techniques, involving woad[72] and madder,[58] have contributed to our understanding of these practices historically. Several studies have documented ongoing traditional practices, including mud dyeing in Japan,[30] mud dyeing in China,[185] the double *ikat telia rumal* with natural alizarin dyeing processes in India,[189] the indigo dyeing process among the Landian Yao people,[33] carpet weaving in Mexico,[190] the batik industry in Indonesia[191] and textile production in Ghana.[62] These studies reveal that some practices are being reinterpreted and adapted to fit contemporary lifestyles due to shifting market demands[30,189]; for example, designers and the community in China collaborate to create tie-dye designs that incorporate traditional natural dyeing methods, modifications to conventional patterns and innovative design themes.[192]

Culture can be examined from two perspectives: the textile makers (producer) and the user (consumer). The study of the consumer in this matter is closely related to consumer preference,[193] such as the consumption behaviours of Chinese and Japanese consumers regarding natural colourant products, while a similar study compared the preferences of Korean and American university students.[31] Knowing consumer preferences provides valuable insights for the industrial development of natural colourants.

7 | INDUSTRIALISING NATURAL COLOURANTS FOR THE TEXTILE AND FASHION INDUSTRY

The last theme, "industrialising of natural colourants", is the focus of our study, because trend forecasting is closely related to mass market companies. From analysing the full papers identified as those concerning "industrialising natural colourants", this study found 33 codes that were later divided into four key themes: (i) industry scalability; (ii) consumer behaviour; (iii) economic value; and (iv) marketing and promotion. These themes are presented in Tables 4–7.

7.1 | Key theme: industry scalability

Codes in this key theme refer to the potential scaling up of natural colourant production,[2,66,168,191,194] as natural colourants present opportunities for practising a "green process" to promote sustainable production and consumption in the textile industry.[2,20,23,32,33,62,109,120,183,194–197] Up until now, the scaling up of natural colourant practices has been conducted in some traditional craft communities in different countries.[23,34,62,186,189–192] The complexity of the textile and fashion industry supply chain means that upscaling natural colourant production from laboratory to industry scale requires radical change and improvements from various angles.[2] This includes using the latest technology in dyeing and extraction,[30,35,71,107,109,168,183,185,194–196] reducing the processing time,[33,62,185,186,191] calculating the effective production costs,[20,23,35,64,66,71,109,121,191,194,196] establishing standards[49,183,191] and revisiting the regulations regarding intellectual properties that have affected natural colourant practitioners.[2,186,187,190]

The current industrial level of dye production has been primarily focused on synthetic dyes.[2,66] A lack of understanding among stakeholders regarding natural colourant production[2,32,183] further challenges the upscaling process. Natural colourants need improved colour fastness, colour consistency and a wider range of

TABLE 4 Codes within the key theme: industry scalability

Code	Code means	No. of occurrences	Reference(s)
Scaling up	Studies about how to scale up the production from small to large industries	5	2,66,168,191,194
Green process	Environmentally friendly process	13	2,20,23,32,33,62,109,120,183,194–197
Cost	Cost-effectiveness throughout the natural dyeing process	11	20,23,35,64,71,109,121,177,191,194,196
Advanced process	Use of the latest technology to enhance dyeing and extraction processes, and to achieve higher dyeability and better colour quality	11	30,35,71,107,109,168,183,185,194–196
Time-consuming process	Traditional practices of natural dyeing require a time-consuming and labour-intensive process	5	33,62,185,186,191
Supply chain	Practices of natural dyes in the long and complex industry supply chain	1	2
Colour quality	Colour inconsistency, colour variation, colour fastness, colour limitation	8	2,32,66,120,191,195,198,199
Standard	Standard for colour quality of natural colourants	3	49,183,191
Radical change	The need to change the fashion industry radically to meet natural colourant requirements	1	2
Patent and regulation	Patents and regulations affected practitioners' knowledge of natural colourants	4	2,185,186,189
Material	Studies consist of natural colourant availability and fibre application	5	2,109,168,194,199
Knowledge gap	Lack of knowledge of natural colourants among industry stakeholders and consumers	3	2,32,183
Lack of infrastructure	Dye production nowadays is not developed and designed for natural dyes	2	2,71
Traditional craft community	Traditional practices of natural colourants in different communities	8	23,34,62,186,189–192
Total number of occurrences		81	

colours[2,32,49,120,191,195,198,199] for various types of fibres[2,109,168,194,199] that are not currently available. The meaning of each code and its frequency are presented in Table 4.

7.2 | Key theme: consumer behaviour

Codes in this key theme focus on how consumers perceive natural colourant products. Table 5 presents the meaning for each code and its frequency. Consumers are increasingly mindful of environmental issues when purchasing textile goods,[32,49,55,121] and this is their primary reason when purchasing natural colourant products.[2,64] Cultural factors also influence consumers' decisions to purchase natural colourant products.[31,185] Nevertheless, consumers still expect high quality[32,49,121,185] and comfortable products,[32] with no allergic reactions[121] and good colour fastness,[2,55,121] when it comes to natural colourant products.

Several authors have studied colour perception and colour sensation regarding natural colourant products, and found that people generally have a positive perception of them,[31,202] feeling unique[31,52] and special.[185] However, colour preferences can vary,[49] and are influenced by culture, age, gender[31,32,64,193,200,201] and different fabrics.[31] It was noted that the preferences are also influenced by social trends[52] and can change over time.[64] Some younger generations prefer Western and modern style clothing.[30,33,183] Considering the relative nature of colour preferences, this means all recipes of natural colourants can be explored in industrial dyeing.[49]

7.3 | Key theme: economic value

Codes in this theme indicate the economic importance of current natural colourant practices and their contribution to local economic and social activities because of their connection with traditional heritage.[30,33,186,190] For

TABLE 5 Codes within the key theme: consumer behaviour

Code	Code means	No of occurrences	Reference(s)
High-quality colour	Consumer demands high-quality products with good durability and degradability	5	2,32,55,121,185
Eco-friendly product	Consumers purchasing garments using natural colourants sought to support more environmentally friendly apparel production	6	2,32,49,55,64,121
Sensorial factor	Colour sensation and perception of natural colourants	7	31,52,64,66,185,200–202
Cultural differences	Consumer preference based on culture	5	31,32,52,64,193
Demographic factors	Preference can be affected by various factors including gender, age, nationality and culture	7	31,32,64,186,193,200,201
Cultural related	Consumers like supporting traditional natural colourant production, which is tied to their cultural heritage	2	31,185
Social trend	Consumer preference varied depending on the shifted social trend	6	30,33,52,64,183,193
Relativity	Consumer preference is relative and changing over time	2	52,66
Wearing experience	Comfort, environmentally friendly dyeing techniques, safety, degradability and durability	2	31,32
Health and safety	Consumers are concerned about natural colourants in terms of causing allergic reactions	1	121
Total number of occurrences		43	

TABLE 6 Codes within the key theme: economic value

Code	Code means	No of occurrences	Reference(s)
Reasonable price	Price becomes a factor for consumers to buy natural colourant products	4	2,32,185,193
High value	High quality of natural colourant products	5	64,109,121,185,191
Sustainable commodities	Value of natural colourant products as environmentally sustainable commodities	5	2,30,64,189,191
Local economy	Natural colourant practices contribute to the local economy	7	23,30,33,186,190,191,194
Total number of occurrences		21	

example, natural colourant products currently have niche production, resulting in higher prices compared with mass-produced products,[185] challenging their commercialisation.[193] Not all consumers are willing to pay more for natural colourant products,[2] despite the global assumption that natural colourant products are environmentally friendly[30,189] and align with the "return to nature" trend.[64] Improving the quality of natural colourant products could increase their value in the global market and influence consumer purchasing decisions.[64,109,191] However, some consumers do appreciate the high value of natural colourant products due to their uniqueness and handmade nature,[185] alluding to their potential for the premium sector.[121] The meaning for each code and its frequency of occurrence are presented in Table 6.

7.4 | Key theme: marketing and promotion

The significance of marketing to promote natural colourant products is heavily influenced by the market demand for sustainable and environmentally friendly products,[30,32,34,35,121,183,189,191] as well as the concept of slow fashion.[155] The most commonly used marketing tool in selling natural colourant products is sustainability,[49,62,64,121,183,194] followed by cultural significance[30,185,193] and, more recently, the safety and comfort of the products.[32,33]

However, more nuanced promotion is needed to increase demand for natural colourant products.[185] It is crucial to effectively communicate information about

TABLE 7 Codes within the key theme: marketing and promotion

Code	Code means	No. of occurrences	Reference(s)
Market demand	A market demand for natural colourant products	9	30,32,34,35,121,155,183,189,191
Marketing strategy	Better communication about natural colourant practices to increase sales	12	2,30,32,38,49,62,64,121,183,185,193,194
Product diversification	Diverse natural colourant products in different ranges, functionalities, colours and more	6	32,64,150,183,185,193
Limited	Limited production can create a luxury market for natural colourant products	3	64,185,191
Customer group	Designing natural colourant products for different customer segments	6	31–33,185,186,193
Education	Consumer education about the realities of using natural colourants	2	2,193
Service	Providing more services to enhance the overall consumer experience	1	32
Total number of occurrences		39	

natural colourants to consumers; many are not familiar with them,[2] and natural colourant products are not easily recognised.[193] Educating consumers about the long and labour-intensive process involved in producing natural colourants can help them understand the high price.[2] Additionally, it is important to change the perception of fading,[2] which has been seen as a negative trait in society.[38] With the right marketing, the limitation of natural colourant production can be leveraged to position the products as luxury items.[64,121,185] Furthermore, creating diverse natural colourant brands across different price ranges,[32] colour shades[64] and product types[183] could lead to varied positioning for natural colourants in the fashion industry, appealing to a wider range of consumer groups, including different demographic and geographic segments.[31,193] Businesses can use services in the purchasing stage and after-sales as marketing tools.[32] Detailed information on each code and its frequency is presented in Table 7.

8 | RESEARCH IN TREND FORECASTING FOR THE TEXTILE AND FASHION INDUSTRY

The earliest identified academic, peer-reviewed journal paper about trend forecasting dated from 2005,[203] when increases in internet retailing, fast fashion, competition, volume of information and complexity of analysis brought intense research interest in developing computational models to support trend forecasting. A total of 37 themes were identified and four key themes emerged: technology, process, business and society (Tables 8–11).

8.1 | Key theme: technology

Codes in this theme were concerned with developing data-driven trend forecasts as opposed to traditional systems referring to the problems of relying on expert judgement, creativity[204,224] and inspiration with little empirical basis.

The term "fashion informatics"[205] was coined to describe various approaches such as computational modelling,[64,203,206,207,215–221,223] using big data,[204–214] machine learning[205,207,209–213,215–218,220–222] and neural networks.[207,209,216–218,222] Current modelling systems were better able to forecast colour, therefore this area of research also sought to develop holistic models to predict colour, fabric and style details.[211,212] The literature noted that trend forecasts needed to address speed of reaction to the fast pace of information and trend development,[206,210,215,218,221,222,225,226] efficiency[210,214,218,223] and accuracy[203,206,209,215–217,221,223] of predictions. Although some authors noted that short fashion cycles led to a lack of datapoints resulting in data constraints,[204,222] other researchers used social media[97,208,210,213,214] to develop consumer-derived data and real-time data[214] to improvee accuracy. The meanings of the codes and frequency of their occurrence are described in Table 8.

