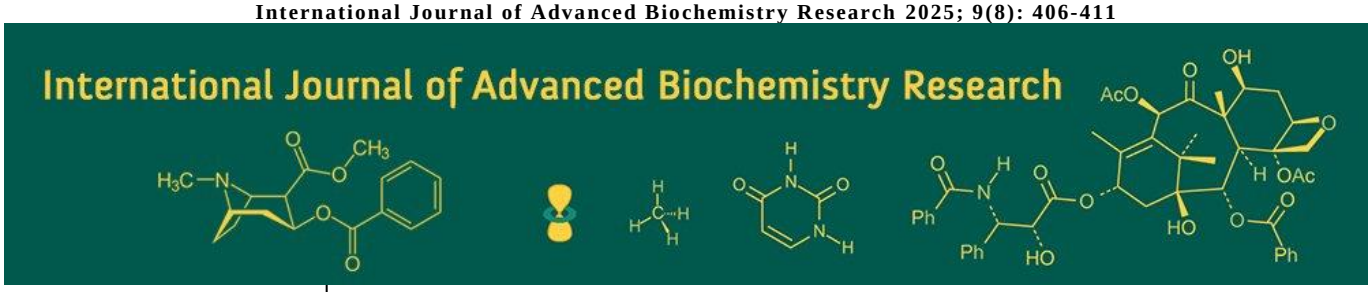

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Potential of natural dyes in silk dyeing: Trends, challenges and future prospects

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Abstract
The coloring materials that are obtained from natural sources are known as natural dyes. Nowadays, with the growing concern for environmental awareness, the textile industry is increasingly turning towards sustainable alternatives with natural dyes. These natural dyes are gaining attention particularly in silk dyeing due to their eco-friendly nature and unique color variation. This review article explores the evolving trends in the use of natural dyes on silk from different sources like plant or vegetable-based dyes, insect-based dyes, mineral dyes, microbial dyes and natural dyes from waste sources. By exploring these emerging trends, it underscores the potential use of natural dyes in silk industry.

Keywords: Natural dye, silk, sustainable, textile industry

Introduction
Color is one of the most powerful elements in design and communication, significantly influencing human psychology, emotions and behavior. In the textile industry, color is not just a matter of aesthetics-it serves as a vital tool to convey mood, identity, cultural values and consumer preferences. Dyeing and printing processes are the coloration techniques that adds value to the textile materials (Dessie and Eshetu, 2021) [1]. Presently, the concept of green fashion has taken the spotlight in textile and clothing industry, because of which efforts are being made to reduce the environmental impact by this industry (Sarma *et al.*, 2025) [2]. Silk has been cherished for its luxurious texture, natural seen, cultural significance, durability. Silk shows high affinity towards dye because it rich in amino and carboxyl groups along with its hydrophilic nature (Yasukawa *et al.*, 2021) [3]. In this contemporary era, concerns over the environmental impact, use of natural dyes have led to a renewed interest over synthetic one, especially for dyeing of silk. Though the synthetic dyes are used widely by the textile industries because of its availability, reproducibility, better color fastness etc., due to some carcinogenic chemicals required to produce these along with the effluents created on using them there is a global surge in the demand for natural dyes (Gokarneshan, 2022) [4]. Natural dye can successfully replace certain harmful synthetic dyes due to their eco-friendly nature (shah and Patel, 2012). Natural dyes can be extracted from different sources like plants, animals and from the minerals (Gokarneshan, 2022) [4]. Addressing the global bioeconomy trend, dyeing the silk with natural dye can boost the global demand of silk in the textile market.

