Minireview Article

Non Medical Application of Bacteria in Dyeing Textile

ABSTRACT

Aims: to revisited new method of producing dyes which is safer for the human health using new unusual source of natural based dyes produce by live cell of bacteria which is engineered biotechnologically.
DIscussion: due to the importance of textile to human life and along with the post modern era, textile products play a vital role in meeting not just mans basic needs, but far beyond. Textile dyeing process need certain dye to make it looks better, comfortable and give certain self confident to their user. Unfortunately, classic synthetic dyes use for a traditional dyeing techniques. These substances are known to be toxic and can cause various health issues. Hence, biotechnology improvement in using dye from bioengineered bacteria offer a breakthrough in a more safer and eco-friendly textile industry. The challenges include the lack of awareness due to not much knowledge about this breakthrough and moreover how to push this approach, which is currently still on a limited lab scale, into a massive and widespread industrial existence.
Conclusion: Environmental and health issues regarding the use of conventional dyes leading to increased awareness of good practice of textile industry. Biotechnology offers alternative approach of safer and responsible dyeing with genetically engineered bacteria. This become the most recent achievement in textile ndustry. This approach is promising, but still needs a lot of effort from all stakeholder to push it from only limited laboratory scale onto a more massive industrial scale.

Keywords: pigment, biotechnology, safe, non-toxic, biodegradable, synthetic dye, toxic, eco-friendly

1. INTRODUCTION

Textiles are a fundamental need for modern humans self-actualization, which accomodates multiple purposes such as protection, comfort, and hygiene; all in style and can affect its user's performance, self-esteem, mood enhancer and and even mental health [1-5]. Textile and clothing provide specific and sufficient protection against internal or external distress and maintain the constant regulates of body temperature, e.g exercise apparel. From all of previously mentioned perspective, human body is in permanent contact with textile materials [6-8].
Throughout history of human civilization, it reflects the materials available to a culture combined civilization as well as the traditional local wisdom technologies to produce it, including its dyeing [9]. In dyeing, color is obtained in textiles and other materials by the use

of colorants (dyes and pigments) [10]. Dyes, natural or synthetic, always react chemically with the correct materials, e.g., textile, they are administered to. Using the correct technique and dyes, it maintains the initial colour from being wiped away [11, 12].
Dyes constities of natural materials are often called natural dyes [10,11]. Historically, people dyed yarn, fabric and even their clothing directly using what the nature or in more specific the environment provide them [13]. This included extract from plants (e.g., fragments dyed red from roots of an old world species of madder (*Rubia tinctoria*), animals (e.g., insects such as Kermes and Cochineal were used to produce shades of red, lichens, and even from shellfish which the Murex created Tyrian purple, the world's most expensive dye.) and minerals (the dyes obtained from natural earth pigments which already been used since ancient times [16], which achieved their tinctorial properties due to the presence of oxides or the hydrated oxids of manganese, with example of mineral dyes are chrome yellow, iron buff, Prussian blue, nankin yellow and manganese brown etc.) [14-16]. The effort to produce natural dyes is very hard because time consuming, costly and need specific handling [17-20].

Nowaday, almost all available dyes in the popular market which used to colour clothing are artificial or synthetic [21]. Artificial/synthetic dyes are widely applicable because it offer some positive aspects, including (1) assemble interesting colours, (2) light-resistant, in condition which the dyes do not fade easily in or under bright light (3) economically and technologically inexpensive to produce- compared to natural dyes, (4) the textile able to retain its original colour and will not wash out, (5) can colour synthetic fabrics like polyester and nylon, unlike natural dyes which limited in their application. The use of heavy metals such as cadmium, mercury, lead, chromium and arsenic are necessary in the production of textile dyes, but their colored effluents are toxic and can damage cells. It is also responsible for causing permanent problem with human's immune systems and various diseases including kidney disease and cancer [22-23].

Due to those issues, scientists began to develop new method of producing dyes which is safer for the human health. A new and unusual source of dyes is bacteria which is engineered biotechnologically and this become the aim of this simple mini-review.

