Chapter

Application of Smart and Functional Dyes in Textiles

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Abstract

Our future will be based on functional and AI based smart products, where every industry wants to develop these kinds of products. Textile industry also cannot remain untouched with this technological innovation. Dyes have been utilising for coloration of textiles since ancient time. But at present with various advancement in technology as well as requirements of consumers, the need for functional and smart dyes arises. Various current researches are based on application of smart and functional dyes on textile to develop smart and functional textiles. The dyes which add the functional and smart properties to the textiles can be called as functional and smart dyes. Functional and smart dyes are available in both synthetic and natural form. But with the environment concern, the researchers are going on to find out natural source of these dyes. Functional dyes such as UV protective dye, antimicrobial dye, moth repellent dye offer specific function after application on textiles. Smart dyes like photochromic, thermochromic, electrochromic and solvatochromic etc. are playing very imp role to develop a smart textile which can offer reversible colour change which leads to impart various properties such as thermoregulation, camophlage properties into the textiles. Functional dyes generally limited to the textiles sector but smart dyes are not just restricted to it. Application of smart dyes is extended to various fields such as automobiles, robotics, aircrafts, medicine and surgery etc. This chapter will mainly deal with the types, application methods and application area of functional and smart dyes especially in connection with textiles.

Keywords: functional dyes, smart dyes, photochromic dyes, thermochromic dyes, electrochromic dyes, solvatochromic dyes, UV protective dyes, antimicrobial dyes, smart textiles, functional textiles

1. Introduction

Smart and functional textiles is the need of the future. There are various methods to develop smart and functional textile which start right form the fibre stage and end in the dyeing and finishing stage. Among these methods, application of smart and functional dyes is considered the most affordable method to develop smart and functional textiles. Traditionally, Dyes has been utilising in textiles generally for coloration purpose. Earlier, consumer wants to buy the textiles mainly due to its aesthetic aspect. Presently, consumer has smart choices. A textile product only having aesthetic property could not allure them. In near future, the product should be smart and functional one to attract the consumer. Smart textiles refer, a textile which can act according to their nearby environment while functional textiles refer, a textile which provides a particular function specially protection from nearby environment. Smart and functional textiles are considered as the part technical textiles. Since last few decade the researchers have been searching the functional as well as smart aspect of dyes. The dyes which can offer smart and functional textiles can be considered as smart and functional dyes. Earlier dyes were categorised as natural dyes and synthetic dyes. Natural dyes were categorised as based on origin (vegetable, mineral and animal), colour (yellow, red, blue), chemical constitution, (indigoid, anthraquinone, alphanapthaquinone, dihydropyrans, anthocynidins, cretonoids), application method (direct, basic, acid, vat, disperse, reactive, mordant) while synthetic dyes were classified as water soluble (direct, basic, acid, reactive), water in soluble (vat, disperse, sulphur) and in situ colour formation (azoic dyes) [1, 2]. But Presently and in near future, the dyes can as be categorised as smart dyes and functional dyes on the basis of providing AI based smartness as well as functionality to the textiles. The types of smart and functional dyes are being described in this chapter.

Smart dyes can sense the nearby environment and make changes accordingly [3]. Smart dyes can change the colour due to various external stimuli such as pH, pressure, temperature, solvents, moisture and electricity. These changes can be permanent or temporary on the basis of need [4]. This phenomenon is known as chromism [5]. There are different types of chromism such as photochromism (induced by sunlight or UV rays), thermochromism (induced by changes in temperature), solvato chromism (induced by polarity of the solvent), hygrochromism (induced by moisture), ionochromism (induced by ions), halochromism (induced by pH value), acido chromism (induced by acids), chemochromism (induced by specific chemical agents like dangerous gases, warfare agents, etc.), electrochromism (induced by electricity), piezochromism (induced by pressure), mechanochromism (induced by deformation of substances) [6]. In the field of textiles mainly photochromism, thermochromism, electrochromism and solvatochromism types of chromism is reported [7–10]. Smart dyes are based on these different kinds of chromism. Several natural and synthetic smart dyes have been discovered. On the basis of external stimuli smart dyes are classified as photochromic dye, thermochromic dye, solvato chromic dye, hygro chromic dye, iono chromic dye, halo chromic dye, acido chromic dye, chemo chromic dye, electrochromic dye, piezo chromic dye, mechnao chromic dye which changes colour respectively due to UV rays, temperature, polarity of solvents, moisture, ions, pH value, acids, specific chemical agent, electricity, pressure, deformation of substance [11]. Despite of having a large group of these dye only a few one makes a way towards textile. Several factors such as bonding with textiles, end uses and comfort of the wearer etc. are considered while application of smart dyes on textiles. Smart dyes like photochromic dyes and thermochromic dyes, are mainly used in textiles sector. Earlier in 90's, the thermochromism and photochromism were widely used particularly in fashion designing field [12, 13]. Thermochromic dyes have better stability in comparison to photochromic dyes hence these are mostly used dyes in textiles in comparison to other smart dyes [14]. Very few researches related to the use of electrochromic dyes, solvatochromic dyes and mechanochromic dyes on fabric are available. Researches related to the use of electrochromic dyes on textiles are still going on [15]. Different parameter of dye such as maximum absorption, no. of wash cycle, different fastness describes the properties of smart dyes [16]. Application of smart dyes are generally extended to fashion, sport and defence and medical related sector. After application of smart dyes, a simple textile can act as a smart textile which can perform the various function such as Camouflage, thermoregulation etc. [17–19].

Functional dyes can add a specific function to the textile such as protection from UV radiation, microbes as well as insects and moth [20–22]. On the basis of these mentioned function, functional dyes can be categorised into UV protective dyes, antimicrobial dyes and insect and moth repellent dyes. Synthetic and natural dyes can provide these functions but presently more attention is being given to natural dyes due to several environmental concerns. Presently due to climate change issue researches on UV protective dyes and antimicrobial dyes have been increased.

Despite of being constant researches on smart and functional dyes, commercial application is very limited. To widen the application area of smart and functional dyes, it is necessary to use a proper application method to impart these dyes onto textile surface. The knowledge of proper bonding mechanism is important in this regard. The relation between fabric properties and application method should be well known to the researcher. It is also important to work on the light stability and washing stability aspect of these dyes. Researches related to preparation and application of these smart and functional dyes on textiles should be carried out in a significant number. Functional group can be added to a traditionally used dye to enhance its functionality. These kinds of researches would be help in the current scenario and also helpful to increases its commercial application.

