Chapter

Functional Properties of Natural Dyed Textiles

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Abstract

Recently, due to harmful effect of climate change and other environmental concerns, the interest towards natural dyes has gained momentum. Presently in this high technological era, only aesthetic appeal of natural dyes could not get full attention of consumers. A consumer is attracted towards a type of product which is not only aesthetic but also have some functional properties. Hence considering this functional aspect, various researches are being carried out to find out the new dimensions of natural dyes. Colours and other functional properties can be achieved by various synthetic agents, but the exploration of new functional properties of natural dyes would be beneficial and relevant for the present as well as for the future. This chapter compiles all functional aspects of natural dyes which are related to adding functional properties such as antimicrobial, UV protection, insect repellent, etc. to textiles which can protect the human being from various kinds of harmful effects of surroundings such as UV radiation, microbes, bacteria and other harmful insects. This chapter will not only deal with available methods for analysis of these functional properties of natural dyes but also explore the reason for functional properties of natural dyes.

Keywords: functional properties, natural dyes, UV protection textiles, antimicrobial property

1. Introduction

Natural dyes are obtained from different natural sources such as plants, insects, animals and minerals. These are used for coloration of textiles and food since ancient time [1–3]. With the advent of synthetic dyes, natural dyes had been subdued for a while. Recently environmental consciousness of consumer increases due to several harmful impacts of synthetic dyes; thus, interest towards natural dyes has again gained momentum [4, 5]. Natural dyes are biodegradable as well as nontoxic. These dyes are safer for environment in terms of safe discharge [6]. In this era of climate change and different lifestyle of human being, the environment around human being becomes more harmful than the previous era. Microbes, moth insects and UV rays are causing various kinds of harmful effects to human being [7–9]. Presently the human does not wear clothes only for modesty. Hygiene, cleanliness and protection become major issues, and thus the demand for functional clothes has also increased. Textile fabric majorly covers the human skin, creating a microclimate. Presently as the climate changes, the requirement for functional clothing arises. Besides providing colour, natural dyes have inherent functional properties such as resistance for bacteria, fungus and moth, UV protection, etc. [10–12]. Fabric as a second skin covers the major part of the body and hence can be used as a preventive measure from near environment. At present, the researches on utilisation of natural dyes in functional finishing of textiles have increased because of the efficiency of natural dyes which provides protection against various harmful agents as well as provides greater comfort. Dyed fabric remains fresh and odour-free in use [13, 14]. Natural dyes obtained from traditional dyes giving plants contain a variety of compounds such as curcumin, crocin, bixin, carthamin, punicalagin, nimbin, etc. known to have therapeutic properties [15]. Many plants contain secondary antimicrobial which gives protection against microbial attack.

Applications of natural dyed textile can be extended to a diverse field such as sportswear and medicinal field due to its various functional properties such as antimicrobial as well as UV protection [16–18].

2. Functional properties of natural dyed textiles

Natural dyes having functional groups such as $-OH$, $-NH_2$, $-COOH$, etc. groups and the textile fibres with active sites ($-OH$, $-SO_3H$, $-COOH$, $-C_6H_5OH$, $-NH_2$) can make a complex with or without mordant. Because of the different interactions of dye and fabric, many functional properties with fastness can be achieved [19]. Besides functional group of natural dye such as tannins, flavonoids, anthraquinone, etc., functional groups of respective fabrics are also responsible for functional properties in the fabric [20]. The following functional properties are obtained through natural dyeing of textiles.