2. APPLICATION OF BACTERIA FOR DYEING TEXTILE

Most living organisms actually contain certain cells that can produce specific colour or pigments, e.g, melanin in human [23]. Beside contributes for colour, melanin also acts as photo-protector, e.g., epidermal melanin or retinal melanin protects its host from harmful UV radiation [24]. In a lower level organisms, microorganism such as bacteria able to generate sufficient substance which act like pigments that can facilitate its survivability [25]. The pigments of bacteria facilitate its existence in the nature, even in harsh and dangerous environments marked with minimum food source [26], extreme temperatures [27], unstable pH [28] and radiation levels [29]. The benefit of using bacterial pigment as textile dyeing: (1) brilliant color, (2) can be applied to many types of fabrics, (3) non-toxic, (4) eco-friendly, (5) high values product, (6) additional functionalities, (7) has anti-microbial, anti-cancer, anti-oxidative properties and so on.

Synthetic derivatives are currently used instead of pigments in many applicative fields, from food to feed, from pharmaceutical to diagnostic, from agronomy to industry [30]. Progress in organic chemistry allowed to obtain rather cheap compounds covering the whole color spectrum [25,30].

Table 1. List of some pigments produced by bacteria

Pigment	colour	Species	Properties	Habitat	Role in bacteria	Miscelaneous
Violacein	Blue-purple	*Chromobacterium violaceum*	Gram-negative β-proteobacteria	Freshwater and marine habitats	Defending against other microorganisms	It was used to dye fibrous materials and nylon cloth after being manufactured by culturing Chromobacterium and Janthinobacterium in a specific media [31].
Violacein	Dark Violet	*Janthinobacterium lividum*	Gram-negative bacteria	various environments, including Antarctica	As an antioxidant, and also has anti-fungal and anti-bacterial effects.	tinting and produced excellent color tone on silk, cotton, wool, nylon, and vinylon. J. lividum cultures can be successfully used for violacein production and for simultaneous dying of fabrics resulting in dyed fabrics with antimicrobial properties without utilization of organic solvents [32].
Indigoidine	Blue-green	*Streptomyces aureofaciens*	Gram-positive, filamentous, spore-forming bacteria that are members of the phylum Actinobacteria	present in almost all environments from deep sea to high mountains	/	Great reproductive capacity, eco-friendly, biotechnologically valuable, producing specialized metabolites with a broad spectrum of bioactivities, such as antioxidant, anticancer, antibiofilm, antifouling, and antibiotic activities, as well as pigments, among others [33].
Carotenoids	Yellow & orange	*Serratia marcescens*	an opportunistic, gram negative, nosocomial pathogen which belongs to family, Enterobacteriaceae	Soil and water	Surviving in areas with high levels of radiation	The pigment was largely effectual and exhibited utmost zones of inhibition, thus demonstrating the finest antimicrobial effect against the microbes tested. The textile yarn materials soaked with this intrinsic dye pigment also exhibited antimicrobial action [34].
Prodigiosin	Red	*Serratia marcescens,*	an opportunistic, gram negative,	Soil, human digestive	Defending against other bacteria	Prodigiosin could be better used to dye acrylic;

Pigment	colour	Species	Properties	Habitat	Role in bacteria	Miscelaneous
		The marine Serratia rubidaea	nosocomial pathogen which belongs to family, Enterobacteriaceae	system, sea		Dyed cotton possesses good rubbing, washing and perspiration color fastness. Prodigiosins endow dyed cotton with antibacterial property against S. aureus and *E. coli* [35].
Prodigiosin	Red	*Streptomyces coelicolor (Actinobacteria)*	Gram-positive microorganism often used as a model of physiological and morphological differentiation in streptomycetes	Soil	Defending against other bacteria, helping cells use iron	Applied as antibacterial silk dyeing [36].
Pyocyanin	Greenish-blue	*Streptomyces coelicolor* (Actinobacteria)	Gram-positive microorganism often used as a model of physiological and morphological differentiation in streptomycetes	Soil	Defending against other bacteria, helping cells use iron	Used by designer named Chieza NA [37].
Pyocyanin	Greenish-blue	*Pseudomonas aeruginosa*	a gram-negative, aerobic, non-spore forming rod	Inside plants and animals	Helping cells use iron, changing to reddish-pink at lower pH levels	Antibacterial, antioxidant, and anticancer properties [38].

3. BASIC STEPS OF BACTERIAL DYEING

The application of bacterial dyes in textiles has been brought to massive commercial industry scale [39]. It has revolutionized the fashion industry with eco-friendly issue and even health related antibacterial product of garment [39-41]. These natural pigments offer good aspiration to better humanity for restoring the contamination that conventional toxic dyes have done to the environment, including affect human health [42].
In the past years, Biotechnology has again delivered us a golden solution to bring life to the dryland, dead waters pollution and so on [43-44]. Biotechnology has change the world for good and even further, including how Biotech textile labs are changing the fashion business forever, and along comes the bright prospective of applying Bacterial textile dyeing [45-46].