2. Types of smart dyes

As discussed in introduction part, only few smart dyes such as photochromic, thermochromic, electrochromic, solvatochromic paved a way for its application in textiles industry. Although researches are still going on to utilise more no. of smart dyes in textile sector. Types of smart dyes that are being used in textiles sector are as follows:

2.1 Electrochromic dyes

Electrochromic dyes are based on electrochromism in which reversible changes of colour occurs due to electricity (gain and loss of electron) [23]. This process occurs generally with some transition metal oxides which conduct both electrically and ions [24]. It is reported that strong electric field can alter the colour of certain dyes [25]. Phthalocyanine dye is a good example of electrochromism [26]. Common electrochromic materials are Polyaniline. In a study, conducting polymer polyaniline layer was formed electrochemically on conducting woven textile substrate which exhibited reversible colour change [27]. During application of electrochromic dyes on textile, performance parameters such as electrochromic contrast, coloration efficiency, write-erase efficiency, switching speed, stability, cycle life, and optical memory are considered. Polyethylene terephthalate (PEPES) membranes were coated with poly-3,4-ethylenedioxythiophene polystyrene sulfonate (PEDOT:PSS) to develop electrochromic textile system [28]. Application of Electrochromic dyes can also be extended to develop smart window curtain which filter sun light accordingly [29]. Other smart application such as display of information or for camouflaging purposes of electrochromic dyes have also been reported [30].

2.2 Thermochromic dyes

Thermochromic dyes causes reversible changes in colour within the absorption spectrum of a thermochromic molecule, usually in the visible light range. These changes are induced by heat. Thermochromic material can be organic, inorganic polymers and sol-gels in nature [31]. Presently, only two type of thermochromic system are used in textiles i.e. liquid crystal type and molecular rearrangement type. Organic leuco dyes also create thermochromic system [32]. Organic thermochromic systems perhaps occur due to equilibrium between molecular species like acid–base, keto-enol, lactim-lactam, stereoisomers or between different crystal structures [33]. Among inorganic thermochromic substances, few examples of metal oxides are known such as indium oxide, zinc oxide, chromium hemitrioxide-alum earth [34]. Application of thermochromic dye on textile can be done using 3 methods which can be used exhaust, continuous method, microencapsulation and printing. In exhaust method thermochromic pigment are applied on to textile with a cationic agent, non-ionic dispersing agent and binder using Material to liquor ratio 1:30 at 70 ° C temperature for half hour [35]. In continuous method thermochromic dye, cationic and non-ionic dispersing levelling agent are applied with acrylic soft binder solution. This solution is applied on textiles through pad dry cure machine. Drying of samples is generally done at 80°C for 3 min while curing is done at 140°C for 2 to 3 minutes [36]. In microencapsulation method, microcapsules were created using colourless dye, precursor and colour developer [37]. These materials melt and solidifies with respective to the application of heat and cold. On melting these material changes its colour, while on solidification come back to its original colour.

Various novel colour effects as well as camouflage designs can be produced using combination of thermochromic, non-thermochromic and mixture of both on the conductive cotton [38]. These thermochromic dyes can take heat from there nearby environment such as sun rays and cause a reversible change in the colour of textiles. These dyes are also establishing their presence in the field of Protective clothing for military [39]. Protective clothing using thermochromic colourant can mimic the colour of its surrounding environment with the change in temperature. Even sometimes colour can change with body temperature. Thermochromic dyes on textiles also used to protect a brand from fake imitation [40]. Microparticles (made of thermochromic and photophoresent dyes) and binder are used to make the brand logo. These logos can be temporary and permanent based on the binder used. The logo made up of thermochromic dye change colour with body temperature [41]. Thermoregulation is also a very imp application of thermochromic dye which is based on heat absorbance (in case of dark colours) and reflectance (in case of light colours). A suitable example of this phenomenon is coating of thermochromic dyes on firemen's uniform on high temperature. The Colour of uniform will be converted to white colour which reflect the heat. Thermochromic dyes can also do thermoregulation via expanding or shrinking the textiles fibre. This Shrinking and expanding of fibres in a fabric causes opening or closing of pores which help regulate the passage of air to the body according to external environment [42].

2.3 Photochromic dyes

Photochromic dyes change its chemical structure due to UV rays. Photochromic effect was first time seen on the tetracene and after that it was observed in potassium salt of dinitomethane [43]. In 1960 first photochromic spiropyrans was developed using printing technique by Ksnebo ltd, Japan. In 1998, photochromic dyes were first time used in textiles to produce camouflage effect. Photochromic dyes also decolorise. This decolourisation is called negative photochromism [44]. Various metal oxides, alkaline earth metal sulphides come under the category of Photochromic dyes. Photochromic dyes are water insoluble hence cannot be applied on wool and cotton [45]. Presently Researches are also going on Water-soluble photochromic dyes. These dyes are relatively cheaper option for textiles and leather. Spirooxazine-based Water-soluble photochromic dyes having sulphonate group have been developed. Sulphonate gp impart water solubility. These water-soluble photochromic dyes are mainly for proteins fibres [46]. The wash fastness and photostability of these dyes are moderate [47].

Application of photochromic dyes can be done on the window curtains and facades. This would be helpful to control sunlight [48]. Heat sensitive photochromic dyes also used as temperature indicator [49, 50]. Dupont company are also working on the camouflaging property of these photochromic dyes to develop camouflaging clothing for armies [51, 52]. Flexible UV sensors based on Photochromic dyes also change its colour due to UV rays which makes a UV detective fabric which help to tell the intensity of UV rays to get protection accordingly [53].

Different application methods have been reported to apply Photochromic dyes and pigments. In a study exhaust method (direct Coloration), photochromic colourants were used with auxiliaries such as dispersing agent and ceramic balls (250 g) and aqueous acetic acid. The dyeing was started at 40° C temperature and temperature raised to 60 ° C and then to 90 ° C [54].

Photochromic colourants as disperse dyes has also been used to dye polyester using exhaust dyeing technique. Photochromic colourants are insoluble in water therefore organic solvents such as Acetone is used to dissolve the photochromic colourant. After dissolution of colourant, dispersing agent is added. Acetic acid is also used to maintain the weak acidity (4.5) of solution. This weak acidity helps to minimise the degradation of colourant. The material to liquor ratio of solution was kept to 1:50. The fabric is dyed at 120 ° C for 45 min. Further, rinsing in cold water was done to reduce the temperature to 70 ° C. This 70 ° C temperature was maintained for 20 minutes with in the solution of sodium hydroxide, sodium dithionite and a non-ionic surfactant. Material to liquor ratio was maintained to 1:30.