Historical perspective of natural dye
The art of dyeing is as old as human civilization. Archaeological evidence reveals early dyeing practices dating back to 4000 BCE (Kulkarni, 2025) [5]. The use of natural dyes in silk has been deeply rooted in many traditional cultures across the globe and Indians are considered as the pioneers in the field of natural dyeing (Sarkar *et al.*, 2023) [6]. Ancient civilizations in India, China and Egypt used plant parts, insects and mineral sources to dye the fabrics in vibrant hues. In 2600BC the first ever natural dye was found (Bishal *et al.*, 2023) [7]. Some of the countries like France, Holland and Germany began the cultivation of dye plants as an industry from 16th century. Until 1856 when the first synthetic dye was created, people are using the natural sources like plants, insects, animals, and minerals to prepare the dye.

Natural dyes were one of significant trade commodities for centuries including most of the nineteenth century (Fereday, 2003) [8]. Use of dyestuffs in China starts from the year 2, 600 BC. The use of cochineal in the textile industry of Mexico and Peru dates back almost 3, 000 years. Alizarin, purpurin and indigo that are used in Chinese Yanghai textiles were identified in the Late Bronze Age. Prehistoric discoveries of textiles in Europe document the use of alizarin and purpurin from the 4th century BC (Kramell, 2014) [9]. The first natural dye alizarin is a coal tar base dye that was commercially made by Perkin's firm in 1869 (Sarkar *et al.*, 2023) [6].

Sources of natural dyes:

There is a wide range of sources from where natural dyes can be extracted. Among those sources plant such as indigo, saffron etc., some insects like cochineal beetles, lac insects and animals like molluscs or shellfish along with the microbes such as *Pseudomonas*, *Bacillus*, *Rhodococcus* etc. are well known. Besides these some minerals like ferrous sulfate, ochre, and clay are also the good source opf natural dye (Kadolph, 2008) [10]. Addition to these, agro-waste such as pumpkin skin, almond shell, silkworm excreta, feces of bovine (Sarma *et al.*, 2025) [2] can be utilized as natural sources of dye.

Plant or vegetable-based dyes: Dyeing of fibers or cloths with plant or vegetable-based dye is an age-old traditional practice. Dyes can be extracted from flowers to the roots of a plant. India is very rich in biodiversity. There are more than 450 numbers of dye-producing plants or vegetables in the country (Bishal *et al.*, 2023) [7]. Among those plants many of them are utilized for dyeing the silk.

a) **Mulberry leaves:** The extract from mulberry leaves produced a brown to yellowish brown colour (Chetia *et al.*, 2023) [11].

b) **Turmeric (*Curcuma longa*):** Roots or tuber of the turmeric yields yellow colored dye. That is useful for dying the silk as well as other natural fibers like cotton and wool. etc. It does not produce any health hazards due to it's medicinal property.

c) **Henna (*Lawsonia inermis*):** Commonly known as as the Egyptian privet or mignonette tree, henna is a well-known dye. Dye is extracted from the leaves of this plant that imparts orange to reddish tone. It shows excellent compatibility with silk and wool fibers, producing rich color (Bishal *et al.*, 2023) [7].

d) **Indigo:** It is the king of all-natural dyestuffs and because of the presence of indican (1H-indol-3yl b-D-glucoside) the leaves extract of indigo yields the significant blue hue (Bishal *et al.*, 2023) [7]. Silk can be dyed successfully with Indigo (Gokarneshan, 2022) [4].

e) **Indian Madder or manjistha (*Rubia cordifolia*):** Madder has been traditionally utilized for centuries to produce red color (Tian *et al.*, 2023) [12]. It is a type of flower bearing plant belonging to the Rubiaceae family that yields red colour from its roots on textile fabrics.

f) **Marigold:** The dye can be isolated from yellow or orange colored marigold flower. Its biological sources are *Tagetus erecta* and *Calendula officinalis*, from Asteraceae family. The main colouring agent in marigold flowers is lutein that gives yellow to orange hue (Chengaiah *et al.*, 2010) [13]. It can be successfully utilised in dyeing of both wool and silk fibres.