2.1 Antimicrobial/antibacterial property

The surrounding of human includes a variety of microorganisms like bacteria and other microbes, which are invisible for the naked eyes. Bacterium is a unicellular organism. It is divided in Gram-positive (*Staphylococcus aureus*) and Gram-negative (*E. coli*) on the basis of chemical and physical properties of their cell walls [21]. Examples of common Gram-positive bacteria are *Staphylococcus aureus, Streptococcus epidermidis and Bacillus cereus*, and the examples of Gram-negative bacteria are *Escherichia coli, Klebsiella pneumonia, Shigella flexneri and Proteus vulgaris* [22]. Clothing majorly covers the human skin or nearby area of direct contact from the human skin. Thus the growth of these microorganisms on fabric affects the wearer as clothes on the human body provide a favourable environment for microbial growth; it provides warmth, oxygen and water as well as nutrients from perspiration. Textile fabrics itself can also be affected by the growth of these microorganisms [23]. Cotton is one of the most affected fabrics by these microbes [24]. Naturally dyed textiles can provide protection against these microorganisms. Antimicrobial properties of natural dyes are due to the presence of various compounds such as anthraquinones, flavonoids, tannins, naphthoquinones, etc. [25]. Various antimicrobial agents are present in natural dye for common human pathogen, but very few are reported in the case of textiles with respect to human pathogenic strain, as testing method is different in the case of testing against textiles. Many plants which have been traditionally used for dyeing are also considered having medicinal properties which provide protection against these harmful microorganisms. For instance, natural dye which is obtained from *Punica granatum* peels having hydrolysable tannins exhibited a notable antimicrobial activity when applied on tencel fabric [26]. Henna leaves having lawsone compound were found to be very effective against *Candida glabrata* in solution as well as after application on wool substrate [27]. It is reported that antibacterial and antifungal properties of natural dye are due to its phenolic content. Phenolic compounds attach on the surface of textiles by forming a complex. When the fabric comes in contact with microbes, these attached phenolic compounds hamper the enzyme production in microbes; thus, further cell reaction would not take place, and at the end cell dies. Natural dyes obtained from *M. composita* leaves having alkaloids, are found to be effective against Gram-positive and Gram-negative bacterial strains [28]. Madder (alizarine functional group) and safflower having carthamin with alum, Zn-sulphate and tannic acid also imparted antibacterial properties, to the dyed poly-amide- 6 fabric [29]. *Rumex maritimus (*golden dock*) and Quercus infectoria (indigo) dyes are found to be the most effective against common microbes like Escherichia coli*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Proteus vulgaris* and *Pseudomonas aeruginosa* [12]. Berberine compound as a cationic dye having quaternary ammonium structure can act as an antibacterial agent. The dyed wool represented a high level of antibacterial activity [30]. Application of natural dyes peony, pomegranate, clove, *Coptis chinensis* (Chinese goldthread) and gallnut extracts on cotton silk and wool fabric provides excellent antibacterial activity against *Staphylococcus aureus*. The possible reported reason for antimicrobial activity of natural dyes obtained from pomegranate peels, *Coptis chinensis*, peony and clove is due to ellagic acid, berberine and eugenol, respectively [31] (**Table 1**).

Antimicrobial testing is a valuable aid for textile production, distribution and consumption. To measure the antimicrobial efficacy of natural dyed textiles, test methods are performed under controlled conditions. The antimicrobial activities are generally tested both qualitatively and quantitatively through standard tests. Some of the available and majorly used AATCC standards for textile are as follows:

One prominent quantitative standard for antimicrobial testing of textiles is AATCC 100-2004 (bacterial reduction method) [32]. Under this test, the test microorganism of standardised concentration is grown in liquid culture. This prepared culture is diluted in a sterilised nutritive solution. Control and natural dyed fabric swatches are inoculated with microorganisms. Inoculated control and test fabrics are allowed to incubate for 24 hours at 37°C, in sealed jars. After incubation, shake for 1 minute; then concentrations of microbes are observed. Finally it is calculated how much microorganism reduces as compared to initial concentration.

$$\text{Percent reduction of bacteria } R = 100\ (B - A)/B \tag{1}$$

where A is the number of bacteria recovered from the inoculated treated test specimen swatches in the jar incubated over the desired contact period while B is the number of bacteria recovered from the inoculated treated test specimen swatches in the jar immediately after inoculation (at "0" contact time).

Another standard method for antimicrobial testing of textiles is parallel streak method (AATTC Test Method 147-2004). The agar surface is streaked with an inoculum of test bacterium. The samples treated with natural dye and the undyed sample (control sample) are placed in close contact with this agar surface. This is incubated for 37°C for 18–24 hours.

The following equation is used to calculate the width of a zone of inhibition along a streak on either.

$$W = (T - D)/2 \tag{2}$$

Name of the natural dye	Botanical name	Responsible component for antimicrobial properties
Pomegranate	*Punica granatum*	Tannins
Henna	*Lawsonia inermis*	Lawsone
Neem	*Melia azedarach*	Phenolic compounds and flavonoids
Madder	*Rubia tinctorum*	di- and trihydroxyanthraquinones
Golden dock	*Rumex maritimus*	Tannins
Oak galls	*Quercus infectoria*	Tannins
Peony	*Paeonia officinalis*	Paenol/paenoside/paeonolide/paenoniflorin
Clove	*Syzygium aromaticum*	Eugenol (2-methoxy-4 allyl-phenol)
Goldthread/Canker root/Huang Lian	*Coptis chinensis*	Alkaloid berberine
Turmeric	*Curcuma longa*	Curcumin or diferuloylmethane with chemical formula of (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) and curcuminoids
Safflower	*Carthamus tinctorius*	Flavonoids

Table 1.
Natural dyes with responsible component for antimicrobial properties.

where W is width of clear zone of inhibition in mm, T is total diameter test specimen and clear zone in mm and D is diameter of the test specimen in mm [33].