Photochromic colourants can also be applied through pad dry cure method. In this method the fabric is dried at 80 ° C for 2 minutes in hot air, followed by 140°C of curing temperature for 3 minutes. Microencapsulation was also used for application of photochromic colourants [55–57].

2.4 Chemo chromic dyes

Chemo chromic dyes change its colour due to differences in pH. Phthalides, fluoranes, triarymethines, and simple azo dyes are the examples of pH sensitive dyes [58].

Conventional exhaust dyeing, solgel method as well as prior addition to electrospinning solution has been reported as methods of application for chemo chromic dyes. Chemo chromic dyes can be used in identify the proteins (of certain microbes) with change of colour. This identification with changing colour indicates the presence of microbes in textiles [59]. Therefore, Application area of Chemo chromic dyes can be widened to medical textiles bandages [60].

2.5 Solvatochromic dyes

Solvatochromic dyes work on the principle of Solvatochromism which corresponds to reversible changes of colour due to solvent polarity. The change in colour is occurred due to shifting in maximum absorption of different solvents [61]. There are two types of solvato chromism i.e. positive solvatochromism and negative solvatochromism. Positive solvatochromism corresponds to a hypsochromic shift induced by a decrease of solvent polarity“ and “negative solvatochromism corresponds to a hypsochromic shift induced by an increase of solvent polarity” [62]. Common example Solvatochromic dyes are pyridinium, merocyanine, and stilbazolium dyes. Solvatochormic dyes can be applied in the textiles using microencapsulation technique. Assembly of microsphere on fabric causes colour change on drying and wetting of the fabric. Application of Solvatochromic dyes in textiles is very limited. These dyes can be used to identify the stale or toxic food due to colour change of packaging [63].

S. No	Smart Dyes	External Stimuli responsible for colour change	Suitable methods of application for textiles	Application in textiles	References
1.	Electrochromic dye	Electricity (gain and loss of electron)	Coating	For displaying information or for camouflaging purposes	[23–30]
2.	Thermochromic dye	Heat (absorption spectrum of a thermochromic molecule)	Exhaust, Continuous method, micro encapsulation	Thermoregulation, Brand forgery detection	[31–42]
3.	Photochromic dye	Light	Exhaust and pad dry cure method	Camophlaging textiles, window curtains, UV detective fabric	[43–57]
4.	Chemo chromic dyes	pH	Conventional exhaust dyeing, solgel method, prior addition to electrospinning solution.	Medical textiles	[58–60]
5.	Solvatochromic dye	UV rays	Micro encapsulation	Packaging	[61–63]
6.	Mechanochromic dye	Deformation (elongation and compression) of polymer on which applied	Melt processing technique, physically dispersed in form of supramolecular aggregates in a matrix in a polymer, Covalent insertion of chromophoric units	Footwear and shaped garment industry	[64–66]

Table 1.
Types of smart dyes used in textile industry.

2.6 Mechanochromic dyes

Mechanachromism is a phenomenon in which a polymer changes it colour due to deformation such as elongation and compression. Elongation and compression occur due to the change in pH, temperature. Mechanachromic dyes are the organic dyes which is applied on polymer and causes changes in colour due to certain mechanical pressure. Mechanochormic dye cannot act alone it require a polymer (material) because only polymer can deform (elongate or compress). In a study 1,4-bis (R-cyano-4- methoxystyryl)-2,5-dimethoxybenzene9 (C1-RG, F) has been incorporated in polyethylene using melt processing technique [64]. In another research mechanochromic polymers have been developed by incorporating a dye filled microcapsules [65]. In a study Polydiacetylenes (PDA) was synthesised by thermal polymerisation of diphenyl sulphide containing bisdiacetylene. It is reported in that study that PDA changes its colour from blue to red due to elongation and compression. In the cool (non-extended state) form, the material has a particular colour, this particular colour changes due to mechanical abrasion which causes heating of surface. Mechanochromic colourants can be physically dispersed in form of supramolecular aggregates in a matrix in a polymer. Covalent insertion of chromophoric units into the macromolecule backbone or side chains has also been used to apply mechanochromic colourants [66]. Application area of mechanochromic dyes can be done in footwear and shaped garment industry in which product can change colour due to deformation (**Table 1**).

3. Types of functional dyes

Functional groups like -OH, -NH2, – COOH of dyes offer various functional properties when applied onto the textile [67]. Both natural and synthetic dyes can perform various functions after application on textiles. Now days more emphasise is being given to the green and sustainable functional dyes which directly comes from nature. Types functional dyes are as follows:

3.1 Antimicrobial/antibacterial dye

Microbes and bacteria cause several kinds of dermal infection, body odour and several other severe health issue [68]. Antimicrobial dyes provide the protection from variety of micro-organisms like gram-positive bacteria such as *Staphylococcus aureus, Streptococcus epidermidis and Bacillus cereus* and gram-negative bacteria such as *Escherichia coli, Klebsiella pneumonia, Shigella flexneri and Proteus vulgaris* and other microbes [69]. A large no. of antimicrobial dyes possesses antimicrobial activity against human pathogen but very few have been reported for textiles. Number of researches have been conducting to find out the antimicrobial properties in various synthetic and natural dyes. Various studies reported that synthetic dyes such as direct, cationic, reactive and disperse dyes provides antimicrobial property to the fabric after dyeing. In a study it was found that Direct Blue 168 dye and copper sulphate as mordanting agent incorporate antimicrobial properties in the acrylic fabric [70]. Similarly, antimicrobial dyes based on azo heterocyclic and/or homocyclic Systems also have biocidal behaviour [71]. Multifunctional antimicrobial dyes have also been developed by adding a functional gp (quaternary ammonium salt group) to a traditional aminoanthraquinoid dye [72]. Most research has been focused on polycationic systems that are more supple for modification. Reactive dyes form homopolar bonds with textile substrates. The synthesised thiazolidinone derivatives exhibiting antimicrobial properties. Synthesised monoazo disperse dyes showed better results against gram positive as well as gram negative bacteria [73]. Application of natural dyes on textiles also offer antimicrobial textiles. Phenolic compounds such as anthraquinones, flavonoids, tannins, naphthoquinones and others in natural dyes are responsible for the antimicrobial activity. When these phenolic compounds reacted with textiles, formation of complex form. This complex hinders (bacteriostatic) or kill (bactericidal) the enzyme production in microbes. At present more emphasis is being given to antimicrobial activity of natural dye due to various environmental concern. From various studies it was found that natural dyes extracted from Pomegranate (*Punica granatum)* peels, Henna (*Lawsonia inermis*) leaves, *M. composita* leaves, Madder (*Rubia tinctorium*) root, safflower, *Rumex maritimus (*Golden dock*)*, *Indigo (Quercus infectoria) leaves,* Berberine provides antimicrobial properties to the fabric. Application of Natural dyes such as peony, clove, *Coptis chinensis* (Chinese goldthread) and gall-nut on fabric also provides protection against *Staphylococcus aureus* due to presence of phenolic compounds [74–78].