g) **Pomegranate:** Dyes obtained from pomegranate peel imparts orange to yellow colour. Since it contains around 19% of total tannin content it can be use as mordant in dyeing process. Granatonine present in the pomegranate peel and grains is the main component that imparts color to the substrate (Goodarzian and Ekrami, 2010) [14]. Pomegranate peel extract in addition with turmeric can increase the dyed fabrics' light resistance capacity. It is applicable for dying silk, cotton and synthetic fibres.

h) **Saffron:** The dye is produced from dry stigmas of the *Crocus sativus* plant. It is commonly known as the "saffron crocus". It imparts a vivid yellow color in the dyed material. It may color cotton, silk, and wool directly (Korankye, 2010) [15].

i) **Wood apple or Bael (*Aegle marmelos*):** It is plant from Rutaceae family which bears yellow green fruit with hard outer covering. Leaves of this plant is use to extract the dye which imparts daisy yellow to lemon yellow color (Sarma *et al.*, 2025) [2].

j) **Annatto (*Bixa orellana*):** It is a perennial evergreen plant that bears globular red-brown spiky seed pods. The outer coating of the seed is used to extract the dye that gives orange to reddish color (Meena *et al.*, 2013) [16].

k) **Teak:** Teak leaves offer a viable option for natural dye that can be utilized to dye the silk and other natural fibres. It has a longstanding history of being used as a natural dye in textile industry in the countries like India, Laos, Indonesia, and Thailand (Kusumawati *et al.*, 2021) [17]. Anthocyanins, an organic substance belonging to the flavonoid group is the natural colouring agents that present on teak's leaves (Roengthanapiboon *et al.*, 2024) [18].

l) **Harad (*Terminalia chebula*):** The seed pericarp can be utilized as a source of dye (Onial *et al.*, 2015) [19]. It is also known as myrobalan and can be use as natural mordant.

m) **Tamarind seeds:** Yellow to brown colored dye can be extracted from the leaves and seeds of tamarind (*Tamarindus indica*). It can be utilized to dye the cotton and silk fabrics.

Insect-based dyes: Natural dyes sourced from insects have significant role in textile coloration, particularly in providing vibrant red shades.

a) **Tyrian purple:** It is considered as one of the earliest known animal base dyes extracted from marine molluscs belonging to snails of the Muricidae family, commonly found in the Levantine Sea (Koren, 2005) [20]. It is a highly expensive dye since to produce a little amount of color thousands of molluscs are required. It is known for its rich violet hue and was traditionally used to dye the garments of royalty and symbolized power and nobility. This dye can be applied to different natural fibers like silk, cotton and wool (Bishal *et al.*, 2023) [7].

b) **Cochineal:** It is native to Central and South America, particularly Mexico and Brazil (Serrano *et al.*, 2011) [21]. These insect produce a red pigment known as carminic acid, which constitutes about 9-10% of their body mass in the form glyceryl myristate. Carminic acid is especially valued for dyeing natural animal fibers due to its excellent color fastness and strong

affinity to protein based textiles (Serrano *et al.*, 2013) [22]. When combined with mordants like aluminum and tin oxide, it yields crimson red and scarlet hues (Khan *et al.*, 2015) [23]. It is used to color the wool and silk from time immemorial.

c) **Lac Dye:** The liquid released by the lac insect (*Lauifer lacca*) is used to make this color. They impart a red pigment because of the presence of main chemical component laccaic acid (Sharma, 2017) [24].

Mineral dyes

Mineral dyes are obtained from naturally occurring inorganic substances, including various metal salts and metal oxides. These pigments are typically categorized based on the colors they produce. Some important mineral dyes are (Agarwal and Tiwari, 1989 ; Singh and Parmar, 1998) [25, 26]

Red pigments

a) **Cinnabar:** Cinnabar also referred as vermillion, a heavy reddish mineral known for its metallic, shiny appearance. It is composed primarily of mercury sulfide (HgS) generally used to create deep red tones.

b) **Red Ochre:** It is a mineral dye consists of iron oxide and used in cultural and artistic contexts. Monks have historically used it to dye their robes, while artists have applied it in with in wall paintings and murals, often mixed with gum as a binder.

c) **Red lead:** In India, red lead is commonly known as sindur and is mainly composed of lead tetroxide and litharge. This vibrant red or orange pigment is widely used in Indian art and carries both aesthetic and cultural significance.