Basic steps of bacterial dyeing are as follows:

1. choose specific strain of bacteria that produce specific pigment and augment its number massively,
2. carefully sterilize the chosen fabric in certain temperature oven to discard of potential contaminant from unwanted bacteria,
3. Bacteria addition with its nutrition media to produce best colour,
4. Grow more bacteria on fabric to induce more production fo pigment,
5. Sterilization to kill bacteria.

The advantage with this “live dyeing” approach is that in each batch of fabric is distinctive and unique [37]. Their patterns cogitate on how the bacterial colonies grow on selective or non-selective condition [47]. The other advantage of live dyeing is that the fabric does not need any harmful chemicals or pre-treating [48]. In addition to the previously mentioned advantages, It is also water-saver and energy-saver because it happens to uses only a small amount of water and energy [49,50]. Dyeing with bacteria basically is a fermentation [35, 46] refine where chosen bacteria metabolise a nutrient and produce their own unique pigment [51-54]. The dyeing process is artisanal. They cultivate the bacteria directly onto the textiles [49,51,52], leaving visible growth patterns that create a new and unique aesthetic with unique one-of-a-kind print, no dyeing achieve is the same.

Up to the present, this approach of live dyeing has only been used in laboratories scale [51]. Concern related to health issues, especially with the handling of bacteria, still prevent the wider application of this technique [52]. Live dyeing also needs to be done carefully and as *lege artis* as possible in a way that does not unintentionally bring in other types of unwanted microorganisms onto the fabric [53]. It would be challenging to use this method on a larger and bigger scale.

In spite of the previously mention concern, the future of bacterial dyeing is promising, with increasing market value and with additional health and sociological benefit. A number of companies are getting involved in genetically engineering bacteria to produce pigments, e.g. Algalife, Ginkgo Bioworks and Colorifix.

As the world becomes more aware and concern about ecology and sustainability, the future of dyes and pigments may come from this microscopic but vigorous bacteria. With the help of new and trustful biotechnology engineering, improvement in dyeing fabrics and textile using live cell can be optimalized into large industrial scale.

4. CONCLUSION

In conventional dyes, harsh chemicals, heavy metals and salts are used to fix the colour in the textile fibre. This bring consequences to the health status of textile industry worker and also pollution to the environment. Biotechnology offers alternative approach to produce colour by dyeing clothes with genetically engineered bacteria is the most recent achievement in textile and fabrics industry. This approach is promising, but still needs a lot of effort from all stakeholder to push it from only laboratory scale onto a more massive industrial scale.

CONSENT (WHERE EVER APPLICABLE)