Perspiration cause formation of bacterial colonies on textiles, which led to bad odour [79]. Various natural dyes can act as a barrier to form these colonies. Natural dyes such as pomegranate, coffe arabica, *Cassia tora*, gardenia Indigo, Peony, clove and pomegranate (*Punica granatum*) reported as a good deodorising agent when applied on textiles [80–82]. Natural dyes extracted from gallnut also act as a deodoriser for textile due to the presence of gallotannin [83].

There is no. of methods to impart antimicrobial dyes on textiles. For proper bonding of textile and dye, the textile surface can be modified through various treatments such as treatment with chemicals, chitosan, enzymes, UV radiation, ultrasound [84]. Application methods can be altered with regard to type of fibre dye and the end use. Therefore, researchers should consider the structure of dye and fibre. The researchers should also have knowledge how this bonding of fibre and dye affect the fabric properties. The products of Health, hygiene as well as medical textiles comes under the application area of antimicrobial dyes.

3.2 UV protective dyes

Presently UV ryas are causing various harmful effects. UV protective dyes enhance the UPF (Ultraviolet Protection Factor) of the textiles. UPF means how much a fabric can protect the wearer from harmful UV rays. In general, all dyes act as a UV absorber because spectral region falls into UV region. Various kind of synthetic dyes are commercially available to enhances the UPF of the fabric. Direct, vat and reactive dyes increases the UPF of fabric [85–87]. Various researches reported that natural dyes can also enhances the UPF of the fabric. Absorption characteristics of natural dyes generally determines the UPF of the fabric [88]. Phenolic compounds in natural dyes work as UV protective agent as these molecules absorb the UV radiation. For instance, *R. maritimus, M. philippinensis, K. lacca, A. catechu and A. nilotica* have tannin content (phenolic compond) thus provide good UPF to the fabric. It is also reported in various studies that, Natural dyes from eucalyptus leaf extract, *Xylocarpus granatum* (*Cedar Mangrove*) bark extract, blossoms of broom (*Cytisus scoparius*) and dandelion (*Taraxacum officinale*), Weld, woad, logwood lipstick tree, madder, brasil wood, and cochineal, gromwell roots, *Acacia*, henna dye extract, chitosan and turmeric dye gallnuts, areca nuts, and pomegranate peels banana peel *babool, ratanjot*, annatto and *manjistha* enhances the UPF of textiles [89–95]. Mordants are used with natural dyes to enhances the fastness properties of the dyes. Several studies reported the positive impact of mordant on the UPF of the fabric. But very few studies also reported the negative impact of mordant on the UPF of the fabric. It means type of the mordant, mordanting method also affect the UPF of the fabric [96, 97]. In case of both synthetic as well as natural dyes, several parameters such as concentration of dye, exhaustion time and extraction and exhaustion temperature affect the UPF of fabric [98, 99]. For instance, it is reported that with the increase of concentration of dye, the UPF of dyed fabric also increases. While exhaustion time and temperature are not causing significant change in the UPF of the fabric. Various studies also report the correlation between the dyeing parameters and UPF.

In a study exhaust method was used for the application of herbal plant extract to enhance the UV protection of the fabric. Madder and cutch dye was applied on nettle fabric using exhaust dyeing method [100]. Pad dry cure method were also used for application of UV protective dye [101].

Application of UV protective dyes can be extended mainly to the clothing of outdoor activities such as fishing, farming, horticulture, gardening, building construction, road construction, postcard distribution, oil production field, military defence services, skiing, police work, professional cycling, surfing [102].

S. No	Functional Dyes	Source	Suitable methods of application for textiles	References
1.	Antimicrobial dyes	**Natural source:** Pomegranate (*Punica granatum*) peels, Henna (*Lawsonia inermis*) leaves, *M. composita* leaves, Madder (*Rubia tinctorium*) root, safflower, *Rumex maritimus* (Golden dock), *Indigo (Quercus infectoria) leaves,* Berberine, peony, clove, *Coptis chinensis* (Chinese goldthread) and gallnut *Synthesised source:* direct, cationic, reactive and disperse dyes, Direct Blue 168 dye and copper sulphate, dyes based on azo heterocyclic and/or homocyclic Systems, developed by adding a functional gp (quaternary ammonium salt group) to a traditional aminoanthraquinoid dye, polycationic systems, Synthesised thiazolidinone derivatives, Synthesised monoazo disperse dyes	Treatment of textiles surface with chemicals, chitosan, enzymes, UV radiation, ultrasound	[70–84]
2.	UV protective dyes	*Natural source: R. maritimus, M. philippinensis, K. lacca, A. catechu and A. nilotica* eucalyptus leaf extract, *Xylocarpus granatum* (*Cedar Mangrove*) bark extract, blossoms of broom (*Cytisus scoparius*) and dandelion (*Taraxacum officinale*), Weld, woad, logwood lipstick tree, madder, brasil wood, and cochineal, gromwell roots, *Acacia*, henna dye extract, chitosan and turmeric dye gallnuts, areca nuts, and pomegranate peels, banana peel, *babool, ratanjot*, annatto and *manjistha* *Synthesised source:* Direct, vat and reactive dyes	Exhaust, pad dry cure and microencapsulation	[85–104]
3.	Moth repellent dyes	Saffron flower waste, onion skin, henna, myrobalan, silver oak leaf, madder, wall nut, dholkanali and yellow roots	Simultaneous dyeing	[105–110]
4.	Mosquito repellent dyes	**Natural source:** Pomegranate peel with polyvinyl alcohol **Synthesised source:** *4-Amino-N, N-diethyl–3-methyl benzamide* (MD).	Exhaust, microencapsulation	

Table 2.
Types of functional dyes used in textile industry.

UV protective dye can also be applied to the clothing of Indoor workers who are potentially exposed to UV radiation for example in hospitals where UV radiation is required for some kind of treatments in some laboratory works, plasma torch operating, printing, lithographing, painting, wood curing, plastic working, in some cases food industry also [103]. Army personnel who have been working in extreme climate conditions also experiences intense solar radiation with terrible heat stress also requires protection from UV rays [104].