Yellow Pigments

a) **Yellow Ochre:** It is derived from iron oxides specially from limonite ($Fe_2O_3.H_2O$). This pigment has been utilized in various applications, including painting in fabrics like sails, and coloring both natural fibers and synthetic fibers.

b) **Raw Sienna:** Raw sienna, an earthy pigment rich in iron oxide, has been among the earlist colorants used by humans-most notably in prehistoric cave art. Its transparency makes it a favoured pigment for glazing techniques in fine art.

Green Pigments

a) **Malachite:** Malachite ($Cu_2(OH)_2CO_3$) is an intense green naturally occurring mineral, that produces vivid, deep green pigment (Bishal *et al.*, 2023) [7].

Blue Pigments

a) **Ultramarine Blue:** This brilliant blue pigment is obtained by grinding the semi-precious mineral lapis lazuli. In India, it has been prized for its intense color and extensively used in textile dyeing.

b) **Lapis lazuli:** It is a metamorphic rock rich in blue color. Used for blue nuances.

Microbial dyes

With the growing global interest in eco-friendly and sustainable alternatives, microbial dyes have emerged as promising substitute for different dye sources. Specially fungi and bacteria (Joshi *et al.*, 2003) [27] have gained popularity in dye making industry as well as in textile industry for their potential to produce stable, vivid pigments in a sustainable manner (Duran *et al.*, 2002) [28]. Microbial dyeing offers several advantages like renewability and biodegradability along with the potential for large scale production under controlled conditions (Kim, 2024) [29]. Recent studies highlight the potential of bacterical species like *Streptomyces* and *Pseudomonas* for textile dyeing because of their ability to produce vibrant pigments with good color fastness and fabric compatibility (Chen, 2023) [30]. Some of the sources are listed below.

a) ***Pseudomonas* spp.:** It is a pigment-producing bacteria responsible for producing some soluble pigments like pyocyanin, pyoverdine, pyorubin and pyomelanin.

b) ***Achromobacter* spp.:** They are gram negative bacteria capable of producing red pigment.

c) ***Bacillus* spp.:** It is a pigment-producing gram-positive bacteria that yields yellow, brown, orange and pink color.

d) ***Rhodococcus* spp.:** This versatile genus can be used in bioprocess technology, bioremediation, pigment synthesis and probiotics in aquaculture. Carotenoids are the pigments that imparts yellow to orange color that is obtained from it.

e) ***Flavobacterium* spp.:** They are the rod-shaped bacteria characterized by the presence of flexirubin, a unique pigment responsible for the color is the main pigment found in them.

Natural dyes from agro-wastes

As the demand for natural dyes continues to grow, the limited availability of conventional sources has driven the interest towards alternative and more sustainable resources. Among these, agro-wastes-the byproducts of agriculture and allied activities have gained significant attention as potential raw materials for natural dye extraction. Agro-waste refers to a wide range of residues leaf behind after different processes. Many of these contains natural pigments such as tannins, flavonoids, carotenoids etc., which can be use to extract the natural dye. This approach not only supports waste management but also aligns with sustainable and green chemistry principles.

a) **Pumpkin skin:** The dried peels of yellow pumpkin can be utilized for preparation of natural dye. Cotton and silk fabric can be dyed with pumpkin skin extract that imparts yellow color (Karthikeyan and Vidya, 2020) [31].