It has been reported that dyed fabric is able to retain almost half of its initial antibacterial properties after few washings. Application of mordant like tannin or other cross-linking agent such as citric acid or any other surface modifications with cationisation or by applying biopolymer is also responsible for wash stability of functional properties of natural dyed textiles.

2.2 UV protection

Presently as the climate change are showing its harmful effects, the need for protection against UV rays has been increased in order to avoid incidences of UV-induced skin damages. Various sunscreen and synthetic UV absorbers for textile fabric are currently available in the market, but researches are carried out to search out eco-friendly alternative such as natural dyes to enhance the aesthetic as well as UV protection property of the fabric. UV protection properties of dyed fabric is analysed using UPF of the fabric. Ultraviolet protection factor (UPF) indicates the UV protection properties of the fabric.

Application of natural dyes on fabric significantly enhances the UPF of the fabric. UPF of fabric is affected by the absorption characteristics of natural dyes [34]. Tannins in plant act as a chemical protector against the UV radiation [35]. Tannin as a phenolic compound absorbs UV radiation due to resonance in structure and hence after the process of attachment on textile surface. These attached molecules absorb the UV radiation and thus protect the skin from absorbing UV rays. Tannin-based natural dyes such as *R. maritimus, M. philippinensis, K. lacca, A. catechu and A. nilotica* have good UV protection properties [36].

Various kinds of natural dyes provide protection against microbes as well as UV rays on different kinds of fabric such as wool, cotton and silk. Natural dyes from eucalyptus leaf extract with ferrous sulphate mordant can provide UV protection properties with antimicrobial properties to the dyed silk fabric [37]. The cotton fabric is dyed with ***Xylocarpus granatum*** (*cedar mangrove*) bark extract. In this experiment, the UPF values of all dyed samples were achieved above the range of 50. It was also reported that it is only possible because of the use of metal mordants as it helped in the formation of tannate complex [38]. Woollen fabric dyed with the blossoms of broom (***Cytisus scoparius***) and dandelion (***Taraxacum officinale***) also provides effective UV protection [39]. *Flos Caryophyllata (clove)* and *acutissima* shell with $FeSO_4$ mordant provide anti-UV properties to the silk fabric and thus the wearer [40]. Weld, woad, logwood lipstick tree, madder, brazilwood and cochineal as natural dyes could provide good UV protection on hemp and flax fabric [41]. Cotton and silk fabrics dyed with gromwell roots absorb most of the UV rays [42]. Cationised cotton fabric dyed with henna dye extract exhibited outstanding enhancement in UV protection [43]. Dyeing of polyester fabric with chitosan and turmeric dye enhances the UPF of the fabric [44]. It was reported in a study that simultaneous dyeing and finishing of silk and wool fabrics with the use of cochineal and weld natural extracts enhanced the UPF and fastness of the fabric. As a result, excellent UPF range with high fastness was obtained [45]. Application of gallnuts, areca nuts and pomegranate peels dyed on silk fabric imparted the UV protection with deodorization and antimicrobial properties [46]. Antibacterial and UV protection properties were also obtained by cotton fabric dyed with banana peel [47]. Mordant with natural dyes such as cutch and madder also positively affects the UPF of the cellulosic nettle fabric. In several cases, the use of mordant improves the UPF value, whereas in most of the cases, mordant lowers the UPF value in comparison to blank [48]. Addition of mordant lowers the UPF value severely. This was most likely due to the complex formation ability of dye. Due to coordination bond formation between the dye and mordant, the structure of the dye changes and so does its light absorption properties. The absorption shifts to higher wavelengths of visible region, thus giving deeper colour but less UPF [49]. Very good UPF values were obtained when the pre-mordanting of jute fabric was done before the actual dyeing with *babool*, *ratanjot*, annatto and *manjistha.* Both bio and chemical mordant were used for this [50]. Chitosan mordanting of green tea dyed cotton fabrics enhanced the UV protection property [51]. Ferrous sulphate as a mordant establishes ternary complex with both fibre and the dye, and the remaining coordination sites of Fe metal can absorb UV radiation by converting electronic excitation energy into thermal energy [47]. Although natural dyes improve the UV protection properties of the textiles, some limitations are associated with it. For example, the amount of UV protection of dyed fabrics also tends to decrease due to exposure to sunlight as well as in laundry process. Therefore, there is a need to do research with the aim of enhancing the durability of natural dye. Traditionally mordants have been used since a long time to improve the stability and durability of natural dyes, but presently various kinds of surface modification techniques are being used to enhance the durability [52] (**Table 2**).