8.2 | Key theme: process

Codes in this theme focused on the variety of activities[208,224,226–230] and systems[39,208,226–228] regarding trend forecasting. The meanings of each code and their

TABLE 8 Codes within the key theme: technology

Code	Code means	No. of occurrences	Reference(s)
Big data	Big data can be structured (numeric) or unstructured (freeform and less quantifiable) and are created with increasing volume, velocity and volume electronically and often requiring computational analysis	11	204–214
Machine learning	The development or use of machine learning tools	14	205,207,209,211–213,215–222
Social media	How social media contributes to trend forecasting	5	207,208,210,213,214
Data constraints	Shortage of datapoints available due to short fashion cycles	2	204,222
Computational modelling	Computer modelling to predict or improve the accuracy of trend forecasts	11	203,206,207,215–221,223
Neural networks	This specific type of modelling system is referred to	10	205,207,209,212,213,216–219,222
Fashion informatics	Data-driven interdisciplinary field using machine learning, social network analysis and computer vision to develop trend forecasting	1	205
Real-time data	The use of information as it becomes available for trend forecasting (eg, Twitter)	1	214
Efficiency	Minimal inputs for maximum output	4	210,214,218,223
Accuracy	Focus on the accuracy of predictions	8	203,206,209,215–217,221,223
Holistic	Model to predict colour, fabric and style details	2	211,212
Creativity	Creative thinking necessary for trend forecasting	2	204,224
Change	The role of trend forecasting in bringing change to fashion styles	2	203,224
Pantone variance with colours adopted	The resulting fashion trends are not always compliant with the predicted colour trend by Pantone	4	39,205,206,210
Speed	Fast pace of information and trend development	8	206,210,215,218,221,222,225,226
	Total number of occurrences	85	

frequency are presented in Table 9. Papers noted the speed and complexity of information[39,208,226–228] and the role of trend development in bringing about a change in fashion style through its curatorial/filtering role[39] of selecting appropriate information. Most papers acknowledged the focus on colour prediction[205,215–217,220,223,225,228,230,231] and the authority of Pantone "Color of the Year",[207,213,217,220,225,228,229] although they noted that retail collections did not necessarily use the forecasted Pantone colours.[39,205,206,210]

8.3 | Key theme: business

Codes in this theme refer to the importance of trend forecasting to business success,[212,214,216,217,220,224,229,230] its role as a marketing tool[205,213,227,228] and its relationships to advertising[227] and consumer behaviour.[39,209,210,229,230] Trend forecasting impacts along the entire supply chain were also observed with a need to consider these, implying further fragmentation of fashion markets and a more fine-grained definition of target consumers.[221] The code meanings and their frequency are presented in Table 10.

8.4 | Key theme: society

This theme focused on the trend of human elements, such as mood and emotions,[203,214] again pointing to the human creative input to the trend forecasting process. The highest number of occurrences was for the role of culture in trend forecasting,[39,203,208,231] followed by historical contexts and development of trend forecasting.[225,227,228] There were surprisingly low numbers of papers discussing the circular economy[39] in the categories of process and sustainability.[228] Code meanings and their frequency are presented in Table 11.

9 | DESK-BASED RESEARCH ABOUT THE EUROPEAN TREND FORECASTING COMPANIES

As described in section 4 ("Research Method"), desk-based research of websites for major European trend forecasting companies reviewed how the company websites are organised and what available information regarding natural colourants is accessible. Seven companies were

TABLE 9 Codes within the key theme: process

Code	Code means	No. of occurrences	Reference(s)
Activities	The activities in the process of trend forecasting	7	208 224,226–230
Complexity	Trend analysis and forecasting is a complex process	5	39,208,226–228
System	The systems nature of trend forecasting within the fashion and textile industry	2	223,228
Colour	Focus of study is on colour	10	205,215–217,220,223,225,228,230,231
Human–technology interface	The role of humans and technology in trend forecasting	1	226
Multifaceted nature	Different ways of trend forecasting operate in the industry	1	39
Filtering/curatorial	Trend forecasting is a process of selecting appropriate information	1	39
Circular economy	The role of trend forecasting in considering the trends in products that can follow the 3R's (Reduce, Reuse, Recycle)	1	39
Pantone authority	Pantone colour system is acknowledged as an authority within the industry	7	207,213,217,220,225,228,229
	Total number of occurrences	35	

TABLE 10 Codes within the key theme: business

Code	Code means	No. of occurrences	Reference(s)
Importance of	How trend forecasting contributes to business success	8	212,214,216,217,220,224,229,230
Fast fashion	The fast fashion business model is an especially difficult area to forecast demand	2	218,222
Marketing	Trend forecasting as a marketing tool	4	205,213,227,228
Advertising	The relationship of trend forecasting to advertising	1	227
Consumer behaviour	The relationship between trend forecasting and consumer behaviour	5	39,209,210,229,230
Supply chain	How trend forecasting impacts on the supply chain	1	221
Market	How trend forecasts must consider differing markets	1	221
	Total number of occurrences	35	

TABLE 11 Codes within the key theme: society

Code	Code means	No. of occurrences	Reference(s)
Historical	Historical contexts and development of trend forecasting	3	225,227,228
Cultural	The role of culture in trend forecasting	4	39,203,208,231
Sustainability	Role of trend forecasting in sustainable business	1	228
Emotion	The role of mood and emotions in trend analysis and forecasting	2	203,214
Sportive	A particular high end fashion trend	2	212,219
Symbol	The role of trend forecasting with cultural symbols	1	231
	Total number of occurrences	13	

reviewed: Colourhouse Scandanavia AB, Carlin Creative Trend Bureau, Peclers, L:SN, The:Future:Laborotary, Lidewij Edelkoort and Worth Global Style Network (WGSN) (displayed in Table 12). An analysis of their websites identified the following practices of the companies:

- All companies offer subscription based login area except Lidewij Edelkoort who offers a consultancy service instead. The:Future:Laboratory also are a consultancy based company, but their login area is for L:SN (their trend forecasting platform)
- Colourhouse and WGSN both offer and describe colour systems that they work with. Colourhouse work with PANTONE-NCS-RAL-D.cipherfm Colour Systems, while WGSN have Coloro. Colourhouse also works with X-Rite and Carlin on a range of colour management systems to enable alignment of colour properties across digital platforms.
- Peclers, L:SN and WGSN websites present trend directions for sectors outside of the fashion and textile industry.

The trend forecasting companies work as consultants to brands and retailers; for example, Carlin works with Lechler, Archroma for colour[232] and on branding projects for Campanile Hotels (part of the Louvre Group).[233]

All the company websites discussed sustainability and natural colourants. Although the difficulties in upscaling were acknowledged, indigo was noted as being of particular interest by all forecasting companies due to increased consumer demand, the take up by brands such as Wrangler and Gap Inc. to denim wear ranges, coupled with certifications from Bluesign, GOTS and Oekotex.[234,235]

Our focus in this paper is on WGSN, a global trend forecasting company, because having access to their reports allowed for further examination. Table 13 identifies numerous reports from across the WGSN website using the keyword search terms "natural dyes", "plant-based", "bio" and "regenerative". Applying the filters "category" and "colour" revealed that only 5%-13% of these reports mentioned natural colourants as a sustainable alternative or discussed more fully their cultural and historical significance.

TABLE 12 Comparison of major European trend forecasting website communications

Companies		Colourhouse Scandanavia AB	Carlin creative trend bureau	Peclers	L: SN	The: Future: Laborotary	Lidewij edelkoort	WGSN
Website communications	Colour system	*						*
	Colour swatches	*						*
	Colour management system	*						
	Trend directions beyond fashion/ textiles			*	*			*
	Media coverage/ public relations		*	*	*			
	Web shop	*			*	*	*	
	Newsletters		*	*	*			*
	Trend reports	*	*	*	*	*	*	*
	Research reports			*	*	*		*
	Consultancy case studies	*	*	*	*			
	Seminars/events (physical)	*			*		*	
	Webinars, podcasts, blogs		*	*	*		*	*
	Services offered	*	*	*	*	*	*	*
	Subscription based/ login	*	*	*	*	*		*
Total = 14		9	7	9	11	5	5	9

Keywords	All reports	Reports under the "Colour" category	%
Natural dyes	1291	162	12.5
Plant-based	1253	64	5.1
Bio	1342	103	7.7
Regenerative	799	59	7.4

TABLE 13 Number of natural dyes/colourants reports on WGSN

Suggestions to consider natural colourants as alternatives to synthetic dyes tended to be raised within the colour ranges of blue, green, pink and brown. The reports, however, frequently did not specify which natural colourants might be used to achieve the colours (apart from indigo). It would seem opportune to increase the range of colours specified and the natural colourant information; for example, broaden the colour palette to more accurately reflect the breadth of colours achievable and to suggest how they might be used more often (to rise above 5%-13% or reports specifically about colour). Including the names of natural colourant sources for colour suggestions would also further encourage and engage decision makers (eg, managers, buyers and designers) in supporting the incorporation of natural colourants within the mainstream and mass market in fashion. As higher education students also access these reports, this would encourage them to research further and develop their knowledge as they enter the fashion and textile industry.

10 | DISCUSSION

Reflecting on our comparison between the SLR and the desk-based review on trend forecasting practices, we discuss four major areas in the next sub-sections that appeared uppermost as barriers, challenges, drivers and opportunities for incorporating natural colourants into the current fashion and textile production systems, as well as the role of trend forecasting practices in this endeavour.

10.1 | Domination of the mass market and fast fashion

It is well documented that in the current textile and fashion industry, large production volumes are required[28] and time and standardisation are key elements, including colour. The current demand of the mass market places time constraints on all activities, and brands[2] are developing closer ties with manufacturers to speed up the process of product development to retail. Efforts to overcome this domination meet multiple challenges at various stages in the supply chain for adopting natural colourant practices in the fashion system. Upscaling to meet modern consumption demands requires radical changes in the fashion system.[2] Using natural colourants is normally a time-intensive process,[62,191] applicable to mainly natural textile fibres,[28] and uses large amounts of water to achieve uniform dye application.[180] While more options for natural colourant sources are being discovered, questions remain about the volume of their availability. Several studies have demonstrated advances in coloration technology for natural colourants; however, most of these studies were conducted at a laboratory scale, making it challenging to replicate these methods at an industrial scale.[66,194] Additionally, intellectual property rights for natural colourants are still underdeveloped, limiting incentives for innovation and commercialisation.[2,185]

The trend forecasting industry is also structured around serving the mass market. Our SLR identified that this industry is historically linked with the synthetic colourant industry to help textile and fashion companies manage product demand.[40,42] Our review of company websites supports this close link because their colour forecasts use current colour systems used by the synthetic colourant industry. Moreover, although our review of WGSN identified more than 1300 reports that mention the words "natural", "bio", "plant-based" or "regenerative", only 5%-13% are with reference to colour. However, growing interest in "ancestral knowledge" and the importance of cultural influences on trends have been noted by WGSN.[235]

Social media plays a role in trend forecasting,[207,208,210,213,214] and there is a complex relationship between trend forecasting and consumer behaviour[39,209,210,229,230] that shapes fashion and textile industry developments. The internet and, in particular, social media, have enabled the consumer to spread trend information quickly and to drive or develop trends, meaning that the speed of the process becomes important.