b) **Almond shell:** Almond (*Prunus dulcis*) shell can be used as natural dyes with the metallic mordants which yields rose, cinnamon, brown and burgundy/reddish colors that can be effectively used in wool fiber (Erdem *et al.*, 2014) [33]. Silk can also be dyed with almond shell extract (Deepali and Shraddha, 2017) [34].

c) **Feces of bovine:** Bovine feces contain lignin components which is a part of the dye that possibly pertains colour to the fiber (Rattan *et al.*, 2008) [35]. Depending on the medium used olive to beige color can be obtain from it (Sarma *et al.*, 2025) [2].

d) **Silkworm excreta:** Silkworm excreta represent a unique agro-waste with potential as a dye source of sericulture origin. can be used for the preparation of natural dye. It is rich in chlorophyll and carotenoids that yields yellowish brown colour (Vila *et al.*, 2018, Tang *et al.*, 2024) [36, 37].

Trends in silk dyeing with natural dyes

In the rapidly evolving textile industry, silk continues to hold a timeless appeal due to its luxurious texture, luster and strength. However, with increasing concerns about environmental sustainability and pollution, there has been a notable shift in dyeing processes used in silk production. Among the most significant developments is the revival and innovation of natural dyeing techniques. Natural dyeing, once a widespread traditional practice, is making a strong comeback in modern textile design. Historical sources of natural dyes such as indigo, madder, turmeric, lac etc. are regaining importance due to their ecological compatibility. Designers and textile producers are increasingly aligning natural dye palettes with contemporary fashion trends. A recent trend in natural dyeing is the use of agro-waste and underutilized botanical resources starting from the onion peels to silkworm excreta. These are being successfully utilized in silk dyeing. These waste materials, previously discarded, are now upcycled into valuable dye sources.

- Eri silk can be effectively dyed with *Aegle marmelos*, *Bixa Orellana*, *Brassica oleracea*, *Curcuma longa*, *Spinach oleracea*, *Lacifer lacca*, *Strobilanthes cusia*, *Areca catechu*, *Phaseolus vulgaris* and feces of bovine. Use of natural dyes to dye the silk fabric is economically feasible and sustainable (Sarma *et al.*, 2005) [2].
- Silk can be colored with *Basella alba* fruit extract that produces different light shades with good light and washing fastness. Dyeing of silk with this fruit extract gives a mordant-free dyeing solution (Balakrishna, 2024) [38].
- A lichen *Parmotrema perlatum* is a promising natural dye that yields purple colour can be used for sustainable silk dyeing (Roychowdhury *et al.*, 2024) [39].
- A wide range of colors can be achieved on the silk fabric by using onion peel (*Allium cepa*) extract with different type of natural mordants lemon peel, dry gooseberry, pomegranate etc (Meenakshi *et al.*, 2023) [40].
- Brown colored dye obained from the *Syzgium cumini* flower can be successfully utilized to color the silk (Santhi and Kowsalya, 2021) [41].
- Andaman satinwood leaves, golden shower pods, neem bark, sappan, acacia bark and burma padauk bark can be use to dye the eri silk yarns that imparts trendy stylish color and also adds excellent level of UV protection property to the silk (Rungruangkitkrai *et al.*, 2020) [42].
- Sophora flower extract is a good natural dye for silk fabric that exhibits good rubbing, washing and perspiration fastness (Yan *et al.*, 2018) [43].
- Beautiful fast pinks and red colours can be obtained from *Caesalpinia sappan*, the native Indian brasilwood tree, while kapila, *Mallotus philippinensis* produces bright yellow on silk (Greenfield, 2005) [44].

To enhance consumer confidence and marketability, products dyed with natural dyes are now being certified by eco-labels such as GOTS (Global Organic Textile Standard) and Oeko-Tex. These certifications ensure that silk fabrics are dyed using safe, non-toxic processes under socially responsible conditions, as sustainability becomes a global priority, such certification adds commercial value and opens up international market opportunities for naturally dyed silk.