Standard testing of specific functional property helps to maintain a quality of textile products [53]. (AATCC-183: 2004) test method is used for analysis of UPF [54]. UPF of the treated fabric samples was determined by using “Lab-sphere’s UV transmittance analyser”. This method is used to determine the UV radiation blocked and transmitted by the textile fabric. The UPF is computed as the ratio of the erythemally weighted ultraviolet radiation (UV-R) irradiance at the detector with no specimen to the erythemally weighted UV-R irradiance at the detector with a specimen present. The formula which is used for calculation of UPF is as follows:

$$UPF = \frac{\Sigma E_\lambda \times S_\lambda \times \Delta\lambda}{\Sigma E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda} \qquad (3)$$

Name of the natural dye/mordant used	Botanical name	Main component for UV protection properties	Fabric	UPF range
Jamun leaves	*Syzygium cumini*	Flavonoids catechin	Cotton	Excellent
Eucalyptus	*Flavonoid*	Tannin	Cotton, wool	Excellent
Madder	*Rubia cordifolia*	Anthraquinone	Cotton, Himalayan nettle	Very good
Cutch	*Acacia catechu*	Catechin (condensed tannin)	Cotton, Himalayan nettle	Excellent
Pomegranate peels	*Punica granatum*	Tannin	Cotton	Excellent
Banana peels	*Musa paradisiaca*	Luteolin	Giza cotton	Excellent

Table 2.
Natural dyes with responsible component for UV protection properties.

UPF rating	UV-R protection	Effective UV-R transmission (%)	UPF labelling
15–24	Good protection	6.7–4.2	15, 20
25–39	Very good protection	4.1–2.6	25, 30, 35
40–50, 50+	Excellent protection	≤2.5	40, 45, 50, 50

Table 3.
UPF classification system (AS/NZS 4399:1996) [55].

where
$E_{\lambda} =$ relative erythemal spectral effectiveness.
$S_{\lambda} =$ solar spectral irradiance.
T_{λ} = average spectral transmittance of the specimen (measured).
$\Delta\lambda$ = measured wavelength interval (nm).

The UV protection category was determined by the UPF values described by the Australian Standards/New Zealand AS/NZS 4399 (1996) given in **Table 3**.

2.3 Deodorising

Odour in textiles is caused by bacterial colonies due to favourable conditions such as perspiration [56]. Various studies reported about the deodorising performance of natural colourants. A study in the deodorising efficiency of gardenia, *Cassia tora* L., coffee sludge and pomegranate rind dyed fabric was observed. Maximum deodorising capacity was found in pomegranate followed by *coffee sludge (Coffea arabica), Cassia tora* and gardenia [57].

Natural dyeing of cotton, wool and silk fabric using gallnut also provides a better deodorising function against ammonia, trimethylamine and acetaldehyde and showed bacterial resistance against *Staphylococcus aureus* and *Klebsiella pneumonia*. The main component in the gallnut extract was found to be gallotannin which is the reason for these functional properties [58].

Natural dyeing of cellulosic and silk fabric with peony, clove and pomegranate (*Punica granatum*) also provides deodorising functionalization [59].

Application of fresh dye of indigo plant provided antimicrobial, sterilising or deodorising effect and treatment effect of atopic dermatitis [60].

Gas detecting tube method was used for deodorising test. It measures the concentration of ammonia gas. Natural dyed fabric is placed in the tube and the concentration of ammonia is observed. The reduction in concentration of ammonia signifies the deodorising capacity of dyed fabric. In blank (reference) tube, the concentration of ammonia is about 500 ppm.