10.2 | Infrastructure geared towards synthetic colourants

Most existing dyeing infrastructures are optimised for synthetic dyes, creating technical hurdles for scaling up

natural dye production.[2,66] Currently, there is a lack of infrastructure in natural colourant practices at an industrial scale, including addressing the knowledge gap among stakeholders about natural colourants, the absence of standardised colourants and the need for established criteria textiles dyed with natural colourants.[49,183] Natural colourants struggle to meet the established standards achieved by synthetic colourants.[2] Problems arise in achieving standardisation—which is important for the mass market—due to the absence of standardised colourants and the low availability of natural colourants in standard ready-to-use form. Additionally, there are limited and non-reproducible colour options,[29–31] leading to issues with colour inconsistency. This inconsistency is a significant concern, because variables such as plant growth conditions, water quality and manufacturing set-ups influence the final output.[2]

This is also illustrated by the current colour-matching systems in use. Colour matching, although a separate activity from trend forecasting, is still important to consider because it helps to communicate colour within trend reports. The Pantone Matching System was the first acknowledged authority within the textile and fashion industry for colour forecasts.[207,213,217,220,225,228,229] From the SLR and website search, we identified four major colour systems widely used in the industry: the Pantone System (TCX and Coated), Coloro and Archroma. All colour systems publish their Colour Trends, and all provide colour swatches in different materials (eg, fabrics, papers). Colour systems ensure standardised colour matching across the supply chain. They are primarily built around the properties and capabilities of synthetic colourants, and offer consistency, scalability and compatibility with current industrial practices. While certain natural colourants can achieve similar hues to synthetic colourants, some struggle to meet the precise colour-matching, stability and scalability requirements demanded by these standardised systems.

Decision makers in product development for retailers and brands may not be aware of the lack of (and complexities in) standardisation of natural colourants. The trend forecasting reports accessed from WGSN had not reported or examined these issues, possibly reinforcing this knowledge gap. This could lead to frustration or delays in the new product development process and, potentially, reluctance in considering natural colourants in the future.

Consumers often view natural and synthetic colourants as binary opposites, with synthetic colourants praised for their durability and natural colourants often criticised for fading, a perception that oversimplifies their value.[38] These issues are reinforced by reports accessed on WGSN.[235,236] The time-consuming and labour-intensive nature of natural colourant production results in high costs, translating into higher prices for consumers. Many consumers are reluctant to pay these prices,[2,62,191] despite the artisanal qualities and environmental benefits associated with natural colourants.[193] Trend forecasting reports published in WGSN also acknowledge the luxury costs.[235,236]

10.3 | Global political and consumer interests for natural colourants

There is a global political drive and consumer interest in the circular economy principles of retaining products for longer, reusing or recycling,[39] and sustainability in general.[228] At the same time, the growing number of advanced research projects to improve sustainability credentials, such as dye uptake and process effectiveness (eg, less water, energy and waste), coupled with the development of scientific testing methods to ensure the quality of natural colourant extract and standardisation of end products (eg, the Natural Organic Dye Standard [or NODS]),[49,183] surely provide optimism that the existing barriers to natural colourants can be overcome in the future.

The trend forecasting industry has a role to play in supporting the incorporation of natural colourants. Like any industry, the trend forecasting industry accommodates changes in industry, market drivers and challenges.[225,227,228] Although the SLR about trend forecasting identified surprisingly few research papers examining sustainability, the desk review of trend forecasting company websites revealed engagement with sustainable solutions for the dyeing industry by reporting on developments. For example, positive drivers for change highlighted in WGSN reports include the rise of multi-stakeholder consortiums such as the ZHDC (ie, Zero Discharge of Hazardous Chemicals associates), as well as the implementation of regulations encouraging companies to adopt environmentally friendly practices, which present natural colourants as a more sustainable alternative to synthetic colourants.[237,238]

10.4 | Supporting and marketing the incorporation of natural colourants

The historical and current significance of the trend forecasting industry is driven by the need for sales in the face of constant change.[228] In the established manner of forecasting, colour is predicted 2 years ahead of the new season, and fibres up to 18 months ahead of the new season, enabling them to be shown at international textile and

fashion style exhibitions ca. 1 year ahead of the new season.[223] The task of trend forecasters in the industry is to provide strategic intelligence that helps the decision-making process in new product development, and in this task, their role may be regarded as one of marketing.

Our examination of the available reports at WGSN identified potential opportunities for trend forecasters to further aid and support brands. As the textile and fashion industry strives for increased sustainability, reports about natural colourants and suggestions for how they might be applied encourage decision makers to consider alternatives to synthetic colourants.[239] Although reports tended to suggest alternative natural colourants within the colour ranges of blue, green, pink and brown, they did not regularly identify or name the sources of natural colourants for these colour ranges (apart from indigo). The BioColour Library recently published a publicly available multidisciplinary dataset of bio-colour showing a bio-colour palette, and providing taxonomical, botanical, mycological and chemical scientific information about bio-colourant sources, bio-colourant products and products containing bio-colourants.[240] Each colour swatch opens a separate view linking to the dye source taxonomy sheet detailing the colour coordinates and reflectance spectrum of dyed samples. These new available resources can help expand colour ranges and naming of the natural sources, which would speed up the search for the relevant sources and, thus, further encourage and engage decision makers (eg, managers, buyers and designers) in supporting the incorporation of natural colourants within the mainstream and fashion mass market.

Good market positioning for natural colourants in the textile and fashion industry can be influenced by trend forecasting as a marketing tool. History has shown that marketing often shapes trends, especially in terms of colour trends. Colour has long been a focus of the trend forecasting industry.[225] As outlined in subsection 8.2. ("Key theme: process"), colour forecasting takes place at the earliest time possible to enable the textiles industry to develop their fibres and yarns for textile production and exhibitions,[223] but colour is also acknowledged to be an important component in consumers' purchasing decisions.[225] All the colour systems related to the companies reviewed provided a "colour of the year" as part of their colour forecast. Historically, the "colour of the year" helped clients make product development colour decisions, but nowadays not all retailers and brands follow this.[39,205,206,210] There is, moreover, much interest in tracking social media to increase the accuracy of forecasts,[198,200–210,215–221,223,224] WGSN report on their research methodologies also using social media research.[238] This not only raises questions regarding just how significant colour forecasts are for the mass market and fast fashion companies, it also provides further opportunities to consider incorporating natural colourants, which may produce more appropriate and sustainable colours for the brand.

Increasing consumer awareness about sustainability and organic practices, particularly in regions where environmental consciousness is growing, could boost the demand for natural colourants.[30,32–35,55,121,155,183,189,191] Consumers increasingly view natural colourants as both sustainable commodities[2,30,64,191] and luxury products,[64,109,121,185,191] providing an opportunity for market positioning. Educating consumers to appreciate these values is essential and, indeed, WGSN reports of consumer interest in craft, community, heritage, identity and individuality are further opportunities to engage with natural colourants and take advantage of the lack of uniformity, that is, promoting what has often been seen as problematic by the industry.[241] Based on the discussion in these four major areas, the question remains whether natural colourants can seamlessly be integrated into existing systems or if parallel standards and tools need to be developed. If natural colourants can achieve comparable results in terms of colour accuracy and performance, they could provide a sustainable alternative to synthetic colourants, encouraging the industry to adopt greener practices. However, this would require further research and significant adjustments, including testing the compatibility of natural colourants with Artificial Intelligence-driven forecasting tools and developing reliable methods to produce accurate colour samples using natural colourants. These steps are essential to ensure that natural colourants can meet the demands of current trend forecasting and production systems, thereby enabling their broader adoption.

11 | CONCLUSION

The aims of this paper were to gain a better understanding of the reasons for the lack of incorporation of natural colourants within the mainstream and fashion mass market and textile industry, as well as of the relationship between the trend forecasting and natural colourant industries. To do so, an SLR was carried out concerning the latest developments in natural colourants and trend forecasting for the textile and fashion industry and compared with a desk-based review of current trend forecasting practices as an important part within the industry.

Examination of the academic literature on natural colourants in fashion and textiles identified five different topics on its development: (i) a wide spectrum of natural colourant sources; (ii) an expansion of the application of

natural colourants; (iii) advances in coloration technology; (iv) preserving the culture and tradition of natural colourants; and (v) industrialising natural colourant practice. Then, from the in-depth analysis focused on those papers identified for "industry scalability", 33 codes were generated and categorised into four key themes: (i) industry scalability; (ii) consumer behaviour; (iii) economic value; and (iv) marketing and promotion. The literature on trend forecasting identified 37 codes, which could be grouped into four key themes: technology, process, business and society.

Comparing these with the desk-based review of trend forecasting approaches to natural colourants identified barriers, challenges, drivers and opportunities to incorporate natural colourants in current trend forecasting within the industry. The current industry is dominated by the mass market and fast fashion, which are heavily focused on high volumes and fast speed through an established infrastructure geared towards synthetic colourants; natural colourant practices struggle to meet these demands. However, global consumer interest and political and legal regulations for more sustainable and greener practices present opportunities for natural colourants to fit in with the industry. With good support and marketing, the incorporation of natural colourants in the industry can be achieved.

Two key issues emerge from this review: the first was that the natural colourant industry is highly innovative, with its focus on increasing sustainability credentials and scalability. Coupled with the technological developments, there is also substantial interest in increasing the marketing of natural colourants but do not appear to be many connections with the trend forecasting industry. The second key issue is that the trend forecasting industry has a role to play in encouraging and supporting the incorporation of natural colourants in the mass market and fast fashion companies. This role is exercised by (i) communicating the latest technological developments to industry decision makers; (ii) presenting data-driven consumer trends; and (iii) encouraging the uptake of natural colourants through accessible reporting and visually inspirational imagery.

Given the trend forecasting industry's interests in natural colourants, it seems opportune for closer links to be developed between researchers and practitioners of natural colourants to produce a better system that enables reporting the names of natural colourant sources and a wider range of colours for suggesting natural colourants.

With accurate communication through marketing, promotion and education, all stakeholders (ie, industry, consumers and educators) can better understand natural colourants.[2,193] Therefore, they can appreciate more the environmental benefits and unique history of natural colourants[2,185] and change existing perceptions about the standard of colour quality based on synthetic dyed colours.[38] There is a knowledge gap with regard to how to work with and use natural colourants on an industrial scale (eg, quality of colour, dye fastness). This implies that integrating natural colourants as part of the curriculum at a higher education level can overcome the knowledge gap among stakeholders. More graduates with natural colourant knowledge may support the radical impact required for the textile and fashion industry, including trend forecasting practices. More research needs to take place to better understand how stakeholders can support the use of natural colourants in the industry, especially educators, to incorporate natural colourants into their curricula for textile and fashion design.

This study is part of ongoing research for the Colour4CRAFTS (C4C) project, which aims to cultivate craft skills in textile coloration, transform traditional processes and shape cultural practices into sustainable, cutting-edge solutions for the future of bio-based practices in creative industries and industrial-scale textile production. The issues identified from this review will guide a future in-depth qualitative study involving educators of textile and fashion designers in higher education institutions, and textile practitioners in the UK and Finland.