Challenges in adopting natural dyes for silk dyeing

Natural dyeing of silk has gained renewed attention due to rising environmental concerns and the demand for sustainable alternatives to synthetic dyes. Despite of its historical roots and aesthetic value, the commercial application of natural dye in textile dyeing industry faces numerous challenges, including issues of color fastness, scalability, availability of raw materials and standardization of processes.

- One of the primary drawbacks of natural dye is their poor color fastness property which makes them less durable and limiting their application in textile industry (Yusuf *et al.*, 2017) [45]. Natural dye often lacks uniformity, leading to issues such as fading, bleeding or color changes upon exposure to light, washing, perspiration etc.
- Natural dyes are typically derived from natural sources like plants, insects etc. and their availability largely depends on season, region, climate *ect.* causing supply chain issues and difficulty in meeting industrial demand. Compared to synthetic one, natural dyes often require large amounts of raw materials to produce a small amount of colorant. This not only increases the cost but also makes the process resource-intensive (Sun *et al.*, 2021) [46].
- Despite of the advancement in different natural dye extraction methods, scaling of these methods for industrial application remains as a big challenge to the textile industry that requires extensive optimization and validation (Kim, 2024) [29].
- Natural dyes offer a relatively narrow color palette, mostly comprising earthy tones, browns, yellows and some blues. The inability to easily achieve bright or neon shades limits design freedom for textile designers and restricts natural dyes' competitiveness in a fashion-driven market.
- To improve color fastness and shade range, natural dyes usually require mordants. Some mordants like copper, chromium or tin salts are toxic and pose ecological as well as health hazards. The widespread use of harmful mordants can negate the eco-friendly benefits of natural dye.

Future prospects

The use of natural dyes in silk dyeing is gaining momentum as the world moves towards more sustainable and eco-friendly choice. With the increasing awareness about the negative impacts of synthetic dyes on health and environment, natural dyes are emerging as a safer alternative. Though challenges remain, due to the innovation of different processing methodes and use of plant-based mordants, that improves color fastness and consistency, there is a ray of hope in upscaling the use of natural dye in textile industry. Now-a-days people are aware of different functional properties of product or materials like UV protection which affects the purchase fabric goods such as coats, scarves, hats and dresses of customers. In addition to being eco-friendly, natural dyes are having UV protection and antibacterial properties which makes it more valuable for the textile industry (Rungruangkitkrai *et al.*, 2020) [42]. If the silk yarns and silk goods can be dyed with natural dyes that are having UV protection properties it will increases the value of silk in global textile market.

Conclusion

The art of silk dyeing is undergoing a thoughtful transformation. With the revival of traditional wisdom and the fusion of scientific innovation, natural dyes are once again becoming a viable and desirable option for silk coloration. As the textile industry redefines its priorities towards environmental health and ethical practices, natural dyeing stands at the forefront of sustainable silk production, bridging the gap between tradition and modernity.