The deodorising capacity of the dyed fabric is calculated using the following formulae:

$$\text{Deodorization performance } (\%) = (\text{Cb} - \text{Cs})/\text{Cb} \times 100 \quad (4)$$

where Cb is the gas concentration (ppm) of test tube without fabric (blank state) and Cs is the concentration of tube with fabrics [61].

2.4 Moth proof and insect repellent

Moth larvae which usually remain concealed cause the great losses to woollen textiles [62]. It has been estimated that 92.5 pounds wool fibre are eaten in 1 year due to the presence of protein in the wool [63]. Various product ranges such as carpet, blanket, namda (felted carpet), shawl and knit wears are majorly produced using wool fibre. Woollen carpet and handicraft play a major role in Indian export [64]. Dark humid conditions with 25–35° temperature are favourable conditions for moth larvae attack. Clothes moth (*Tineola bisselliella*) and carpet beetle (*Anthrenus verbasci*) are distributed in all the areas. Anti-moth finishing agents are DDT, permethrin, permethrin/hexahydro-pyrimidine derivative, cyhalothrin, etc. Some of these chemicals have been banned, while permethrin pyrimidine chlorine-based compounds are used widely as an anti-moth finishing agent for textiles, but these are becoming less effective on beetle larvae. The demand for replacing the permethrin and other synthetic anti-moth agent is increasing due to ecotoxicity of these anti-moth agents. The demand for natural anti-moth agent is increased due to eco-consciousness of consumers. In the case of natural dyes, its chemical structure also plays an important role in determining the anti-moth properties. Very few info are available for natural dyed anti-moth properties. Saffron flower waste, onion skin, henna, myrobolan, silver oak leaf, madder, wall nut, dholkanali and yellow roots were observed to impart anti-moth properties to wool, depending on the amount of tannin in their chemical composition. Natural dyes having higher amount of tannin repel the moths more effectively. In various experiments it has been reported that the natural dye having more than about 40% tannin is effective as an anti-moth agent, for instance, the dye extracted from silver oak, walnut husk and pomegranate rind having 47.87, 44.31 and 45.23% tannin, respectively, works as effective anti-moth agent [65].

For testing anti-moth properties, natural dyed and undyed woollen fabric samples were kept in petri dishes. Ten alive carpet beetles were put on each petri dish. Petri dish were kept in incubator (time: 15 days, temp: 30–35, RH 50–60%). Weight loss of the fabric due to moth attack is observed. Visual examination of the damaged fabric and number of alive moths were also done. For the comparative analysis, Eulon (a synthetic anti-moth) is also used [66].

2.5 Mosquito repellent

Dangerous diseases due to mosquito bite like dengue, malaria and chikungunya hit over 1.13 million people in the country last year [67]. Global warming also increases the growth of mosquitoes and thus the growth in disease like malaria, yellow fever and dengue fever [68]. Pomegranate peel dyed cotton fabric using different conc. of polyvinyl alcohol provides 80 percent mosquito repellency [69].

Mosquito repellency test is performed using a prepared cage of 40 cm × 40 cm. Fifty mosquitos are collected. Perforated transparent plastic is used to cover two opposite sides, while the other side of the cage is covered with carton [70].

3. Chemical compound structure and related functional properties of natural dyes

Indigoid, pyridine, carotenoid, quinonoid, flavonoids, betalains, anthocyanin, anthraquinone and tannins are the major chemical compounds found in natural dyes. These chemical structures are also one basis for the classification of natural dyes [3]. These functional groups provide a specific functional property to the textiles.

3.1 Indigoid

The colouring matter in indigo plant leaves is a light yellow substance called indican (1H-indol-3yl b-D-glucoside) (**Figure 1**) [71]. Natural indigoid dyes are mainly obtained from woad (*Isatis tinctoria L. Brassicaceae*, also known as dyer's woad) and the indigo plant (*Indigofera tinctoria L*) in temperate climates [72].

The cotton fabric dyed with fermented indigo leaves exhibited excellent UV protection as well as antimicrobial activity against *Staphylococcus aureus*. But dyed sample was observed to be relatively inactive against *Klebsiella pneumonia*, while in the case of application of silk the negligible protection was observed. Deodorisation capacity of these dyed fabrics was found to be low [73]. Indigo dyed samples with ferrous sulphate as a metal mordant were observed to fall under good UV protection category [74].