ACKNOWLEDGEMENTS

This publication acknowledges financial support received for the research contained herein, funded by the European Union Horizon "Research and Innovation Action" Horizon-CL2-2022 HERITAGE-01-04 programme for the Colour4CRAFTS project, no. 101094809. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Agency. Neither the European Union nor the granting authority can be held responsible for them. We thank Professor Chris Carr, Dr. Peter Broadbent and Dr. Muriel Rigout for supporting this research at the data collection and literature review stages.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

ORCID

Bintan Titisari https://orcid.org/0000-0001-6399-7141
Pammi Sinha https://orcid.org/0000-0003-4384-9429

REFERENCES

1. Fletcher K, Grose L. *Fashion & Sustainability: Design for Change*. Hachette UK; 2012.
2. Doty K, Green DN, Haar S. Natural dyes in the United States: An exploration of natural dye use through the lens of the circuit of style-fashion-dress. *Cloth Text Res J*. 2024;42:310-324. doi:10.1177/0887302x241229222
3. Dabas D, Elias RJ, Lambert JD, Ziegler GR. A colored avocado seed extract as a potential natural colorant. *J Food Sci*. 2011; 76(9):C1335-C1341. doi:10.1111/j.1750-3841.2011.02415.x
4. Samanta AK, Awwad NS, Algarni HM. *Chemistry and Technology of Natural and Synthetic Dyes and Pigments*. IntechOpen; 2020.
5. Gürses A, Açıkyıldız M, Güneş K, Gürses MS. Dyes and pigments: their structure and properties. In: Gürses A, Açıkyıldız M, Güneş K, Gürses MS, eds. *Dyes and Pigments*. Springer International Publishing; 2016:13-29.
6. Abate MT, Zhou Y, Guan J, Chen G, Ferri A, Nierstrasz V. Colouration and bio-activation of polyester fabric with curcumin in supercritical CO_2: part II – effect of dye concentration on the colour and functional properties. *J Supercrit Fluids*. 2020;157:104703. doi:10.1016/j.supflu.2019.104703
7. Chen L, Duan Q, Chen J, Yang Y, Wang B. Antioxidant-assisted coloration of wool with xanthophylls extracted from corn distillers' dry grain. *Color Technol*. 2016;132(3):208-216. doi:10.1111/cote.12206
8. Haddar W, Elksibi I, Meksi N, Mhenni MF. Valorization of the leaves of fennel (Foeniculum vulgare) as natural dyes fixed on modified cotton: a dyeing process optimization based on a response surface methodology. *Ind Crop Prod*. 2014;52: 588-596. doi:10.1016/j.indcrop.2013.11.019
9. Mongkholrattanasit R, Saiwan C, Rungruangkitkrai N, et al. Ecological dyeing of silk fabric with lac dye by using padding techniques. *J Text Inst*. 2014;106(10):1106-1114. doi:10.1080/00405000.2014.976957
10. Nakpathom M, Somboon B, Narumol N, Mongkholrattanasit R. Dyeing of Cationized cotton with natural colorant from purple corncob. *J Nat Fibers*. 2017;15(5):668-679. doi:10.1080/15440478.2017.1354742
11. Wizi J, Wang L, Hou X, Tao Y, Ma B, Yang Y. Ultrasound-microwave assisted extraction of natural colorants from sorghum husk with different solvents. *Ind Crop Prod*. 2018;120: 203-213. doi:10.1016/j.indcrop.2018.04.068
12. Wang F, Gong J, Ren Y, Zhang J. Eco-dyeing with biocolourant based on natural compounds. *R Soc Open Sci*. 2018;5(1): 171134. doi:10.1098/rsos.171134
13. Räisänen R, Primetta A, Toukola P, Fager S, Ylänen J. Biocolourants from onion crop side streams and forest mushroom for regenerated cellulose fibres. *Ind Crop Prod*. 2023;198: 116748. doi:10.1016/j.indcrop.2023.116748
14. Raisanen R, Primetta A, Nikunen S, et al. Examining safety of Biocolourants from fungal and plant sources-examples from Cortinarius and Tapinella, Salix and Tanacetum spp. and dyed Woollen fabrics. *Antibiotics (Basel)*. 2020;9(5):266. doi:10.3390/antibiotics9050266
15. Agnhage T, Perwuelz A, Behary N. Towards sustainable Rubia tinctorum L. dyeing of woven fabric: how life cycle assessment can contribute. *J Clean Prod*. 2017;141:1221-1230. doi:10.1016/j.jclepro.2016.09.183
16. Räisänen R, Montero GA, Freeman HS. A fungal-based anthraquinone emodin for polylactide and polyethylene terephthalate in supercritical carbon dioxide (SC-CO_2) dyeing. *Color Res Appl*. 2021;46(3):674-680. doi:10.1002/col.22627
17. Vuthiganond N, Chitichotpanya P, Nakpathom M, Mongkholrattanasit R. Ecological dyeing of acrylic yarn with colorant derived from natural lac dye. *J Metals Mater Minerals*. 2022;32(4):71-78. doi:10.55713/jmmm.v32i4.1529
18. Habib N, Adeel S, Ali A, Mia R, Khan SR, Qayyum MA. Ultrasonic-assisted sustainable pollution free advanced method for isolation of colouring material from Amba Haldi (*Curcuma aromatica*) for wool dyeing. *Sci Prog*. 2023;106(3):1-20. doi:10.1177/00368504231188610
19. Islam MR, Khan ANN, Mahmud RU, Haque SMN, Khan MMI. Sustainable dyeing of jute-cotton union fabrics with onion skin (allium CEPA) dye using banana peel (Musa) and guava leaves (*Psidium guajava*) extract as biomordants. *Pigm Resin Technol*. 2022;53(3):369-375. doi:10.1108/prt-03-2022-0031
20. İşmal ÖE. Greener natural dyeing pathway using a by-product of olive oil; prina and biomordants. *Fibers and Polymers*. 2017; 18(4):773-785. doi:10.1007/s12221-017-6675-0
21. Erdem İşmal Ö, Yıldırım L, Özdoğan E. Use of almond shell extracts plus biomordants as effective textile dye. *J Clean Prod*. 2014;70:61-67. doi:10.1016/j.jclepro.2014.01.055
22. Jahangiri A, Ghoreishian SM, Akbari A, et al. Natural dyeing of wool by madder (*Rubia tinctorum* L.) root extract using tannin-based Biomordants: colorimetric, fastness and tensile assay. *Fibers and Polymers*. 2018;19(10):2139-2148. doi:10.1007/s12221-018-8069-3
23. Yang R, Zhang Y, Ranjitkar S, et al. Reusing wasteroot of Rubia wallichiana dyeing from Monpa of Tibet in China. *Sci Rep*. 2021;11(1):14331. doi:10.1038/s41598-021-93848-8
24. Fried R, Oprea I, Fleck K, Rudroff F. Biogenic colourants in the textile industry – a promising and sustainable alternative to synthetic dyes. *Green Chem*. 2022;24(1):13-35. doi:10.1039/D1GC02968A
25. Rymbai H, Sharma RR, Srivastav M. Bio-colorants and its implications in health and food industry–a review. *Int J Pharmacol Res*. 2011;3(4):2228-2244.
26. Mongkholrattanasit R, Nakpathom M, Vuthiganond N. Eco-dyeing with biocolorant from spent coffee ground on low molecular weight chitosan crosslinked cotton. *Sustain Chem Pharm*. 2021;20:1-9. doi:10.1016/j.scp.2021.100389
27. Mapari SAS, Meyer AS, Thrane U. Photostability of natural Orange−red and yellow fungal pigments in liquid food model systems. *J Agric Food Chem*. 2009;57(14):6253-6261. doi:10.1021/jf900113q
28. Torres FAE, Zaccarim BR, de Lencastre Novaes LC, et al. Natural colorants from filamentous fungi. *Appl Microbiol Biotechnol*. 2016;100(6):2511-2521. doi:10.1007/s00253-015-7274-x
29. Parmar M, Phutela UG. Biocolors: the new generation additives. *Int J Curr Microbiol App Sci*. 2015;4(7):688-694.
30. Linton C. "Making it for our country": An ethnography of mud-dyeing on Amami Ōshima Island. *Text*. 2019;18(3):250-277. doi:10.1080/14759756.2019.1690837
31. Choi J, Kim S. Cross-cultural study of color sensation and sensibility for Korean traditional fabrics with natural indigo

dyeing. *Fibers and Polymers*. 2013;14(1):138-145. doi:10.1007/s12221-013-0138-z
32. Xu H, Song H-y. Key factors influencing Chinese consumers' demand for naturally dyed garments: data analysis through KJ method and KANO model. *Sustainability*. 2024;16(3):1-28. doi:10.3390/su16031189
33. Li S, Cunningham AB, Fan R, Wang Y. Identity blues: the ethnobotany of the indigo dyeing by Landian Yao (Iu mien) in Yunnan, Southwest China. *J Ethnobiol Ethnomed*. 2019;15(1):13. doi:10.1186/s13002-019-0289-0
34. Ciptandi F, Susilowati TH, Ramadhan MS. Opportunities of using Spirulina platensis as homemade natural dyes for textiles. *Open Agric*. 2021;6(1):819-825. doi:10.1515/opag-2020-0167
35. Guddi K, Sur S, Sarkar A. Analysis of floral biomass utilization feasibility of Ixora coccinea for its cost-effective application as a natural colorant. *Biomass Convers Biorefinery*. 2022;14(14):15661-15675. doi:10.1007/s13399-022-03668-7
36. Erdem I, Ö, Yıldırım L. An overview of faba bean: utilisation of husks in natural dyeing. *Int J Cloth Sci Technol*. 2019;32(2):188-196. doi:10.1108/ijcst-02-2019-0014
37. Visibly RLB. Invisible: the enigmatic history of Technology in the Fashion-Industrial Complex. In: Pouillard V, Dube-Senecal V, eds. *The Routledge History of Fashion and Dress, 1800 to the Present*. Routledge Histories; 2023:61-80.
38. Casselman KD. Praxis and paradox: the culture of natural dyes in Britain, 1750–1900. *Text*. 2015;7(1):6-26. doi:10.2752/175183509x411735
39. Garcia CC. Fashion forecasting: an overview from material culture to industry. *J Fash Market Manag Int J*. 2022;26(3):436-451. doi:10.1108/jfmm-11-2020-0241
40. Cooper R, Junginger S, Lockwood T. *The Handbook of Design Management*. Bloomsbury; 2017.
41. Sinha P. The role of designing through making across market levels in the UK fashion industry. *Des J*. 2000;3(3):26-44. doi:10.2752/146069200789390079
42. Brannon EL. *Fashion Forecasting*. 3rd ed. Fairchild; 2010.
43. Kim E, Fiore AM, Kim H. *Fashion Trends: Analysis and Forecasting*. Bloomsbury Publishing; 2013.
44. McKelvey K, Munslow J. *Fashion Forecasting*. John Wiley & Sons; 2009.
45. Diane T, Cassidy T. *Colour Forecasting*. Wiley; 2009.
46. Perna R. *Fashion Forecasting: A Mystery or a Method?* . Fairchild Publications; 1995.
47. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*. 2021;372:n160. doi:10.1136/bmj.n160
48. Colour4CRAFTS. About Colour4CRAFTS. 2025. Accessed June 11, 2025. https://colour4crafts.eu/about/
49. Karadag R. Establishing a new international standard for natural dyed textile goods [natural organic dye standard (NODS)]. *J Nat Fibers*. 2023;20(1):1-22. doi:10.1080/15440478.2022.2162187
50. Shams Nateri A, Dehnavi E, Hajipour A, Ekrami E. Dyeing of polyamide fibre with cochineal natural dye. *Pigm Resin Technol*. 2016;45(4):252-258. doi:10.1108/prt-05-2015-0043
51. Patil H, Yadav S, Athalye A. Valorisation of Napier grass through fibre extraction and coloration by natural dye from Rubia tinctorum. *Color Technol*. 2024;140:858-867. doi:10.1111/cote.12747
52. Tian G, Cui R, Liu C, Hu X. Natural dyeing with madder: exploring traditional techniques and color characteristics. *Fibres Text Eastern Eur*. 2023;31(4):10-21. doi:10.2478/ftee-2023-0031
53. Vadood M, Haji A. A hybrid artificial intelligence model to predict the color coordinates of polyester fabric dyed with madder natural dye. *Expert Syst Appl*. 2022;193:116514. doi:10.1016/j.eswa.2022.116514
54. Agnhage T, Zhou Y, Guan J, et al. Bioactive and multifunctional textile using plant-based madder dye: characterization of UV protection ability and antibacterial activity. *Fibers and Polymers*. 2017;18(11):2170-2175. doi:10.1007/s12221-017-7115-x
55. Akgül E, Bahtiyari Mİ, Kizilkaya Aydoğan E, Benli H. Use of Topsis method for designing different textile products in coloration via natural source "madder". *J Nat Fibers*. 2021;19(14):8993-9008. doi:10.1080/15440478.2021.1982106
56. Du H, Wang Q, Tian M, Yang X. Simple crystallization approach for enhancing function of plant-based madder dye and performance of dyed fabric. *Heliyon*. 2019;5(8):e02232. doi:10.1016/j.heliyon.2019.e02232
57. Feiz M, Norouzi H. Dyeing studies of wool fibers with madder (Rubia tinctorum) and effect of different mordants and mordanting procedures on color characteristics of dyed samples. *Fibers Polym*. 2015;15(12):2504-2514. doi:10.1007/s12221-014-2504-x
58. Ford L, Rayner CM, Blackburn RS. Degradation of lucidin: new insights into the fate of this natural pigment present in Dyer's madder (*Rubia tinctorum* L.) during the extraction of textile artefacts. *Dyes Pigments*. 2018;154:290-295. doi:10.1016/j.dyepig.2018.03.023
59. Haji A, Vadood M. Environmentally benign dyeing of polyester fabric with madder: modelling by artificial neural network and fuzzy logic optimized by genetic algorithm. *Fibers and Polymers*. 2021;22(12):3351-3357. doi:10.1007/s12221-021-1161-0
60. Lo C-hH. Degumming silk by CO_2 supercritical fluid and their dyeing ability with plant indigo. *Int J Cloth Sci Technol*. 2020;33(3):465-476. doi:10.1108/ijcst-06-2019-0072
61. Mongkholrattanasit R, Klaichoi C, Rungruangkitkrai N, Vuthiganond N, Nakpathom M. Eco-printing on cotton fabric with natural indigo dye using wild Taro corms as a new thickening agent. *J Nat Fibers*. 2021;19(13):5435-5450. doi:10.1080/15440478.2021.1875381
62. Seidu RK, Eghan B, Ofori EA, Fobiri GK, Afriyie AO, Acquaye R. Sustainable traditional natural dyeing practice in Daboya and Ntonso communities of Ghana. *Res J Text Appar*. 2023;29:1-14. doi:10.1108/rjta-07-2023-0071
63. Silva LMC, Silva PMS, Pagnan CS, Ayres E. Insights into the dyeing using natural indigo (Indigofera tinctoria): toward an environmentally friendly garment. *Color Technol*. 2023;140(1):114-124. doi:10.1111/cote.12704
64. Wang W-C, Jou C-H, Kao J-M, Wu W-C, Ko Y-H. Exploring the Green Design of Hakka Cultural Creative Textiles for sustainable development. *Appl Sci*. 2022;12(19):1-15. doi:10.3390/app121910042