3.3 Moth proof and mosquito repellent dyes

Moth proof and mosquito repellent dyes provides protection against moths and mosquitos after application on textiles. Synthetic moth proof or mosquito repellent are generally available in colourless form. Therefore, moth proof and mosquito repellent dyes available in natural form. Various natural dyes contain tannin which can also act as a moth proofing agent. It has been reported in a research that the natural dyes having more than about 40% tannin is effective as an anti-moth agent. In various studies, it was reported that natural dye extracted from Saffron flower waste, onion skin, henna, myrobalan, silver oak leaf, madder, wall nut, dholkanali and yellow roots provides anti-moth properties after application on textiles [105]. Application of dye extracted form pomegranate peel with polyvinyl alcohol can act as mosquito repellent [106]. The mosquito repellent property of synthesised *4-Amino-N, N-diethyl–3-methyl benzamide* (MD) coupled with three different naphthol were assessed. Cotton fabric dyed with MD and naphthol showed very good and durable mosquito repellence. *N, N-diethyl-m-toluamide* (DEET) is used to synthesise the MD [107]. Pomegranate peels Extract can also act as mosquito repellent dye after its application on textiles.

Moth proof dyes were applied using exhaust method in which condition such as (Concentration of colourant-5%, temperature. 90°C degree, M:L- 1;:40, and pH 5–6, were maintained. Simultaneous dyeing with mothproofing agent on wool fabric were also reported. Result of this study showed that undyed and only mordanted fabric provides lesser protection from *D. maculatus* in comparison to madder dyed wool fabric. Mosquito repellent dyes are applied on fabric using either using exhaust method, pad dry cure and microencapsulation methods. [108, 109].

Mothproof and insect repellent dyes is textile museum and library to protect the textiles and books. Mosquito repellent dyes can also be applied to the children's clothing, pram and curtains [110] (**Table 2**).

4. Conclusion

This high technological era is not only based on beautiful products but it is based on "beauty with artificial intelligence". Various researches are being conducted to develop a smart and functional textile which is not only appealing due to its looks but also have an artificial intelligence to give signal according to the change in nearby environment. Dyes can play important role to develop smart and functional textiles. Besides the functionality, sustainable and green aspect of dyeing are also being considered during synthesis and application smart and functional dyes. In comparison to the conventional dyes smart dyes can add a special intelligence to textile fabric such as thermoregulation, camouflaging. Similarly, functional dyes application on textile provides protection form UV rays, unhygienic conditions and insects. Despite of having such an intelligence of to perform according to nearby environment, various smart dyes have lost their ability to develop colour after several molecular transformation. This phenomenon is known as fatigue resistance.

Similarly, functional dyes also have limitation with regards to durability and comfort properties of the fabric. For instance, UV protective dyes have less stability in light and laundry. The fabric dyed with antimicrobial dyes as well as moth and Mosquito repellent also do not have very good wash fastness. These stability-related issue of smart and functional dyes can be enhanced to utilise proper application methods. Different application methods like surface modification (plasma treatment and UV irradiation, etc.) and microencapsulation to enhance the stability of these functional as well as smart dyes. Application method should be such type that could make a balance between comfort properties and stability.

Abbreviations

AI	Artificial Intelligence
UPF	Ultraviolet Protection Factor
UV	Ultraviolet Radiation
PDA	Polydiacetylenes
M:L	Material to liquor ratio

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References

[1] Gregory P. Classification of Dyes by Chemical Structure. The Chemistry and Application of Dyes. 1990. pp 17-47

[2] Gürses A, Açıkyıldız M, Güneş K, Gürses S. Classification of Dye and Pigments. Dyes and Pigments 2016. pp 31-45.

[3] Rijavec T. and Bračko S. Smart dyes for medical and other textiles. Materials, Systems and Applications. Woodhead Publishing Series in Textiles. 2007. DOI: 10.1533/9781845692933.1.123

[4] Periyasamy S. and Khanna G. Thermochromic colors in textiles Americos Industries India. 2008. Retrieved from www.americosind.com

[5] Ferrara M. and Bengisu M. Intelligent design with chromogenic materials. Journal of the International Colour Association (2014): 3, 54-66

[6] Somani P R. Chromic Materials, Phenomena and their Technological Applications. Applied Science Innovations Pvt. Ltd. 650p.

[7] Gong X, Hou C, Zhang Q, Li Y and Wang H. Solvatochromic structural color fabrics with favourable wearability properties. Journal of Material Chemistry.8. 2008.

[8] Ibrahim W. An Investigation into Textile Applications of Thermochromic Pigments. PhD thesis

[9] Morsümbül S and Akumbasar P. Photochromic textile materials. IOP Conference Series Materials Science and Engineering. 2018. 459(1):012053 DOI: 10.1088/1757-899X/459/1/012053.

[10] Kelly F M and Cochrane C Handbook of Smart Textiles Color-Changing Textiles and Electrochromism. pp 859-889

[11] Christie R M. Chromic materials for technical textile applications. In book: Advances in the Dyeing and Finishing of Technical Textiles 2013 DOI: 10.1533/9780857097613.1.3

[12] Morsümbül S and Akçakoca E P and Kumbasar IOP Conference Series: Materials Science and Engineering, Volume 459, Aegean International Textile and Advanced Engineering Conference (AITAE 2018)5-7 September 2018, Lesvos, Greece

[13] Coghlan A. Technology: Clothes that change colour in the heat of the moment. New scientist. 1991. Retrieved from https://www.newscientist.com/article/mg13017684-900-technology-clothes-that-change-colour-in-the-heat-of-the-moment/

[14] Chowdhury M A, Joshi M and Butola B S Photochromic and Thermochromic Colorants in Textile Applications. March 2014Journal of Engineered Fibers and Fabrics 9(1):107-123. DOI: 10.1177/155892501400900113

[15] Sheng M, Zhang L, West J L and Fu *S. multicolor* Electrochromic Dye-Doped Liquid Crystal Yolk–Shell Microcapsules *ACS Appl. Mater. Interfaces* 2020, 12, 26, 29728-29736.