3.2 Anthraquinone

These dyes have anthraquinone (**Figure 2**) as a main colouring agent. These are generally in red colour also called mordant dyes. Madder, lacs, kermes and cochineal natural dyes have anthraquinone chemical structure [75].

The madder dye having anthraquinone structure improved both the UV protection performance and the antibacterial activity (against *Staphylococcus aureus* (*S. aureus*) and *Escherichia coli* (*E. coli*)) of the PET fabric. UV protection factor increased up to 106 and antibacterial activity up to 86% against both types of bacteria tested [76]. Excellent UV protection properties were achieved with the application of cochineal dye on silk and wool fabrics [45].

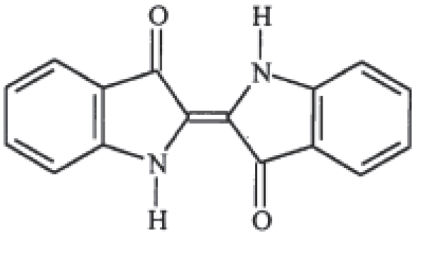

Figure 1.
Indigo.

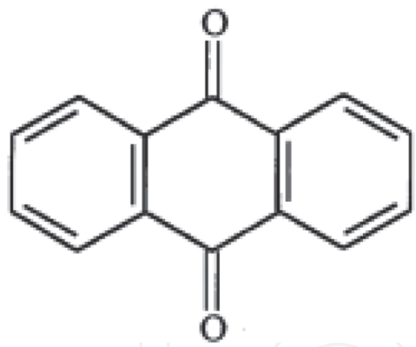

Figure 2.
Anthraquinone.

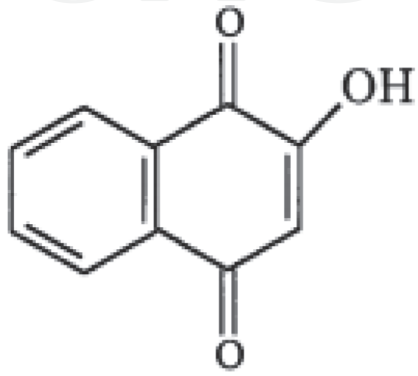

Figure 3.
Alpha naphthoquinone.

The ultraviolet protection factor (UPF) values of lac (having anthraquinone structure) dyed silk fabric with and without metal mordants also ranged between very good and excellent for the silk fabric [77].

3.3 Alpha naphthoquinones

Lawsone, henna, juglone and shells of unripe walnut natural dyes contain alpha naphthoquinone (**Figure 3**); these dyes are similar to disperse dyes [78].

It has been reported in a study that application of henna extract on cantonised cotton fabric showed outstanding enhancement in UV protection with minimal impact on the tensile strength against harmful UV radiation due to alpha-napthaquinone [79].

3.4 Flavonoids

The basic structural feature of flavonoid compounds is the 2-phenyl-benzo pyrane or flavan nucleus, which consists of two benzene rings linked through a heterocyclic pyrane ring (**Figure 4**). Mostly all yellow-coloured natural dyes are derivatives of hydroxyl and methoxy-substituted flavones and isoflavones. A common example of flavonoid containing dye is weld (*Reseda luteola)* (containing luteolin pigment). Other plant sources are *Allium cepa* (onion), *Artocarpus heterophyllus/Artocarpus integrifolia* (jackfruit), *Myrica esculenta* (Kaiphal), *Datisca cannabina* (Hemp), *Delphinium zalil* (Yellow larkspur), *Gossypium herbaceum*, *Sophora japonica/Styphnolobium japonicum*, *Butea monosperma/Butea frondosa* (flame of the forest/palas), *Mallotus philippinensis* (Kamala), *Bignonia chica/ Arrabidaea chica* (Carajuru/Puca), *Commelina communis and Pterocarpus santalinus* (red sandalwood) [80].

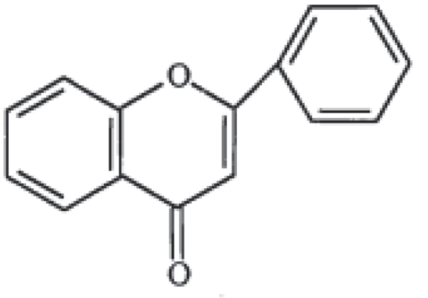

Figure 4.
Flavones (a class of flavonoids).