Not needed

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

Not needed

REFERENCES

CHANGE REFERENCES FOLLOW THE RULES OF JOURNAL

1. Kumar B, Somkuwar V. (2021). Introductory Chapter: Functional Textiles. https://doi.org/10.5772/intechopen.100212.
2. Saeed M, Lakhan AB, Keeryo ZA. (2022). An Analysis of Workplace Attire and Employees Performance by Mediating Role of Organizational Identification and Self Esteem. Research Journal for Societal Issues. 2022;4: 176-189. https://doi.org/10.56976/rjsi.v4i1.41
3. Jain M. Effect of Minimalistic Clothing Style on Self-Esteem among Young Adults. International Journal of Research Publication and Reviews, 2022;3(12):1039-1043
4. Wenderski M, Jung J, Wasilewski J. (2024). The use of clothing as a mood enhancer and its effect on mental health in emerging adults in Canada during a global pandemic. Conference: Bridging the Divide. https://doi.org/10.31274/itaa.17340.
5. Sulthana RS. Influence Of Fashion And Textiles On Mental Health. Journal Of Positive School Psychology. 2022; 6(9): 5003-8
6. Singha K, Maity S, Pandit P, Mondal Md.IH. 1 - Introduction to protective textiles. Ed(s): Md. Ibrahim H. Mondal, In The Textile Institute Book Series, Protective Textiles from Natural Resources, Woodhead Publishing, 2022, pp 3-38, ISBN 9780323904773, https://doi.org/10.1016/B978-0-323-90477-3.00023-7.
7. Gavin TP. Clothing and thermoregulation during exercise. Sports Med. 2003;33(13):941-7. https://doi.org/10.2165/00007256-200333130-00001.
8. Matusiak M. Interaction between the human body and textiles. International cotton conference. Bremen 2021. https://baumwollboerse.de/wp-content/uploads/vortraege/CCB_2021-Poster-Matusiak.pdf
9. Hameed U. (2023). Evolution of clothes. https://doi.org/10.13140/RG.2.2.22602.75200.
10. Nassar GE, Mohammed NS, Nawar SH, Etawy MS, Hassabo AG. Importance of Colours in Industrial Design. J. Text. Color. Polym. Sci., 2024; 21 (2):231-40
11. Shang SM. 13 - Process control in dyeing of textiles. Ed(s): Majumdar A, Das A, Alagirusamy R, Kothari VK. In Woodhead Publishing Series in Textiles, Process Control in Textile Manufacturing, Woodhead Publishing, 2013, pp 300-38, ISBN 9780857090270, https://doi.org/10.1533/9780857095633.3.300.
12. Islam MT, Islam T, Islam T, Repon MR. Synthetic Dyes for Textile Colouration: Process, Factors and Environmental Impact. Textile & Leather Review. 2022; 5:327-373. https://doi.org/10.31881/TLR.2022.27
13. Ferreira E, Hulme A , McNab H, Quye A. The Natural Constituents of Historical Textile Dyes. Chemical Society reviews. 2004; 33. 329-36. https://doi.org/10.1039/b305697j.
14. Potts D. On the history of madder (Rubia peregrina L., and Rubia tinctorum L.) in pre-modern Iran and the Caucasus. Asiatische Studien - Études Asiatiques. 2022; 76. https://doi.org/10.1515/asia-2021-0039.
15. Alaskar A, Hassabo AG.Recent Use of Natural Animal Dyes in Various Field. J. Text. Color. Polym. Sci., 2021; 18 (2):191-210. https://doi.org/10.21608/jtcps.2021.79791.1067
16. Garofano I, Duran A, Pérez-Rodríguez J, Robador M. Natural Earth Pigments From Roman and Arabic Wall Paintings Revealed by Spectroscopic Techniques. Spectroscopy Letters. 2011;44: 560-5. https://doi.org/10.1080/00387010.2011.610655.
17. Mozaffari E. Alum Mineral and the Importance for Textile Dyeing. Current Trends in Fashion Technology & Textile Engineering. 2018;3. https://doi.org/10.19080/CTFTTE.2018.03.555619.
18. Islam T, Md. Rashedul Islam K, Hossain S, Abdul Jalil M, Mahbubul Bashar M. Understanding the Fastness Issues of Natural Dyes [Internet]. Dye Chemistry - Exploring Colour From Nature to Lab [Working Title]. IntechOpen; 2024. Available from: http://dx.doi.org/10.5772/intechopen.1005363
19. Yadav S, Tiwari KS, Gupta C, Tiwari MK, Khan A, Sonkar SP (eds). A brief review on natural dyes, pigments: Recent advances and future perspectives. In books Results in Chemistry,Volume 5, 2023, 100733, ISSN 2211-7156, https://doi.org/10.1016/j.rechem.2022.100733.