65. Sen A, Bhowal A, Datta S. Application of natural dye on polytrimethylene terephthalate fiber. *Res J Text Appar*. 2019;23(1):71-90. doi:10.1108/rjta-06-2018-0041
66. Karadag R. Cotton dyeing with cochineal by just in time extraction, Mordanting, dyeing, and fixing method in the textile industry. *J Nat Fibers*. 2022;20(1):2108184. doi:10.1080/15440478.2022.2108184
67. Whitworth I, Koren ZC. Orchil and Tyrian purple: two centuries of Bedfords from Leeds. *Ambix*. 2016;63(3):244-267. doi:10.1080/00026980.2016.1246160
68. Jin J, Liu J, Wang D, Gao S, Zhao F, Wang Y. Reconstruction of traditional safflower (*Carthamus tinctorius* L.) dyeing and red colors in the Qing dynasty (17th-19th century). *Dyes Pigments*. 2022;207:1-10. doi:10.1016/j.dyepig.2022.110697
69. Nakamura R, Tanaka Y, Ogata A, Masakazu N. Scientific evidence by fluorescence spectrometry for safflower red on ancient Japanese textiles stored in the Shosoin treasure house repository. *Stud Conserv*. 2014;59(6):367-376. doi:10.1179/2047058413y.0000000082
70. Ben Ticha M, Baaka N, Mabrouk S, Boudokhane C, Dhaouadi H. A sustainable application of turnsole (Dyer's litmus) extract to dye protein fibers: development of a microwave-assisted dye extraction process. *Journal of Natural Fibers*. 2022;19(9):3571-3584. doi:10.1080/15440478.2022.2072442
71. Karadag R. Sustainable and mass production of cotton dyeing with natural dye (weld) in the textile industry. *J Nat Fibers*. 2021;19(15):10935-10945. doi:10.1080/15440478.2021.2002781
72. Cardon D, Koren ZC, Sumi H. Woaded blue: a colorful approach to the dialectic between written historical sources, experimental archaeology, chromatographic analyses, and biochemical research. *Heritage*. 2023;6(1):681-704. doi:10.3390/heritage6010037
73. Jiang H, Guo R, Mia R, et al. Eco-friendly dyeing and finishing of organic cotton fabric using natural dye (gardenia yellow) reduced-stabilized nanosilver: full factorial design. *Cellulose*. 2022;29(4):2663-2679. doi:10.1007/s10570-021-04401-9
74. Younis M, Adeel S, Haider MZ, Mia R, Imran M. Enhancing silk dyeing with eco-friendly colorant extracted from Cassia fistula brown pods using green mordants. *Sustain Chem Pharm*. 2024;37:101410. doi:10.1016/j.scp.2023.101410
75. Haji A. Application of D-optimal design in the analysis and modelling of dyeing of plasma-treated wool with three natural dyes. *Color Technol*. 2019;136(2):137-146. doi:10.1111/cote.12445
76. Manicketh TJ, Francis MS. Extraction of natural colorants from Araucaria columnaris, Macaranga peltata and Averrhoa bilimbi for textile coloration. *Int J Cloth Sci Technol*. 2020;32(6):789-801. doi:10.1108/ijcst-06-2019-0075
77. Boruah G, Phukan AR, Kalita BB, Pandit P, Jose S. Dyeing of mulberry silk using binary combination of henna leaves and monkey Jack bark. *J Nat Fibers*. 2019;18(2):229-237. doi:10.1080/15440478.2019.1616649
78. Haji A, Sayyed Sadroddin Q, Majid N. The use of D-optimal design in optimization of wool dyeing with Juglans regia bark. *Ind Text*. 2018;69(2):104-110. doi:10.35530/it.069.02.1509
79. Ji X, Zhao Z, Ren Y, Xu F, Liu J. Dyeing properties, color gamut, and color evaluation of cotton fabrics dyed with Phellodendron amurense Rupr. (Amur Cork tree bark). *Molecules*. 2023;28(5):1-13. doi:10.3390/molecules28052220
80. Maulik SR, Chakraborty L, Pandit P. Evaluation of cellulosic and protein fibers for coloring and functional finishing properties using simultaneous method with eucalyptus bark extract as a natural dye. *Fibers Polym*. 2021;22(3):711-719. doi:10.1007/s12221-021-0092-0
81. Mongkholrattanasit R, Punrattanasin N, Rungruangkitkrai N, Somboon B, Narumol N, Nakpathom M. Dyeing, fastness and UV protection properties of cotton fabric dyed with mangrove bark extract. *Cellul Chem Technol*. 2016;50(1):163-171.
82. Punrattanasin N, Nakpathom M, Somboon B, Narumol N, Rungruangkitkrai N, Mongkholrattanasit R. Silk fabric dyeing with natural dye from mangrove bark (Rhizophora apiculata Blume) extract. *Ind Crop Prod*. 2013;49:122-129. doi:10.1016/j.indcrop.2013.04.041
83. Silva PMS, Fiaschitello TR, Queiroz RS, et al. Natural dye from croton urucurana Baill. Bark: extraction, physicochemical characterization, textile dyeing and color fastness properties. *Dyes Pigments*. 2020;173:1-14. doi:10.1016/j.dyepig.2019.107953
84. Vuthiganond N, Nakpathom M, Mongkholrattanasit R. Metal-free dyeing of cotton fabric using mangrove bark polyphenols via azoic dyeing. *Fibers Polym*. 2019;19(12):2524-2532. doi:10.1007/s12221-018-8341-6
85. Mahboob M, Adeel S, Barkaat S, et al. Microwave-assisted santalin extraction from Pterocarpus santalinus for mordanted woolen yarn dyeing. *Sustain Chem Pharm*. 2023;35:101224. doi:10.1016/j.scp.2023.101224
86. Werede E, Jabasingh SA, Demsash HD, Jaya N, Gebrehiwot G. Eco-friendly cotton fabric dyeing using a green, sustainable natural dye from Gunda Gundo (*Citrus sinensis*) orange peels. *Biomass Convers Biorefinery*. 2021;13(6):5219-5234. doi:10.1007/s13399-021-01550-6
87. Hong KH. Preparation and properties of cotton fabrics dyed by Aronia (Aronia melanocarpa) extract and chitosan. *Fash Text*. 2023;10(1):14. doi:10.1186/s40691-023-00334-y
88. Mun J, Lee S, YingXing B, Lee J. Dyeability of 3D printed thermoplastic polyurethane (TPU) material using turmeric and lac natural dyes. *Fibers and Polymers*. 2023;24(5):1727-1739. doi:10.1007/s12221-023-00172-1
89. Zare A. Improving the color strength of poly(ethylene terephthalate) fabrics with a turmeric natural dye. *Pigm Resin Technol*. 2022;52(3):369-376. doi:10.1108/prt-04-2022-0044
90. Al Sarhan TM, Salem A. Turmeric dyeing and chitosan/titanium dioxide nanoparticle colloid finishing of cotton fabric. *Indian J Fibre Textile Res*. 2018;43:464-473.
91. Ma X, Wei Y, Wang S, Zuo X, Shen B. Sustainable ultrasound-assisted ultralow liquor ratio dyeing of cotton fabric with natural turmeric dye. *Text Res J*. 2019;90(5–6):685-694. doi:10.1177/0040517519878793
92. Dehnavi E, Shams-Nateri A, Khalili H. Wool dyeing with binary mixture of natural dyes. *Pigm Resin Technol*. 2016;45(1):52-61. doi:10.1108/prt-06-2014-0045
93. Talebpour F, Veysian M, Malekan F. Evaluation of dyeing properties of carpet woolen yarn with natural and wild pomegranate Peel (Punica granatum). *J Nat Fibers*. 2017;15(2):219-228. doi:10.1080/15440478.2017.1325424