It has been reported that quercetin, a flavonoid, imparted better antioxidant, antibacterial and UV protection performance to silk fabric [81]. Flavonoids and anthocyanin from red onion skin (*Allium cepa* L.) are natural dyes with antibacterial activity and UV protection after application on wool and cotton fabric [82].

3.5 Di-hydropyrans

These are closely related to flavones in terms of chemical structure [83]. Logwood, brazilwood and sappanwood are common example of di-hydropyrans (**Figure 5**) which generally provide darker shades on silk wool and cotton [84].

Dyeing with logwood dye having di-hydropyrans showed maximum zone of inhibition against *F. solani* and *P. decumbens* even without any mordanting [85].

3.6 Anthocyanidins

Anthocyanins (**Figure 6**) are water-soluble natural pigments belonging to the phenolic family [86]. Carajurin, a direct orange colour for silk coloration, is obtained from the leaves of *Bignonia chica*. These are commonly found in red, purple, blue-coloured flowers and fruits.

It was reported that red reddish dyed silk fabric also provides the antioxidant, antimicrobial activities and UV protection property due to anthocyanin [87].

3.7 Carotenoids

Carrots are the main source of carotene presence due to double bond conjugation.

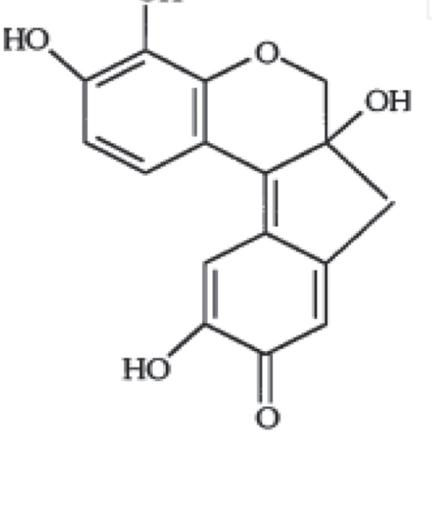

Figure 5.
Di-hydropyrans.

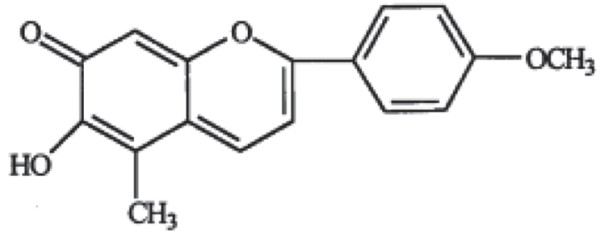

Figure 6.
Anthocyanin.

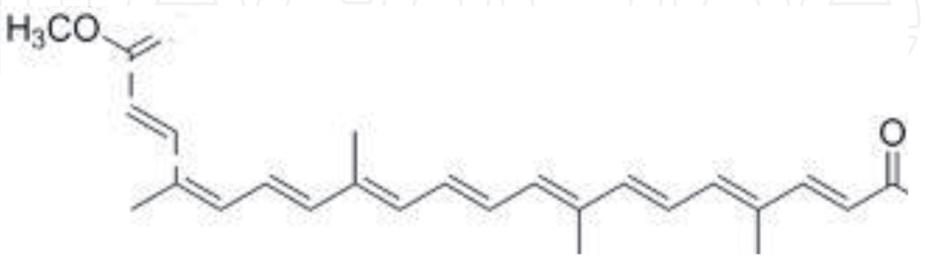

Figure 7.
Carotenoids.

Annatto and saffron come under the carotenoid (**Figure 7**) family. It has been reported that carotenoids have anti-radiation property [88].

3.8 Tannins

Tannins are higher-molecular-weight phenolic compounds. The molecular weight of tannins ranges between 500 and 3000. It is found in a wide range of natural flora such as fruit, pods, plant galls, leaves, bark, wood and roots. Tannins are generally divided into two groups (**Figures 8** and **9**):