[16] Abate M T. Seipela S, Yu J, Viková M, Vik M, Ferri A, Guanc J, Chen G, Nierstrasza V. Supercritical CO2 dyeing of polyester fabric with photochromic dyes to fabricate UV sensing smart textiles. Dyes and Pigments. 2020. Volume 183

[17] Karpagam K R, Saranya K S, Gopinathan J and Bhattacharyya A. Development of smart clothing for military applications using thermochromic colorants. Journal of the Textile Institute. 108: 7. 2016. 755-765p

[18] Baumbach J. Colour and camouflage: design issues in military clothing,

in Advances in Military Textiles and Personal Equipment. Woodhead Publishing Series in Textiles 2012. Pages 79-102

[19] Urquhart J. Smart textile uses sweat as switch to keep wearer cool or warm royal society of chemistry. Royal society of chemistry. 2019. Retrieved from https://www.chemistryworld.com/news/smart-textile-uses-sweat-as-switch-to-keep-wearer-cool-or-warm/3010099.article

[20] Reda M. and El-Shishtawy. Functional Dyes, and Some Hi-Tech Applications. 2009. https://doi.org/10.1155/2009/434897.

[21] Mishra V R, Ghanavatkar C W, Sekar N. UV protective heterocyclic disperse azo dyes: Spectral properties, dyeing, potent antibacterial activity on dyed fabric and comparative computational study. Spectrochimical Acta Part A: Molecular and Biomolecular Spectroscopy.2019. 223.117353

[22] Mohamed F A and Ibrahim H M. Antimicrobial dyes based on heterocyclic and/or homocyclic systems for dyeing and textile finishing Textile Research Division, National Research Center. 2014. 8(8), .285-301.

[23] Gregory P. Electrochromic Dyes. In: High-Technology Applications of Organic Colorants.1991. Topics in Applied Chemistry. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-3822-6_7 pp 53-56

[24] Granqvist, C. G Electrochromic Metal Oxides: An Introduction to Materials and Devices https://application.wiley-vch.de/books/sample/3527336109_c01.pdf

[25] John R. Platt. Electrochromism, a Possible Change of Color Producible in Dyes by an Electric Field. 1961. J. Chem. Phys. 34, 862 https://doi.org/10.1063/1.1731686

[26] Mortimer R J. Switching Colors with Electricity. American Scientist. 2013. 101(1):38. DOI: 10.1511/2013.100.38

[27] Granqvist C J Energy-Efficient Windows: Present and Forthcoming Technology in Materials Science for Solar Energy Conversion Systems. 1991

[28] Graßmann C, Mann M, Langenhove L V and Pfeiffer, A. S. Textile Based Electrochromic Cells Prepared with PEDOT: PSS and Gelled Electrolyte

[29] Michaelis A, Berneth H, Haarer D, Kostromine S, Neigl R, Schmidt R. Electrochromic Dye System for Smart Window Applications. Advanced material.2001. 13(23). 1825-1828.

[30] Yablonovitch E. Electrochromic Adaptive Infrared Camouflage. Interim Progress Report U.S. Army Research Office DAAD University of California, Los Angeles. Period covered: August 1999 – January 2005.

[31] S. Periyasamy and Khanna G. Thermochromic colors in textiles. 2008

[32] Strižić M, Suzana J, Preprotic P, Gunde M K. Dynamic Colour Changes of Thermochromic Leuco Dye and Liquid Crystal Based Printing Inks. Conference: 4th International Joint Conference on Environmental and Light Industry Technologies. 2013. DOI: 10.13140/RG.2.2.34274.56005

[33] Ajeeb F, Younes B, Khsara A K. Investigating the Relationship between Thermochromic Pigment Based knitted Fabrics Properties and Human Body Temperature

[34] Lieva Van Langenhove(ed.) Smart Textiles for Medicine and Healthcare: Materials, Systems and Applications

[35] Matsuda K and Irie M. Chemistry Letters. 2006. 35: 1204

[36] Chowdhury, M.A.; Butola, B. and Joshi. M. Application of thermochromic

colorants on textiles: Temperature dependence of colorimetric properties. Coloration Technology. 2013. 129(3) DOI: 10.1111/cote.12015

[37] Aksoy S A and Alkan C. January 2, 2018. Microencapsulation of Three-Component Thermochromic System for Reversible Color Change and Thermal Energy Storage,

[38] Chowdhury M A, Butola B and Joshi M. Development of Responsive Camouflage Textile using Thermochromic and Non-thermochromic Colorants. 2013

[39] Langenhove L V. Smart Textiles for Medicine and Healthcare: Materials, Systems and Applications.

[40] Americos thermochromic microcapsule. Retrieved from https://www.kenencoregroup.com/smart-colorants.html

[41] Tebbe, G. Textile material for garments. United States Patent Application Publication US 2002/0137417 A1. 2002-09-26.

[42] Hibbert, R. Textile innovation, 2002. London.

[43] Durr, and Bouas-Laurent, H, Pure Applied Chemistry, 2001; 73; 639.

[44] Aiken S, Edgar R, Gabbutt C, Heron B M, Hobson P A. Negatively photochromic organic compounds: Exploring the dark side. Dyes and Pigments.2018.149:92-121.

[45] Billah R, Christie R M, Shamey, R Direct coloration of textiles with photochromic dyes. Part3: Dyeing of wool with photochromic acid dyes. 2012. Review of Progress in Coloration and Related Topics 128(6):488-492. DOI: 10.1111/j.1478-4408.2012.00406.x.

[46] Billah R, Christie R M, Shamey R M. Direct coloration of textiles with photochromic dyes. Part 1: Application of spiroindolinonaphthoxazines as disperse dyes to polyester, nylon and acrylic fabrics. 2008. Coloration Technology 124(4):223-228. DOI: 10.1111/j.1478-4408.2008.00145.x

[47] Shah M R B Photochromic protein substrates, Mol Cyst Liq Cryst, 2005. 431, 235/[535]-239/[539].

[48] Addington D M and Schodek D L . Smart materials and new technologies, Amsterdam, Elsevier.2005.

[49] F Fu and L Hu. Temperature sensitive colour-changed composites, in Advanced High Strength Natural Fibre Composites in Construction, 2017.