94. Rehan M, Ibrahim GE, Mashaly HM, Hasanin M, Rashad HG, Mowafi S. Simultaneous dyeing and multifunctional finishing of natural fabrics with hibiscus flowers extract. *J Clean Prod*. 2022;374:133992. doi:10.1016/j.jclepro.2022.133992
95. Kovacevic Z, Sutlovic A, Matin A, Bischof S. Natural dyeing of cellulose and protein fibers with the flower extract of Spartium junceum L. *Plant Mater (Basel)*. 2021;14(15):4091. doi:10.3390/ma14154091
96. Nadeem T, Javed K, Anwar F, Malik MH, Khan A. Sustainable dyeing of wool and silk with *Conocarpus erectus* L. leaf extract for the development of functional textiles. *Sustainability*. 2024;16(2):811. doi:10.3390/su16020811
97. Chakraborty L, Pandit P, Roy Maulik S. Acacia auriculiformis-a natural dye used for simultaneous coloration and functional finishing on textiles. *J Clean Prod*. 2020;245:1-7. doi:10.1016/j.jclepro.2019.118921
98. Priyanka R, G R. A study on natural dyes extracted from Eichhornia crassipes and Thespesia populnea flowers on the functional and physical properties. *J Nat Fibers*. 2021;19(14):9167-9176. doi:10.1080/15440478.2021.1982810
99. Manyim S, Kiprop AK, Mwasiagi JI, Mecha AC. Eco-friendly dyeing of pretreated cotton fabric using a natural dye extract from Erythrina abyssinica. *J Nat Fibers*. 2021;19(14):8319-8331. doi:10.1080/15440478.2021.1964125
100. Mongkholrattanasit R, Saiwan C, Rungruangkitkrai N, et al. Eco-dyeing of silk fabric with Garcinia Dulcis(Roxb.) Kurz bark as a source of natural dye by using the padding technique. *J Nat Fibers*. 2015;13(1):65-76. doi:10.1080/15440478.2014.984056
101. Cuce M, Kilinc M, Kilinc N, Tekin A, Kut D. Color, fastness, and antimicrobial properties of wool fabrics dyed with Helichrysum Arenarium Subsp. Aucheri extract. *J Nat Fibers*. 2020;19(3):797-809. doi:10.1080/15440478.2020.1848706
102. Klančnik M. Printing with natural dye extracted from Impatiens glandulifera Royle. *CoatingsTech*. 2021;11(4):445. doi:10.3390/coatings11040445
103. Odero MP, Kiprop AK, K'Owino IO, Arimi M, Manyim S. Evaluation of dyeing properties of natural dyes extracted from the heartwood of Prosopis juliflora on cotton fabric. *Res J Text Appar*. 2020;25(1):19-30. doi:10.1108/rjta-06-2020-0058
104. Karadag R, Yildiz Y. Examination of dyeing properties of the dyed organic cotton knitting fabrics using yarrow (*Achillea biebersteinii* AFAN and *Achillea millefolium* L.). *J Nat Fibers*. 2021;19(14):7374-7381. doi:10.1080/15440478.2021.1946881
105. Nakpathom M, Somboon B, Narumol N, Mongkholrattanasit R. Application of waste Camellia oleifera fruit shell for printing on PP nonwoven. *J Text Inst*. 2020;1-8. doi:10.1080/00405000.2020.1820708
106. Vankar PS, Begum A. Natural dyeing of khadi cotton using rare earth salts as mordant with annatto extract. *Pigm Resin Technol*. 2023;53:1-4. doi:10.1108/prt-05-2023-0037
107. Buyukakinci YB, Karadag R, Guzel ET. Organic cotton fabric dyed with dyer's oak and barberry dye by microwave irradiation and conventional methods. *Industria Textila*. 2021;72(1):30-38. doi:10.35530/it.072.01.1755
108. Swamy VN. Assessment of calorimetric, antibacterial and fastness properties of silk fabric dyed with *Casuarina equisetifolia* L. leaf extract. *Indian Journal of Traditional Knowledge*. 2017;16(4):714-719.
109. Pham CTN, Phan HN, Hoang TT, Dao TTT, Bui HM. A study on the coloration effectiveness of Chromolaena odorata on the worsted wool fabric. *Res J Text Appar*. 2022;29:1-18. doi:10.1108/rjta-07-2022-0089
110. Costa AFS, de Amorim JDP, Almeida FCG, et al. Dyeing of bacterial cellulose films using plant-based natural dyes. *Int J Biol Macromol*. 2019;121:580-587. doi:10.1016/j.ijbiomac.2018.10.066
111. Adeel S, Kiran S, Alam M, Farooq T, Amin N, Gulzar T. Alkanna tinctoria-based sustainable alkanin natural colorant for eco-dyeing of wool. *Environ Sci Pollut Res Int*. 2023;30(10):27073-27080. doi:10.1007/s11356-022-23806-y
112. Palaskar SS, Kale RD, Deshmukh RR. Application of natural yellow (curcumin) dye on silk to impart multifunctional finishing and validation of dyeing process using BBD model. *Color Res Appl*. 2021;46(6):1301-1312. doi:10.1002/col.22678
113. Abate MT, Ferri A, Guan J, Chen G, Nierstrasz V. Colouration and bio-activation of polyester fabric with curcumin in supercritical CO_2: part I-investigating colouration properties. *J Supercrit Fluids*. 2019;152:104548. doi:10.1016/j.supflu.2019.104548
114. Dodangeh M, Gharanjig K, Tang R-C, Grabchev I. Functionalization of PAMAM dendrimers with curcumin: synthesis, characterization, fluorescent improvement and application on PET polymer. *Dyes Pigments*. 2020;174:108081. doi:10.1016/j.dyepig.2019.108081
115. Baseri S. Natural bio-source materials for Green dyeing of cellulosic yarns. *J Nat Fibers*. 2021;19(9):3517-3528. doi:10.1080/15440478.2020.1870626
116. Kushwaha A, Singh S, Chaudhary K. Eco-friendly multifunctional dyeing of pineapple using Nyctanthes Arbortristis dye and acacia Nilotica bio-mordant. *Sustain Chem Pharm*. 2023;34:101146. doi:10.1016/j.scp.2023.101146
117. Amutha KS, Sudhapriya N. Dyeing of textiles with natural dyes extracted from *Terminalia arjuna* and *Thespesia populnea* fruits. *Ind Crop Prod*. 2020;148:14810. doi:10.1016/j.indcrop.2020.112303
118. Bashir M, Adeel S, Aftab M, Mia R, Imran M. Microwave-assisted cleaner extraction of tannin from *Terminalia chebula*: a promising green method for sustainable leather dyeing. *Sustain Chem Pharm*. 2024;37:101336. doi:10.1016/j.scp.2023.101336
119. Song JE, Kim SM, Kim HR. Improvement of dye affinity in natural dyeing using Terminalia chebula retzius (*T. chebula*) applied to leather. *Int J Clothing Sci Technol*. 2017;29(5):610-626. doi:10.1108/ijcst-03-2017-0029
120. Yan X, Hong L, Pei S, et al. A natural yellow colorant from Buddleja officinalis for dyeing hemp fabric. *Ind Crop Prod*. 2021;171:113968. doi:10.1016/j.indcrop.2021.113968
121. Zhang B, Wang L, Luo L, King MW. Natural dye extracted from Chinese gall – the application of color and antibacterial activity to wool fabric. *J Clean Prod*. 2014;80:204-210. doi:10.1016/j.jclepro.2014.05.100
122. Wu J, Sun L, Lin L. Dyeing of silk with extract from Coreopsis tinctoria. *Pigm Resin Technol*. 2023;54:39-52. doi:10.1108/prt-07-2023-0061
123. Fan F, Wu X, Wen J, Lin G, Lin J, Yin Q. Atmospheric pressure air plasma treatment to improve Dyeability with cortex Phellodendri plant powder dye: An ecofriendly and energy-

efficient approach for silk processing. *Fibers and Polymers*. 2023;24(10):3611-3625. doi:10.1007/s12221-023-00331-4

124. Baseri S. Agricultural crop of Scrophularia striata as a new dye for eco-friendly dyeing and bioactive finishing of handwoven piles. *Sustain Chem Pharm*. 2023;33.1-11. doi:10.1016/j.scp.2023.101088
125. Adeel S, Anjum F, Zuber M, Hussaan M, Amin N, Ozomay M. Sustainable extraction of Colourant from Harmal seeds (Peganum harmala) for dyeing of bio-Mordanted wool fabric. *Sustainability*. 2022;14(19):1-11. doi:10.3390/su141912226
126. Yilmaz F. Application of Glycyrrhiza glabra L. root as a natural antibacterial agent in finishing of textile. *Ind Crop Prod*. 2020;157:112899. doi:10.1016/j.indcrop.2020.112899
127. Erdem İşmal Ö, Özdoğan E, Yıldırım L. An alternative natural dye, almond shell waste: effects of plasma and mordants on dyeing properties. *Color Technol*. 2013;129(6):431-437. doi:10.1111/cote.12047
128. Erdem İşmal Ö, Yıldırım L, Özdoğan E. Valorisation of almond shell waste in ultrasonic biomordanted dyeing: alternatives to metallic mordants. *J Text Inst*. 2014;106(4):343-353. doi:10.1080/00405000.2014.949503
129. İşmal ÖE, Yıldırım L. Almond shell as a natural colorant. *Indian Journal of Fibre & Textile Research*. 2012; 37:358-363.
130. Haji A, Shahmoradi Ghaheh F, Indrie L. Pomegranate fallen leaves as a source of natural dye for mordant-free dyeing of wool. *Color Technol*. 2022;139(2):165-170. doi:10.1111/cote.12651
131. Rehman F, Sanbhal N, Naveed T, Farooq A, Wang Y, Wei W. Antibacterial performance of Tencel fabric dyed with pomegranate peel extracted via ultrasonic method. *Cellulose*. 2018; 25(7):4251-4260. doi:10.1007/s10570-018-1864-6
132. Tian Y, Liu Q, Zhang Y, Hou X, Zhang Y. Obtaining colored patterns on polyamide fabric with laser pretreatment and pomegranate peel dyeing. *Text Res J*. 2022;92(11–12):2080-2089. doi:10.1177/00405175221076038
133. Jose S, Kadam V, Gupta V, Badanayak P. Simultaneous dyeing and ultraviolet protection of wool fabric with pomegranate rind using TiO_2 nanoparticles. *J Nat Fibers*. 2022;19(16): 12736-12745. doi:10.1080/15440478.2022.2073506
134. Baaka N, Haddar W, Ben Ticha M, Mhenni MF. Eco-friendly dyeing of modified cotton fabrics with grape pomace colorant: optimization using full factorial design approach. *J Nat Fibers*. 2018;16(5):652-661. doi:10.1080/15440478.2018.1431997
135. Mansour R, Ezzili B, Farouk M. The use of response surface method to optimize the extraction of natural dye from winery waste in textile dyeing. *J Text Inst*. 2016;108(4):528-537. doi:10.1080/00405000.2016.1172821
136. Baaka N, Ben Ticha M, Haddar W, Hammami S, Mhenni MF. Extraction of natural dye from waste wine industry: optimization survey based on a central composite design method. *Fibers and Polymers*. 2015;16(1):38-45. doi:10.1007/s12221-015-0038-5
137. Baaka N, Mahfoudhi A, Mhenni MF. Orange peels waste as a low cost cotton natural dye. *Moroc J Chem*. 2017;5(2):259-265.
138. Naveed T, Babar AA, Rashdi SY, et al. Dyeing and colorfastness properties of Tencel fabric treated with natural dye xtracted from Orange Peel. *Surf Rev Lett*. 2020;28(3):2050055. doi:10.1142/s0218625x20500559
139. Hou X, Chen X, Cheng Y, Xu H, Chen L, Yang Y. Dyeing and UV-protection properties of water extracts from orange peel. *J Clean Prod*. 2013;52:410-419. doi:10.1016/j.jclepro.2013.03.004
140. Erdem İşmal Ö. A route from olive oil production to natural dyeing: valorisation of prina (crude olive cake) as a novel dye source. *Color Technol*. 2014;130(2):147-153. doi:10.1111/cote.12068
141. Weber G, Chen HL, Hinsch E, Freitas S, Robinson S. Pigments extracted from the wood-staining fungi Chlorociboria aeruginosa, Scytalidium cuboideum, and S. Ganodermophthorum show potential for use as textile dyes. *Color Technol*. 2014;130(6):445-452. doi:10.1111/cote.12110
142. Räisänen R, Nousiainen P, Hynninen PH. Emodin and dermocybin natural anthraquinones as high-temperature disperse dyes for polyester and polyamide. *Text Res J*. 2001; 71(10):922-927.
143. Räisänen R, Nousiainen P, Hynninen PH. Emodin and dermocybin natural anthraquinones as mordant dyes for wool and polyamide. *Text Res J*. 2001;71(11):1016-1022.
144. Hernández V, Galleguillos F, Sagredo N, Machuca Á. Color fastness of fabrics after dyeing with fungal dyes. *Int J Cloth Sci Technol*. 2020;33(2):232-240. doi:10.1108/ijcst-12-2019-0196
145. Verma H, Sharma AK, Rani A, Thiyam G, Pavan M. Optimization of the process parameters for dyeing silk fabric with a fungal pigment using RSM. *Sustain Chem Pharm*. 2023;35:1-13. doi:10.1016/j.scp.2023.101192
146. Venil CK, Yusof NZ, Aruldass CA, Ahmad W-A. Application of violet pigment from Chromobacterium violaceum UTM5 in textile dyeing. *Biologia*. 2016;71(2):121-127. doi:10.1515/biolog-2016-0031
147. Roychowdhury R, Maiti S, Adivarekar RV, Singhal RS. Sustainable dyeing of silk using an acetylshikonin-based natural colourant from the lichen *Parmotrema perlatum*. *Green Chem*. 2024;26(2):904-917. doi:10.1039/d3gc03686c
148. Eyupoglu C, Eyupoglu S, Merdan N. Investigation of dyeing properties of mohair fiber dyed with natural dyes obtained from Candelariella reflexa. *J Nat Fibers*. 2022;19(16):12829-12848. doi:10.1080/15440478.2022.2076273
149. Kim H, Kim HR. Production of coffee-dyed bacterial cellulose as a bio-leather and using it as a dye adsorbent. *PLoS One*. 2022;17(3):e0265743. doi:10.1371/journal.pone.0265743
150. Toussaint L, Bruggeman D, van den Eijnde J. Fungi fabrics and living colors: toward Ecocentric biodesign? *Des Issues*. 2024;40(1):92-106. doi:10.1162/desi_a_00746
151. Che J, Yang X. A recent (2009–2021) perspective on sustainable color and textile coloration using natural plant resources. *Heliyon*. 2022;8(10):e10979. doi:10.1016/j.heliyon.2022.e10979
152. Mongkholrattanasit R, Klaichoi C, Rungruangkitkrai N. Reactive dye printing on cotton fabric using modified starch of wild taro corms as a new thickening agent. *Cellul Chem Technol*. 2021;55:1119-1129.
153. Mongkholrattanasit R, Klaichoi C, Rungruangkitkrai N. Printing silk fabric with acid dye using a new thickening agent. *J Nat Fibers*. 2021;19(15):10802-10812. doi:10.1080/15440478.2021.2002769
154. Raza ZA, Anwar F, Abid S. Sustainable antibacterial printing of cellulosic fabrics using an indigenous chitosan-based thickener with distinct natural dyes. *International Journal of Clothing Science and Technology*. 2021;33(6):914-928. doi:10.1108/ijcst-01-2020-0005