20. Pizzicato B, Pacifico S, Cayuela D, Mijas G, Riba-Moliner M. Advancements in Sustainable Natural Dyes for Textile Applications: A Review. Molecules. 2023; 28. 5954. https://doi.org/10.3390/molecules28165954.
21. Mabuza L, Sonnenberg N, Marx-Pienaar N. Natural versus synthetic dyes: Consumers' understanding of apparel coloration and their willingness to adopt sustainable alternatives. Resources, Conservation & Recycling Advances, 2023; 18: 200146. https://doi.org/10.1016/j.rcradv.2023.200146.
22. Singha K, Pandit P, Maity S, Sharma S. (2021). Harmful environmental effects for textile chemical dyeing practice. https://doi.org/10.1016/B978-0-323-85204-3.00005-1.
23. Ali SA, Naaz I. Biochemical aspects of mammalian melanocytes and the emerging role of melanocyte stem cells in dermatological therapies. Int J Health Sci (Qassim). 2018 Jan-Feb;12(1):69-76.
24. Solano F. Photoprotection and Skin Pigmentation: Melanin-Related Molecules and Some Other New Agents Obtained from Natural Sources. Molecules. 2020; 25(7):1537. https://doi.org/10.3390/molecules25071537
25. El-Naggar NE-A, Saber WIA. Natural Melanin: Current Trends, and Future Approaches, with Especial Reference to Microbial Source. Polymers. 2022; 14(7):1339. https://doi.org/10.3390/polym14071339
26. Tsouko E, Tolia E, Sarris D. Microbial Melanin: Renewable Feedstock and Emerging Applications in Food-Related Systems. Sustainability. 2023; 15(9):7516. https://doi.org/10.3390/su15097516
27. Yang X, Chen Y, Zhang L. Melanin precursors mediated adaption to temperature changes in fungus and animal via inhibition of lipid-mediated ferroptosis. Sci. China Life Sci. 2023; 66, 1800–17. https://doi.org/10.1007/s11427-022-2265-6
28. Kim H, Lee UJ, Song H, Lee J, Song WS, Noh H, Kang MH, Kim BS, Park J, Hwang N, Kim BG. Synthesis of soluble melanin nanoparticles under acidic conditions using Burkholderia cepacia tyrosinase and their characterization. RSC Advances. 2022; 12. 17434-17442. https://doi.org/10.1039/D2RA01276F.
29. Cordero RJB, Vij R, Casadevall A. Microbial melanins for radioprotection and bioremediation. Microb Biotechnol. 2017 Sep;10(5):1186-1190. https://doi.org/10.1111/1751-7915.12807.
30. Orlandi VT, Martegani E, Giaroni C, Baj A, Bolognese F. Bacterial pigments: A colorful palette reservoir for biotechnological applications. Biotechnol Appl Biochem. 2022 Jun;69(3):981-1001. https://doi.org/10.1002/bab.2170.
31. Ahmed A, Ahmad A, Li R, Al-Ansi W, Fatima M, Mushtaq BS, Basharat S, Li Y, Bai Z. Recent Advances in Synthetic, Industrial and Biological Applications of Violacein and Its Heterologous Production. J Microbiol Biotechnol. 2021 Nov 28;31(11):1465-1480. https://doi.org/10.4014/jmb.2107.07045.
32. Kanelli M, Mandic M, Kalakona M, Vasilakos S, Kekos D, Nikodinovic-Runic J, Topakas E. Microbial Production of Violacein and Process Optimization for Dyeing Polyamide Fabrics With Acquired Antimicrobial Properties. Front Microbiol. 2018 Jul 10;9:1495. https://doi.org/10.3389/fmicb.2018.01495.
33. Sarmiento-Tovar AA, Silva L, Sánchez-Suárez J, Diaz L. Streptomyces-Derived Bioactive Pigments: Ecofriendly Source of Bioactive Compounds. Coatings. 2022; 12(12):1858. https://doi.org/10.3390/coatings12121858
34. Venil CK, Dufossé L, Velmurugan P, Malathi M, Lakshmanaperumalsamy P. Extraction and Application of Pigment from Serratia marcescens SB08, an Insect Enteric Gut Bacterium, for Textile Dyeing. Textiles. 2021; 1(1):21-36. https://doi.org/10.3390/textiles1010003
35. Ren Y, Gong J, Fu R, Li Z, Li Q, Zhang J, Yu Z, Cheng X. Dyeing and antibacterial properties of cotton dyed with prodigiosins nanomicelles produced by microbial fermentation. Dyes and Pigments. 2016;138. https://doi.org/10.1016/j.dyepig.2016.11.043.
36. Nuanjohn T, Suphrom N, Nakaew N, Pathom-Aree W, Pensupa N, Siangsuepchart A, Dell B, Jumpathong J. Actinomycins from Soil-Inhabiting Streptomyces as Sources of Antibacterial Pigments for Silk Dyeing. Molecules. 2023 Aug 8;28(16):5949. https://doi.org/10.3390/molecules28165949.
37. Chimileski S. Bacterial Dyes in Fashion. Nov. 4, 2017. https://asm.org/articles/2017/november/bacterial-dyes-in-fashion
38. Abdelaziz AA, Kamer AMA, Al-Monofy KB, Al-Madboly LA. Pseudomonas aeruginosa's greenish-blue pigment pyocyanin: its production and biological activities. Microb Cell Fact. 2023 Jun 8;22(1):110. https://doi.org/10.1186/s12934-023-02122-1.
39. Rather L, Mir S, Ali S, Salam S, Li Q. Research progress, challenges, and perspectives in microbial pigment production for industrial applications - A review. Dyes and Pigments.2022; 210. 110989. https://doi.org/10.1016/j.dyepig.2022.110989.
40. Waktola G. Industrial Application of Bacterial Pigments. J Appl Microb Res. 2023;6 (2):01-04.
41. Syaifudin A, Sutrisno S. Antibacterial Activity and Potential Of Natural Textile Dyes From Sea Water Bacteria. Al-Hayat: Journal of Biology and Applied Biology, 2022; 5(1), 33-46. https://doi.org/10.21580/ah.v5i1.13446