[50] Zhang Y, Hu Z, Xiang H, Zhai G, Zhu M. Fabrication of visual textile temperature indicators based on reversible thermochromic fibers. Dyes and Pigments. 2019. 162: 705-711

[51] Santos L D M, Townes D E, Patricio G R, Winterhalter C A, Dugas A, O'Neill T R, Lomba R A, Quinn B J. Camouflage U.S. Marine corps utility uniform: pattern, fabric, and design. US patent. 2001

[52] ALDIB M. An Investigation of the Performance of Photochromic Dyes and their Application to Polyester and Cotton Fabrics pHD Thesis. Watt University. Scottish Borders Campus School of Textiles and Design. 2013

[53] Viková M, and Vik M Description of photochromic textile properties in selected color spaces 2014

[54] Aldib M and Christie R M. School of Textiles & Design. Textile applications of photochromic dyes. Part 4: application of commercial photochromic dyes as disperse dyes to polyester by exhaust dyeing

[55] Little A F and Christie, R *M. textile* applications of photochromic dyes. Part

1: Establishment of a methodology for evaluation of photochromic textiles using traditional colour measurement instrumentation April 2010 Coloration Technology 126(3):157-163 DOI: 10.1111/j.1478-4408.2010.00241.x

[56] Aldib M and Christie R *M. textile* applications of photochromic dyes. Part 5: application of commercial photochromic dyes to polyester fabric by a solvent-based dyeing method. Coloration technology. 2013. Volume129, Issue2. Pages 131-143

[57] Topbas O, Sariisik A M, Erkan, G and Ek O Photochromic microcapsules by coacervation and in situ polymerization methods for product-marking applications. Iranian Polymer Journal. 2020. 29: 117-132.

[58] Christie R M. Chromic materials for technical textile applications. In Advances in the Dyeing and Finishing of Technical Textiles; Woodhead Publishing: Oxford, UK; Cambridge, UK; Philadelphia, PA, USA; New Delhi, India, 2013; pp. 3-36.

[59] Stojkoski V and Kert M. Design of pH Responsive Textile as a Sensor Material for Acid Rain. Polymers (Basel). 12(10): 2251. 2020 doi: 10.3390/polym12102251

[60] 内森·扎马利帕杰夫·葛雷. Chemochromic medical articles. 2014 - Boston Scientific Scimed, Inc

[61] Nigam S and Rutan S. Principles and Applications of Solvatochromism Applied Spectroscopy 2001. 55(11):362-DOI: 10.1366/0003702011953702

[62] Papadakis R and Tsolomitis A. Synthesis, substituent and solvent effects on the UV-Vis spectra of 4-pentacyanoferrate-4′-aryl substituted bipyridinium complex salts. 2008. Conference: ICPOC 2008 - 19th IUPAC Conference on Physical Organic ChemistryAt: Santiago de Compostela Spain

[63] Gong X, Hou C, Zhang Q, Li Y and Wang H. Solvatochromic structural color fabrics with favorable wearability properties. Journal of Material chemistry.

[64] Crenshaw B R, Burnworth M, Khariwala D, Hiltner A, Mather P T, Simha R, Weder C. Deformation-Induced Color Changes in Mechanochromic Polyethylene Blends. Macromolecules. 2007. 40(7) DOI: 10.1021/ma062936j

[65] Calvino C, Henriet E Li, Muff L F, Schrettl S, Weder C. Mechanochromic Polymers Based on Microencapsulated Solvatochromic Dyes. 2020Macromolecular Rapid Communications 41(7) DOI: 10.1002/marc.201900654

[66] Ciardelli F, Giacomo R, Pucci A. Dye-Containing Polymers: Methods for Preparation of Mechanochromic Materials. 2012. Chemical Society Reviews 42(3) DOI: 10.1039/c2cs35414d

[67] Vankar, P. Chemistry of Natural Dyes. RESONANCE. 2000. 73-80 pp. https://www.ias.ac.in/article/fulltext/reso/005/10/0073-0080

[68] Aly R, Baron S (ed.). Microbial Infections of Skin and Nails. In: Medical Microbiology. 4th ed. Galveston (TX): University of Texas Medical Branch at Galveston; 1996. Chapter 98.

[69] Lowy F. Bacterial classification, structure and function. 2009;44(12): 977-983.

[70] Yusuf M, Shabbir M, Mohammad F. Natural colorants: Historical, processing and sustainable prospects. Natural Products and Bioprospecting. 2017;7(1): 123-145. DOI: 10.1007/s13659-017- 0119-9.

[71] F. A. Mohamed, H.M. Ibrahim. researches and reviews in bio sciences volume 8 issue 8. Antimicrobial

dyes based on heterocyclic and/or homocyclic systems for dyeing and textile finishing

[72] Sun G and Ma M. Multifunctional antimicrobial dyes. Patent no. US20050011012A1. University of California University of California San Francisco UCSF.

[73] Abedi D, Mortazavi S M, Mehrizi M K, Feiz M. Antimicrobial Properties of Acrylic Fabrics Dyed with Direct Dye and a Copper Salt. 2008. Textile Research Journal 78(4):311-319. DOI: 10.1177/0040517508090486.

[74] Mohammed S, Morsy A M, Apasery A E. Huda Mahmoud Disperse Dyes Based on Aminothiophenes: Their Dyeing Applications on Polyester Fabrics and Their Antimicrobial Activity Molecules. 2013 18(6):7081-92 DOI: 10.3390/molecules18067081.

[75] 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). DOI:10.1007/s10570-018-1864-6

[76] Yusufa M, Shahida M, Khan M I, Khan S A, Khan M A. Mohammed, F. Dyeing studies with henna and madder: A research on effect of tin (II) chloride mordant. *Appl Environ Microbiol*. 2014. 80(21): 6611-6619.

[77] Pal A, Tripathi Y C, Kumar R, Upadhyay L. Antibacterial Efficacy of Natural Dye from Melia composita Leaves and Its Application in Sanitized and Protective Textiles Journal of Pharmacy Research 2016. 10(4):154-159

[78] Lee Y H, Hwang E K, Baek Y M, Kim, H D. Colorimetric Assay and Antibacterial Activity of Cotton, Silk, and Wool Fabrics Dyed with Peony, Pomegranate, Clove, Coptis chinenis and Gallnut Extract Materials. Fibers and Polymers. 2009. 17 (4):560-568

[79] Teufel L, Pipal A, Schuster K C, Staudinger T, Red B. Material-dependent growth of human skin bacteria on textiles investigated using challenge tests and DNA genotyping. Journal of Applied Microbiology 2009108(2):450-61 Follow journal DOI: 10.1111/j.1365-2672.2009.04434.x.

[80] Pargai D, Jahan S and Gahlot M. Functional Properties of Natural Dyed Textiles. In book: Chemistry and Technology of Natural and Synthetic Dyes and Pigments. Intechopen. 2020.