1. Condensed tannins (proanthocyanidins)

2. Hydrolysable (pyrogallol) [89]

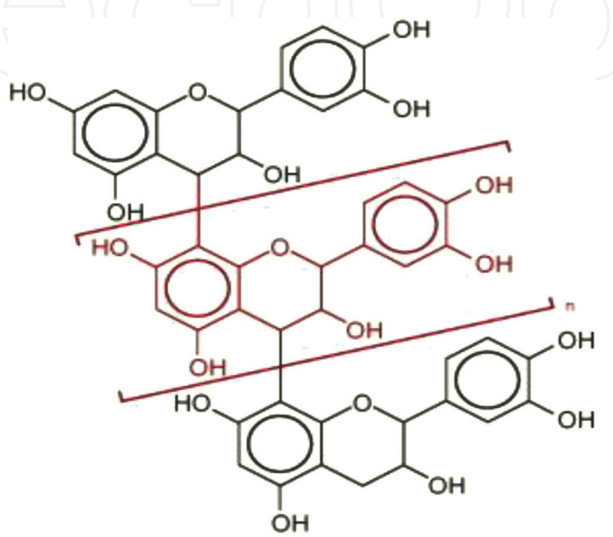

Figure 8.
Condensed tannins.

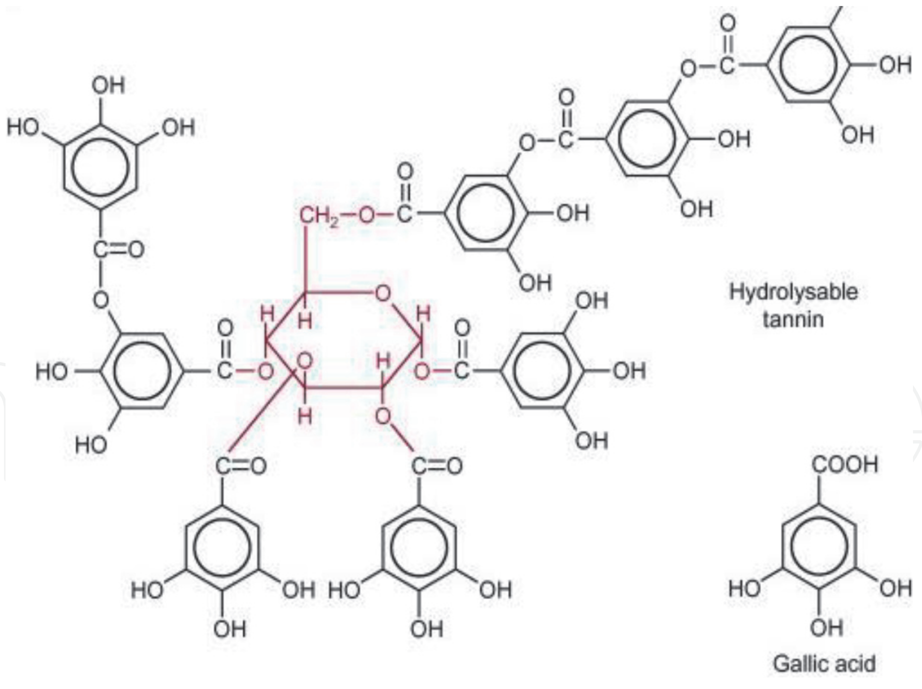

Figure 9.
Hydrolysable tannins.

Tannin is considered as a protective agent against microbes and UV rays. Antimicrobial and antioxidant properties of dyed wool fabric were observed to have improved after application of tannin [90].

4. Conclusion

Presently the consumers become aware of hygienic healthy and protective lifestyle; hence there is a necessity of clothing with functional properties as it covers the major part of the body. The various changes in climate and environment require more protection against UV rays, microbes and insects protecting human from vector-borne diseases, and clothes do not only cover the modesty or basic requirement but also are more functional in terms of protection. Aesthetic as well as medicinal properties of natural dyes has been exploring since ancient time. The glory of natural dyes somewhat subdued after the invention of synthetic dye and presently with the increase of eco-consciousness. Various researches have been conducted on functional aspect of natural dyes, but still there is a need to find out the possible sources for more prominent protection.

Although the natural dyed textiles are promising to provide functional properties such as antimicrobial, UV protection and mosquito as well as moth repellence, still the stability-related issues with natural dyes also need to be significantly addressed. Various researches are being organised with this aspect. This stability-related issue can be enhanced with proper knowledge of interaction of fabric natural dye and mordant future performance of natural dyes. Proper combination of dye, fabric and mordants help to enhance the wash stability. Different techniques like surface modification (plasma treatment and UV irradiation, etc.) and microencapsulation can be used to enhance the stability of the functional properties of dyes. This would further lead to a more stable functional property. Extraction- and application-related issues of natural dyes should also be sorted out. The whole life cycle of natural dyes requires different areas of science; thus, collaborative efforts are required for more prominent results in terms of colour as well as providing functional properties.

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