Reference

1. Dessie A, Eshetu B. The role of binders and its chemistry in textile pigment printing. J Text Sci Eng. 2021;11(1):1-6.
2. Sarma P, Choudhury FB, Basumatari D, Kalita K, Gosh SS, Baruah BB, *et al.* Development and evaluation of indigenous natural dyes: extraction methods, absorption efficiency and color fastness on eri silk. J Nat Fibers. 2025;22(1):2465670.
3. Yasukawa A, Fukuyama M, Iwai K. Dyeing silk and cotton fabrics using Fuji apple peel and properties of dyed fabric. Text Res J. 2021;91(21-22):2669-2681.
4. Gokarneshan N. A review of some significant trends in dyeing of silk with natural dyes. Int J Res Eng Sci. 2022;10(1):44-48.
5. Kulkarni K. Evolution of Textile Dyes: A Journey Through Colour and Culture [Internet]. Fibre2Fashion; 2025 Jan [cited 2025 Aug 9]. Available from: https://www.fibre2fashion.com/industry-article/10268/evolution-of-textile-dyes-a-journey-through-colour-and-culture
6. Sarkar D, Khan AM, Chakraborthy O, Sarkar I, Maitra S. Natural dye: antiquity to future perspective. Pharma Innov J. 2023;12(6):1536-1544.
7. Bishal A, Ali KA, Ghosh S, Parua P, Bandyopadhyay B, Mondal S, *et al.* Natural dyes: its origin, categories and application on textile fabrics in brief. Eur Chem Bull. 2023;12(8):9780-9802.
8. Freeday G. Natural Dyes. London: British Museum Press; 2003.
9. Kramell A. Dyes of Late Bronze Age textile clothes and accessories from the Yanghai archaeological site, Turfan, China: determination of the fibers, color analysis and dating. Quat Int. 2014;348:214-223.
10. Kadolph S. Natural dyes: a traditional craft experiencing new attention. Delta Kappa Gamma Bull. 2008;74(4):14-17.
11. Chetia P, Priyadarshini P, Manimegalai S, Radha P, Kumaran K, Tilak M. Phytochemical analysis and extraction of natural dyes from mulberry leaves. Pharma Innov J. 2023;12(8):1500-1504.
12. Tian G, Cui R, Liu C, Hu X. Natural dyeing with madder: exploring traditional techniques and color characteristics. Fibres Text East Eur. 2023;31(4):80-87.
13. Chengaiah B, Rao KM, Kumar KM, Aagusundaram M, Chetty CM. Medicinal importance of natural dyes—a review. Int J PharmTech Res. 2010;2(1):144-154.
14. Goodarzian H, Ekrami E. Wool dyeing with extracted dye from pomegranate (Punica granatum) peel. World Appl Sci J. 2010;8(11):1387-1389.
15. Korankye O. Extraction and Application of plant dyes to serve as colorants for food and textiles [PhD thesis]. [Kumasi, Ghana]: Kwame Nkrumah University of Science & Technology; 2010.
16. Meena Devi VN, Ariharan VN, Nagendra Prasad P. Annatto: eco-friendly and potential source for natural dye. Int Res J Pharm. 2013;4(6):106-108.
17. Kusumawati N, Muslim S, Kistyanto A. Utilization of teak leaf waste as an environmentally friendly dye. IOP Conf Ser Earth Environ Sci. 2021;709(1):012015.
18. Roengthanapiboon N, Sindhuphak A, Egwutvongsa S. Dyeing of silk yarn with natural dye from teak leaves. Rev Gest Soc Ambient. 2024;18(2):e04033.
19. Onial P, Dayal R, Rawat MSM, Kumar R. Utilization of Terminalia chebula Retz. fruits pericarp as a source of natural dye for textile applications. Indian J Nat Prod Resour. 2015;6(2):114-121.
20. Koren ZC. The first optimal all-Murex all-natural purple dyeing in the Eastern Mediterranean in a millennium and a half. In: Dyes in History and Archaeology 20. London: Archetype Publications; 2005. p. 136-149.
21. Serrano A, Sousa MM, Hallett J, Lopes JA, Oliveira MC. Analysis of natural red dyes (cochineal) in textiles of historical importance using HPLC and multivariate data analysis. Anal Bioanal Chem. 2011;401(2):735-743.
22. Serrano A, Sousa M, Hallett J, Simmonds MS, Nesbitt M, Lopes JA. Identification of Dactylopius cochineal species with high-performance liquid chromatography and multivariate data analysis. Analyst. 2013;138(20):6081-6090.
23. Khan ZH, Mamun RA, Hasan R. Dye-sensitized solar cell using used semiconductor glass and natural dye: towards alternative energy challenge. Int J Renew Energy Res. 2015;5(2):550-556.
24. Sharma KK. Lac insects and host plants. In: Omkar, editor. Industrial Entomology. Singapore: Springer; 2017. p. 157-180.
25. Agarwal OP, Tiwari R. Mineral pigments of India. In: Compendium of the national convention of natural dyes. Lucknow: National Handloom Development Corporation; 1989.
26. Singh K, Parmar SS. Are natural dyes safer than synthetic dyes? Text Trends. 1998;40(11):23-27.
27. Joshi VK, Attri D, Bala A, Bhushan S. Microbial pigments. Indian J Biotechnol. 2003;2(3):362-369.
28. Duran N, Teixeira MF, De Conti R, Esposito E. Ecological-friendly pigments from fungi. Crit Rev Food Sci Nutr. 2002;42(1):53-66.
29. Kim DD. Beyond natural dyes: embracing sustainable innovations in industrial textile dyeing. Glob Sci J. 2024;12(9):48-67.
30. Chen H. Microbial production of natural pigments for textile dyeing. Biotechnol Adv. 2023;58:107921.
31. Karthikeyan G, Vidya AK. Production and application of natural dye from skin of yellow pumpkin vegetable. Int J Rec Sci Res. 2020;11(03):37828-37839.
32. Esfahlan AJ, Jamei R, Esfahlan RJ. The importance of almond (*Prunus amygdalus* L.) and its by-products. Food Chem. 2010;120(2):349-360.
33. Ozkan I, Yilmaz L, Ozdogan E. Use of almond shell extracts plus biomordants as effective textile dye. J Clean Prod. 2014;70:61-67.
34. Sontakke D, Ninawe S. A study on dyeing of silk fabric with almond shells (*Prunus amygdalus* L.) waste. Int J Res Granthaalayah. 2017;4(5):60-72.