[81] Hwang E K, Lee Y H, Kim H D. Dyeing, fastness, and deodorizing properties of cotton, silk, and wool fabrics dyed with gardenia, coffee sludge, *Cassia tora*. L., and pomegranate extracts. Fibers and Polymers 2008. 9(3):334-340. DOI: 10.1007/s12221-008-0054-9

[82] Koh E and Hong K H. Gallnut extract-treated wool and cotton for developing green functional textiles. Dyes and Pigments 2014103:222-227 DOI: 10.1016/j.dyepig.2013.09.015

[83] Lee Y H, Hwang E K, Baek Y M, Kim, H D. Colorimetric Assay and Antibacterial Activity of Cotton, Silk, and Wool Fabrics Dyed with Peony, Pomegranate, Clove, Coptis chinenis and Gallnut Extract Materials. Fibers and Polymers. 2009. 17 (4):560-568

[84] Erkan G, Şengül K and Kaya S. Dyeing of white and indigo dyed cotton fabrics with Mimosa tenuiflora extract April 2014 Journal of Saudi Chemical Society 18(2). DOI: 10.1016/j.jscs.2011.06.001

[85] Kan C W and Au C H. Effect of direct dyes on the UV protection property of 100% cotton knitted

fabric. Fibers and Polymers volume 16, pages1262-1268(2015)

[86] Bajaj P, Kothari V K, Ghosh S B. Some Innovations in UV Protective Clothing", Indian J. of Fibres and Textile Research 2000 35 (4) 315-329

[87] Wong W Y, Lam J K C and Kan C W. Influence of reactive dyes on ultraviolet protection of cotton knitted fabrics with different fabric constructions. 2015. https://doi.org/10.1177/0040517515591776

[88] Gupta D, Ruchi. UPF characteristics of natural dyes and textiles dyed with them. 2007. Colourage 54(4):75-80.

[89] Pisitsak P, Hutakamol J, Jeenapak S, Wanmanee P, Nuammaiphum J and Thongcharoen R Natural dyeing of cotton with Xylocarpus granatum bark extract: Dyeing, fastness, and ultraviolet protection properties. Fibers and Polymers. 2016. 17 (4):560-568.

[90] Křížová and Wiener. Comparison of UV Protective Properties of Woollen Fabrics Dyed with Yellow Natural Dyes from Different Plant Sources. Environmental Sciences. 2016. 2 (7):2454-9916

[91] Griffoni D, Bacci L, Zipoli G, Carreras G, Baronti S. and Sabatini F. Laboratory and outdoor assessment of UV protection offered by flax and hemp fabrics dyed with natural dyes, Photochem. Photobiol. 2009.85: 313-320

[92] Hong K, Bae J H, Jin S R, Yang J S. Preparation and properties of multi-functionalized cotton fabrics treated by extracts of gromwell and gallnut Cellulose 2011. 19(2): 507-515. DOI: 10.1007/s10570-011-9613-0

[93] Alebeida O K, Taoa Z, Seedahmedc A. New Approach for Dyeing and UV Protection Properties of Cotton Fabric Using Natural Dye Extracted from Henna Leaves. Fibres & Textiles in Eastern Europe. 2015. 23(5):61-65

[94] Orabodee S, Chotima S, Jantip S, Potjanart S, Porntip S B. Effect of Chitosan and Turmeric Dye on Ultraviolet Protection Properties of Polyester Fabric. Applied Mechanics & Materials Academic Journal. 2014. 535: 658.

[95] Jung, J.S. Study of Fastness, UV Protection, Deodorization and Antimicrobial Properties of Silk Fabrics Dyed with the Liquids Extracted from the Gallnuts, Areca Nuts, and Pomegranate Peels. MATEC Web of Conferences. 2016.49:1-6

[96] Gawish SM, Mashaly HM, Helmy HM, Ramadan AM and Farouk R. 2017. Effect of Mordant on UV Protection and Antimicrobial Activity of Cotton, Wool, Silk and Nylon Fabrics Dyed with Some Natural Dyes. Journal of Nanomedicine & Nanotechnology. 8:1

[97] Pargai D, Gahlot M, Rani A. Ultraviolet protection properties of nettle fabric dyes with natural dyes. Ind. J. Fibre Text Res. 2016. 41(4): 418-425

[98] Pargai D and Jahan S. Direct Application of *Vitis vinifera* (Grape) Leaves Extract on Cotton Fabric: A Potential to Prevent UV Induced Skin Problems. Current World Environment 2018. 13(1):165-171 Follow journal DOI: 10.12944/CWE.13.1.16

[99] Osterwalder U, Rohwer H. Improving UV Protection by Clothing — Recent Developments 2002. cancer research160:62-9 DOI: 10.1007/978-3-642-59410-6_9

[100] Sarkar. A K. An evaluation of UV protection imparted by cotton fabrics dyed with natural colorants

BMC Dermatol. 2004; 4: 15. doi: 10.1186/1471-5945-4-15

[101] Mongkholrattanasit R. UV protection properties of silk fabric dyed with eucalyptus leaf extract. The Journal of The Textile Institute Volume. 2011.102 (3)

[102] Adams J. Research on Pad-Dry Dyeing and Ultraviolet Protection of Silk Fabric Using Dyes Extracted from Laccifer lacca Kerr. Advanced Materials Research 2014. 1010-1012:512-515. DOI: 10.4028/www.scientific.net/AMR.1010-1012.512 'Sun-protective Clothing', *Journal of Cutaneous Medicine and Surgery*, 1998.3(1): 50-53

[103] Schmidt**.** Textile Sun Protection for Soldiers in Extreme Climates. 2010. Retrieved from http://www.army-technology.com/contractors/personal/hohenstein/press1.html

[104] Zajtchuk R, Military Dermatology. Office of The Surgeon General. Department of the Army, United States of America. Retrieved from https://fas.org/irp/doddir/milmed/milderm.pdf

[105] Shakyawa D B, Raja ASM, Kumar A, Pareek P K. Antimoth finishing treatment for woollens using tannin containing natural dyes. Indian journal of fibre and textile research 2015. 40. 200-202p

[106] Rimpi and Singh A. Protection and application of natural mosquito repellents cotton fabric through dyeing

[107] Teli M D. Dyeing of cotton fabric for improved mosquito repellency. 2017. 427-434.

[108] Sajib M I, Banna B U, Mia R, Ahmed B, Chaki R, Alam S S, Rasel M A, Tanjirul Mosquito repellent finishes on textile fabrics (woven & knit) by using different medicinal natural plants 6:4 : 2020

[109] Thite A G, Gudiyawar M Y. Development of Microencapsulated Ecofriendly Mosquito Repellent Cotton Finished Fabric By Natural Repellent Oils. International journal of sciences technology and management.

[110] Nazari A and Branch Y. Efficient mothproofing of wool through natural dyeing with walnut hull and henna against *Dermestes maculatus* 2016. 755-765