155. Agrawal A, Chopra S. Sustainable dyeing of selected natural and synthetic fabrics using waste teak leaves (Tectona Grandis L.). *Res J Text Appar*. 2020;24(4):357-374. doi:10.1108/rjta-05-2020-0046
156. Hossain MA. UV-visible-NIR camouflage textiles with natural plant based natural dyes on natural fibre against woodland combat background for defence protection. *Sci Rep*. 2023;13(1):5021. doi:10.1038/s41598-023-31725-2
157. Klančnik M. Screen printing with natural dye extract from Japanese knotweed rhizome. *Fibers and Polymers*. 2021;22(9):2498-2506. doi:10.1007/s12221-021-0955-4
158. Grande R, Raisanen R, Dou J, et al. In situ adsorption of red onion (*Allium cepa*) natural dye on cellulose model films and fabrics exploiting chitosan as a natural mordant. *ACS Omega*. 2023;8(6):5451-5463. doi:10.1021/acsomega.2c06650
159. Islam MT, Liman MLR, Roy MN, Hossain MM, Repon MR, Mamun MAA. Cotton dyeing performance enhancing mechanism of mangiferin enriched bio-waste by transition metals chelation. *J Text Inst*. 2021;113(4):567-579. doi:10.1080/00405000.2021.1892337
160. Amutha K, Annapoorani SG, Sakthivel P, Sudhapriya N. Eco-friendly dyeing of textiles with natural dyes extracted from commercial food processing waste materials. *Journal of Natural Fibers*. 2022;19(15):10394-10411. doi:10.1080/15440478.2021.1993506
161. Melaku A, Demeke G, Aschale M, Alemayehu F, Semegn G. Extraction and characterization of natural dye stuff from spent coffee ground and bio-mordant from mango bark. *J Nat Fibers*. 2023;20(2): 1-17. doi:10.1080/15440478.2023.2276725
162. Shams Nateri A, Dehnavi E. The effect of mordanting method on the absorption behavior of natural dyes. *Pigm Resin Technol*. 2021;51(5):489-498. doi:10.1108/prt-05-2021-0050
163. Bahlool SO, Kenawy ZM. Dyeing of some Egyptian cotton varieties using agricultural wastes (peanut outer skin). *Res J Text Appar*. 2023;29:324-340. doi:10.1108/rjta-07-2023-0079
164. Yılmaz F, Bahtiyari Mİ. Use of tea and tobacco industrial wastes in dyeing and antibacterial finishing of cotton fabrics. *AATCC Journal of Research*. 2020;7(5):25-31. doi:10.14504/ajr.7.5.4
165. Kalebek NA. Fastness and antibacterial properties of polypropylene surgical face masks dyed with coffee grounds. *J Text Inst*. 2021;113(7):1309-1315. doi:10.1080/00405000.2021.1926129
166. Magalhães GR, Militão GFG, de Farias NO, et al. Acryloyl esters of emodin for waterless dyeing and toxicological studies. *Color Technol*. 2023;140(4):620-628. doi:10.1111/cote.12731
167. Souissi M, Guesmi A, Moussa A. Valorization of natural dye extracted from date palm pits (*Phoenix dactylifera*) for dyeing of cotton fabric. Part 1: optimization of extraction process using Taguchi design. *J Clean Prod*. 2018;202:1045-1055. doi:10.1016/j.jclepro.2018.08.115
168. Vankar PS, Gangwar A. Natural dyeing mediated by atmospheric air pressure plasma treatment of polyester. *Pigm Resin Technol*. 2023;53(5):569-575. doi:10.1108/prt-07-2022-0093
169. Üren N, Kutlu B. Natural dyeing of plasma treated wool with avocado seed extract and use of tartaric acid as bio-mordant. *Color Technol*. 2024;140:868-882. doi:10.1111/cote.12752
170. Haji A, Qavamnia SS, Bizhaem FK. Optimization of oxygen plasma treatment to improve the dyeing of wool with grape leaves. *Ind Text*. 2016;67(4):244-249.
171. Haji A, Payvandy P. Application of ANN and ANFIS in prediction of color strength of plasma-treated wool yarns dyed with a natural colorant. *Pigm Resin Technol*. 2020;49(3):171-180. doi:10.1108/prt-10-2019-0089
172. Koske MC, Kiprop AK, Chepkwony SC, K'Owino IO. Optimized dyeing of cotton with semi-synthetic Embelin Ninhydrin dye obtained by chemical modification of Embelin from Embelia Schimperi. *J Nat Fibers*. 2022;19(16):13831-13839. doi:10.1080/15440478.2022.2107143
173. Popescu V, Astanei D-G, Burlica R, et al. Sustainable and cleaner microwave-assisted dyeing process for obtaining eco-friendly and fluorescent acrylic knitted fabrics. *J Clean Prod*. 2019;232:451-461. doi:10.1016/j.jclepro.2019.05.281
174. Velmurugan P, Kim JI, Kim K, et al. Extraction of natural colorant from purple sweet potato and dyeing of fabrics with silver nanoparticles for augmented antibacterial activity against skin pathogens. *J Photochem Photobiol B*. 2017;173:571-579. doi:10.1016/j.jphotobiol.2017.07.001
175. Ke G, Zhao Z, Shuhui C, Li J. Green natural dye from Buddleja officinalis and its ultrasonic dyeing on cotton fabric. *Pigm Resin Technol*. 2021;51(1):110-117. doi:10.1108/prt-10-2020-0110
176. Yameen M, Asghar F, Adeel S, et al. Enhancing wool dyeing with clove bud (*Syzygium aromaticum*) based natural dye via microwave treatment using a central composite design. *Sci Prog*. 2023;106(4):368504231215593. doi:10.1177/00368504231215593
177. Karadag R, Buyukakinci BY, Torgan E. Extraction and natural cotton dyeing of Valonia oak and Anatolian buckthorn by microwave irradiation. *J Nat Fibers*. 2020;19(1):159-172. doi:10.1080/15440478.2020.1731907
178. Adeel S, Rehman F-U, Amin A, et al. Sustainable exploration of coffee extracts (*Coffea arabica* L.) for dyeing of microwave-treated bio-mordanted cotton fabric. *Pigm Resin Technol*. 2022;52(3):331-340. doi:10.1108/prt-02-2022-0024
179. Popescu V, Blaga AC, Cascaval D, Popescu A. *Beta vulgaris* L.-a source with a great potential in the extraction of natural dyes intended for the sustainable dyeing of wool. *Plants (Basel)*. 2023;12(10):1933. doi:10.3390/plants12101933
180. Wang L, Hu H, Du Y, et al. Eco-friendly and sustainable application of gardenia yellow extraction as natural dye source for dyeing and bio-functional finishing of cotton fabric. *Cellulose*. 2024;31(4):2583-2601. doi:10.1007/s10570-023-05724-5
181. Noor S, Ali S, Hussain T. Optimization of dye extraction conditions from (*Camellia sinensis*) Green tea leaves using response surface methodology. *Asian J Chem*. 2015;27(11):4111-4114. doi:10.14233/ajchem.2015.19109
182. Islam MS, Molla MTH, Bashar MA, Chandra D, Islam MR, Ahsan MS. Ultrasound-assisted extraction of natural dye from Swietenia mahagoni and its application on silk fabric. *Indian Journal of Fibre & Textile Research*. 2021; 46: 69-77.
183. Maulik SR, Bhowmik L, Agarwal K. Batik on handloom cotton fabric with natural dye. *Indian Journal of Traditional Knowledge*. 2014; 13(4): 788-794.
184. Jemo D, Parac-Osterman D. Identification of natural dyes on 18th century liturgical textiles from Dubrovnik. *Fibres Text East Eur*. 2017;25:113-120. doi:10.5604/12303666.1227891
185. Lin SH, Mammel K. Dye for two tones: the story of sustainable mud-coated silk. *Fash Pract*. 2015;4(1):95-112. doi:10.2752/175693812x13239580431388