35. Rattan VK, Purai A, Singh H, Manoochehri M. Adsorption of dye from aqueous solution by cow dung ash. Carbon Lett. 2008;9(1):65-71.
36. Vila NT, Silva MG, Musialak AL, Fernandes M, Souto AP, Ferreira AJS. Silkworm excrement used for dyeing textiles. IOP Conf Ser Mater Sci Eng. 2018;460:012028.
37. Tang Y, Xia W, Li Q. Novel and environmentally friendly paste-bath dyeing of protein fibers with mulberry leaf and silkworm excrement. Ind Crops Prod. 2024;209:118080.
38. Balakrishnan S. Silk fabric dyeing with Basella alba (Sri Lankan green spinach fruit) natural dyes: mordant-free dyeing approaches. Ind Crops Prod. 2024;222:119337.
39. 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):854-867.
40. Meenakshi, Pal H, Kumari P. A study of onion peel dyeing on silk fabric. Int J Eng Res Technol. 2023;12(02):40-45.
41. Santhi M, Kowsalya S. Dyeing of silk with eco-friendly natural dyes obtained from flower of Syzygium cumini (SC) plant using different mordants. J Glob Biosci. 2021;10(11):9109-9116.
42. Rungruangkitkrai N, Mongkholrattanasit R, Phoophat P, Chartvivatpornchai N, Sirimungkararat S, Wongkasem K, *et al.* UV-protection property of Eri silk fabric dyed with natural dyes for eco-friendly textiles. IOP Conf Ser Mater Sci Eng. 2020;773(1):012027.
43. Yan S, Pan S, Ji J. Silk fabric dyed with extract of Sophora flower bud. Nat Prod Res. 2018;32(3):308-315.
44. Greenfield AB. A Perfect Red: Empire, Espionage and the Quest for the Color of Desire. New York: HarperCollins Publishers; 2005.
45. Yusuf M, Shabbir M, Mohammad F. Natural colorants: historical, processing and sustainable prospects. Nat Prod Bioprospect. 2017;7(1):123-145.
46. Sun J, Liang F, Liu Y. Ionic liquid-based extraction of anthocyanins from purple sweet potatoes. Food Chem. 2021;351:129286