42. Lellis B, Fávaro-Polonio C, Pamphile J, Polonio J. Effects of textile dyes on health and the environment and bioremediation potential of living organisms. Biotechnology Research and Innovation. 2019; 3. https://doi.org/10.1016/j.biori.2019.09.001.
43. Maestre FT, Solé R, Singh BK. Microbial biotechnology as a tool to restore degraded drylands. Microb Biotechnol. 2017 Sep;10(5):1250-1253. https://doi.org/10.1111/1751-7915.12832.
44. Rout AK, Dey S, Parida P, Bhattacharya M, Pradhan S, Behera B.(2022). Role of Modern Biotechnology in the Era of River Water Pollution. https://doi.org/10.1007/978-3-030-83553-8_4.
45. Radhakrishnan S, Radhakrishnan S. (2019). Application of Biotechnology in the Processing of Textile Fabrics. In Muthu SS (ed.), Roadmap to Sustainable Textiles and Clothing, Textile Science and Clothing Technology, https://doi.org/10.1007/978-981-287-065-0_9,
46. Sarkar S, Saha P, Sultana N, Akter S. Exploring Textile Dye from Microorganisms, an n-friendly Alternative. Microbiology Research Journal International. 2017;18: 1-9. https://doi.org/10.9734/MRJI/2017/29861.
47. Bonnet M, Lagier JC, Raoult D, Khelaifia S. Bacterial culture through selective and non-selective conditions: the evolution of culture media in clinical microbiology. New Microbes New Infect. 2019 Nov 30;34:100622. https://doi.org/10.1016/j.nmni.2019.100622.
48. Mouro C, Gomes AP, Costa RV, Moghtader F, Gouveia IC. The Sustainable Bioactive Dyeing of Textiles: A Novel Strategy Using Bacterial Pigments, Natural Antibacterial Ingredients, and Deep Eutectic Solvents. Gels. 2023; 9(10):800. https://doi.org/10.3390/gels9100800
49. Walker KT, Li IS, Keane J. Self-pigmenting textiles grown from cellulose-producing bacteria with engineered tyrosinase expression. Nat Biotechnol, 2024. https://doi.org/10.1038/s41587-024-02194-3
50. Barletta I, van der Kraan M, Kronholm J. (2017) Climate implications of waterfree dyeing of biofibers (ClimaDYE). https://publications.lib.chalmers.se/records/fulltext/254430/local_254430.pdf
51. Banchero M, Sicardi S, Ferri A, Manna L. Supercritical Dyeing of Textiles -- From the Laboratory Apparatus to the Pilot Plant. Textile Research Journal - TEXT RES J. 2008;78. 217-223. https://doi.org/10.1177/0040517507081297.
52. Aouf RS. Colorifix harnesses bacteria for non-toxic clothes dyeing. 24 November 2023. https://www.dezeen.com/2023/11/24/colorifix-harnesses-bacteria-non-toxic-dyeing-clothes/
53. Steiner H. Dyeing Textiles with Bacteria: Making LB-Agar Plates. https://www.opencell.bio/news/dyeing-textiles
54. Padden A, Dillon V, John P, Edmonds J, Collins M, Alvarez N. Clostridium used in mediaeval dyeing. Nature, 1998; 396. https://doi.org/225. 10.1038/24290.
55. Choudhury AKR. Eco-friendly dyes and dyeing. Adv Mat Tech Env: 2018: 2(1):145-176
56. Kramar A , Kostic M. Bacterial Secondary Metabolites as Biopigments for Textile Dyeing. Textiles. 2022;2. https://doi.org/10.3390/textiles2020013.