186. McIntosh LS, Peni YA. Alorese textiles, specifically Tenapi, and their production of Ternate Island, Alor regency, NTT, Indonesia. *Arch Androl*. 2021;102:209-239. doi:10.4000/archipel.2667
187. Niemeyer HM, Agüero C. Dyes used in pre-Hispanic textiles from the middle and late intermediate periods of San Pedro de Atacama (Northern Chile): new insights into patterns of exchange and mobility. *J Archaeol Sci*. 2015;57:14-23. doi:10.1016/j.jas.2015.02.003
188. Wozniak MM, Witkowski B, Ganeczko M, Gierczak T, Biesaga M. Textile dyeing in medieval Sudan evidenced by HPLC-MS analyses: material traces of a disappeared activity. *J Archaeol Sci Rep*. 2021;38:103098. doi:10.1016/j.jasrep.2021.103098
189. Khurana P, Pant S. Telia Rumal, double Ikat fabric of Andhra Pradesh. *Indian Journal of Traditional Knowledge*. 2016; 15(1): 167-172.
190. O'Connell MJ. Traditional weaving cultures in a global market: the case of Zapotec weavers. *Int J Fashion Stud*. 2021;8(1): 85-103. doi:10.1386/infs_00038_1
191. Rosyida A, Suranto S, Masykuri M, Margono M. Optimisation of the process of dyeing cotton fabric with natural dyes from jackfruit wood by immersion without heating. *Pigm Resin Technol*. 2021;51(6):663-673. doi:10.1108/prt-03-2021-0034
192. Bian X, Li L. Collaborations between older women of Chinese ethnic minority and fashion designers: the "Momhandworks" project. *Fash Pract*. 2021;13(1):177-184. doi:10.1080/17569370.2021.1874103
193. Xue X, Li L. Fashion consumption of naturally dyed products: a cross-cultural study of the consumption of blue-dyed apparel between China and Japan. *Fibres & Textiles in Eastern Europe*. 2023;31(1):52-65. doi:10.2478/ftee-2023-0006
194. Pandit P, Jose S, Pandey R. Groundnut Testa: an industrial agro-processing residue for the coloring and protective finishing of cotton fabric. *Waste Biomass Valorization*. 2020;12(6): 3383-3394. doi:10.1007/s12649-020-01214-y
195. Vankar PS, Shukla D, Wijayapala S, Samanta AK. Innovative silk dyeing using enzyme and Rubia cordifolia extract at room temperature. *Pigm Resin Technol*. 2017;46(4):296-302. doi:10.1108/prt-06-2016-0065
196. Nazari A, Montazer M, Afzali F, Sheibani A. Optimization of proteases pretreatment on natural dyeing of wool using response surface methodology. *Clean Techn Environ Policy*. 2013;16(6):1081-1093. doi:10.1007/s10098-013-0709-0
197. Jose S, Pandit P, Pandey R. Chickpea husk – a potential agro waste for coloration and functional finishing of textiles. *Ind Crop Prod*. 2019;142:111833. doi:10.1016/j.indcrop.2019.111833
198. Gecchele E, Negri S, Cauzzi A, et al. Optimization of a sustainable protocol for the extraction of Anthocyanins as textile dyes from plant materials. *Molecules*. 2021;26(22):1-19. doi:10.3390/molecules26226775
199. Vankar PS, Shanker R, Wijayapala S. Dyeing of cotton, wool and silk with extract of *Allium cepa*. *Pigm Resin Technol*. 2009;38(4):242-247. doi:10.1108/03699420910973332
200. Çelik Yılmaz N, Yılmaz A, Yılmaz F. Coloring of woolen fabrics with natural resources and investigating the color perceptions of children on these fabrics. *J Nat Fibers*. 2022; 20(1):1-12. doi:10.1080/15440478.2022.2134269
201. Yi E, Choi J. Intergenerational differences of color sensation and preference for naturally dyed fabrics. *Fibers and Polymers*. 2008;9:646-652.
202. Yi E, Rhee Y-J. A psychophysical approach to color sensory evaluation of yellowish natural dye fabrics. *Fibers and Polymers*. 2009;10(2):200-208. doi:10.1007/s12221-009-0200-z
203. Cho HS, Lee J. Development of a macroscopic model on recent fashion trends on the basis of consumer emotion. *Int J Consum Stud*. 2005;29(1):17-33. doi:10.1111/j.1470-6431.2005.00370.x
204. DuBreuil M, Lu S. Traditional vs. big-data fashion trend forecasting: an examination using WGSN and EDITED. *Int J Fash Des Technol Educ*. 2020;13(1):68-77. doi:10.1080/17543266.2020.1732482
205. Han A, Kim J, Ahn J. Color trend analysis using machine learning with fashion collection images. *Cloth Text Res J*. 2021;40(4):308-324. doi:10.1177/0887302x21995948
206. Shi M, Chussid C, Yang P, Jia M, Dyk Lewis V, Cao W. The exploration of artificial intelligence application in fashion trend forecasting. *Text Res J*. 2021;91(19–20):2357-2386. doi:10.1177/00405175211006212
207. Chakraborty S, Hoque SMA, Kabir SMF. Predicting fashion trend using runway images: application of logistic regression in trend forecasting. *Int J Fash Des Technol Educ*. 2020;13(3): 376-386. doi:10.1080/17543266.2020.1829096
208. Gaimster J. The changing landscape of fashion forecasting. *Int J Fash Des Technol Educ*. 2012;5(3):169-178. doi:10.1080/17543266.2012.689014
209. Silva E, Hassani H, Madsen D, Gee L. Googling fashion: forecasting fashion consumer behaviour using Google trends. *Soc Sci*. 2019;8(4):111. doi:10.3390/socsci8040111
210. An H, Park M. Approaching fashion design trend applications using text mining and semantic network analysis. *Fash Text*. 2020;7(1):34. doi:10.1186/s40691-020-00221-w
211. Zhao L, Li M, Sun P. Neo-fashion: a data-driven fashion trend forecasting system using catwalk analysis. *Cloth Text Res J*. 2021;42(1):19-34. doi:10.1177/0887302x211004299
212. Ding Y, Ma Y, Liao L, Wong WK, Chua T-S. Leveraging multiple relations for fashion trend forecasting based on social media. *IEEE Trans Multimed*. 2022;24:2287-2299. doi:10.1109/tmm.2021.3078907
213. Fu Y, Fisher M. The value of social media data in fashion forecasting. *Manuf Serv Oper Manag*. 2023;25(3):1136-1154. doi:10.1287/msom.2023.1193
214. Rudniy A, Rudna O, Park A. Trend tracking tools for the fashion industry: the impact of social media. *J Fash Mark Manag*. 2023;28(3):503-524. doi:10.1108/jfmm-08-2023-0215
215. Yu Y, Hui C-L, Choi T-M. An empirical study of intelligent expert systems on forecasting of fashion color trend. *Expert Syst Appl*. 2012;39(4):4383-4389. doi:10.1016/j.eswa.2011.09.153
216. Chang Li X, Pan R, Gao W. Fashion color Forecasting by applying an improved Back propagation neural network. *J Donghua Univer*. 2013;30(1):58-62.
217. Hsiao SW, Lee CH, Chen RQ, Yen CH. An intelligent system for fashion colour prediction based on fuzzy C-means and

gray theory. *Color Res Appl*. 2016;42(2):273-285. doi:10.1002/col.22057
218. Ren S, Chan H-L, Ram P. A comparative study on fashion demand forecasting models with multiple sources of uncertainty. *Ann Oper Res*. 2016;257(1–2):335-355. doi:10.1007/s10479-016-2204-6
219. An H, Kim S, Choi Y. Sportive fashion trend reports: a hybrid style analysis based on deep learning techniques. *Sustainability*. 2021;13(17):1-16. doi:10.3390/su13179530
220. Wang W, Liu Y, Song F, Wang Y. Color trend prediction method based on genetic algorithm and extreme learning machine. *Color Res Appl*. 2021;47(4):942-952. doi:10.1002/col.22769
221. Koren M, Shnaiderman M. Forecasting in the fashion industry: a model for minimising supply-chain costs. *Int J Fash Des Technol Educ*. 2023;16(3):308-318. doi:10.1080/17543266.2023.2201508
222. Choi T-M, Hui C-L, Liu N, Ng S-F, Yu Y. Fast fashion sales forecasting with limited data and time. *Decis Support Syst*. 2014;59:84-92. doi:10.1016/j.dss.2013.10.008
223. Lin JJ, Sun PT, Chen JJR, Wang LJ, Kuo HC, Kuo WG. Applying gray model to predicting trend of textile fashion colors. *J Text Inst*. 2010;101(4):360-368. doi:10.1080/00405000802435827
224. Lopes MV. The discourse of fashion change: trend forecasting in the fashion industry. *Fashion, Style & Popular Culture*. 2019;6(3):333-349. doi:10.1386/fspc.6.3.333_1
225. Johnson O, Ulrich P. The relationship between color cycles in home furnishings and apparel, 1969–2009. *Fash Text*. 2018;5(1):12. doi:10.1186/s40691-017-0124-y
226. Garcia CC. Contemporary changes and challenges in the practice of trend forecasting. *Int J Fashion Stud*. 2023;10(1):75-98. doi:10.1386/infs_00086_1
227. Powers D. Thinking in trends: the rise of trend forecasting in the United States. *J of Histor Res Market*. 2018;10(1):2-20. doi:10.1108/jhrm-09-2016-0021
228. Cassidy TD. Colour forecasting. *Text Prog*. 2020;51(1):1-137. doi:10.1080/00405167.2019.1659564
229. Vijayalakshmi D, Ramachandran T. An exploratory study on the techniques of fashion forecasting. *J Text Assoc*. 2012;73(3):163-239.
230. Noh M, Ulrich P. Querying fashion professionals' forecasting practices: the Delphi method. *Int J Fash Des Technol Educ*. 2013;6(1):63-70. doi:10.1080/17543266.2013.765510
231. Doshi S. The influence of culture, evolving symbolisms and globalization on defining colour forecasting in India. *Fashion, Style & Popular Culture*. 2022;9(1):9-26. doi:10.1386/fspc_00107_1
232. Carlin. Colour: Our DNA. Accessed December 1, 2024. https://www.carlin.co/colourissimo
233. Carlin. Campanile strategic & creative consulting. Accessed December 1, 2024. https://www.carlin.co/realisations/louvre-hotels
234. Morgan-Petro S. Apparel 2014. Fashion. Accessed February 6, 2014. https://wgsn.com/fashion/article/52096
235. Clark J. Colour Intelligence: Indigo Dye. 2021. Intelligence. https://www.wgsn.com/fashion/article/89688
236. Smith C. Sustainability & Innovation: Responsible Colour. 2023. Innovation. Accessed January 24, 2023. https://www.wgsn.com/fashion/article/63b3f445db6ac2ee7acb736c
237. Smith C. Sustainability & Innovation: Dye Challenges & Solutions. 2024. Intelligence. Accessed November 29, 2024. https://www.wgsn.com/fashion/article/6722441cbcf6fadb32b1ab73
238. Diamond M, Rissmann L, Yeung Q. Sustainability Bulletin: May 2024. 2024. Intelligence. Accessed May 2, 2024. https://www.wgsn.com/fashion/article/66222aec1aca7e2d4d4bafb1
239. Samba U. Advanced Colour 2029. Future Strategies. 2024 Accessed December 23, 2024. https://www.wgsn.com/fashion/article/671f608c8727c3c3e1db379d
240. Primetta A, Hyttinen J, Negi A, Gaitan J, Räisänen R. BioColour Library. Accessed January 9, 2025. https://library-biocolour.2.rahtiapp.fi/pages/
241. Boaler N, Smith C, Cano A. Buyers' Briefing: Men's Colour & Print S/S 24. 2023. Buyers' Briefing. Accessed April 28, 2023. https://www.wgsn.com/fashion/article/642c09e4fc917bb24a7dd742

AUTHOR BIOGRAPHIES

Bintan Titisari is a postdoctoral researcher at the School of Design, University of Leeds. Her research interests are in the textile and fashion design industry, focusing on the interdisciplinary aspects of textile design, craft practices, colourants, sustainable practices and consumer behaviour.

Pammi Sinha is a Professor in Fashion Management at the School of Design, University of Leeds. Her research interests span strategic management of the fashion design process, post-consumer textiles waste, remanufacture of fashion, craft heritage and digital methods to support sustainable fashion design.

How to cite this article: Titisari B, Sinha P. A systematic review of natural colourants and trend forecasting practices for the textile and fashion industry. *Coloration Technology*. 2025;1-27. doi:10.1111/cote.12836