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Review Article

Application of natural dyes on textiles

Ashis Kumar Samanta[a] & Priti Agarwal
Institute of Jute Technology, 35 Ballygunge Circular Road, Kolkata 700 019, India

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This paper reports the studies available on the characterization and chemical/biochemical analysis of natural dyes; extraction of colorants from different natural sources; effects of different mordants and mordanting methods; conventional and non-conventional methods of natural dyeing; physico-chemical studies on dyeing process variables and dyeing kinetics; development of newer shades and analysis of colour parameters for textiles dyed with natural dyes; and test of compatibility for application of binary mixture of natural dyes. The chemical modification of textile substrate for improving dyeability, attempts for improvement in overall colour fastness properties and survey of some traditional processes of natural dyeing in different parts of India have also been discussed.

Keywords: Cationic dye fixing agent, Colour fastness, Dye characterization, Natural dye, UV absorber

1 Introduction

Natural dyes are known for their use in colouring of food substrate, leather as well as natural protein fibres like wool, silk and cotton as major areas of application since pre-historic times. Since the advent of widely available and cheaper synthetic dyes in 1856 having moderate to excellent colour fastness properties, the use of natural dyes having poor to moderate wash and light fastness has declined to a great extent. However, recently there has been revival of the growing interest on the application of natural dyes[1,2] on natural fibres due to worldwide environmental[3,4] consciousness. Although this ancient art of dyeing with natural dyes withstood the ravages of time, a rapid decline in natural dyeing continued due to the wide availability of synthetic dyes at an economical price. However, even after a century, the use of natural dyes never erode completely and they are still being used. Thus, natural dyeing of different textiles and leathers has been continued mainly in the decentralized sector for specialty products alongwith the use of synthetic dyes in the large scale sector for general textiles/apparels owing to the specific advantages and limitations of both natural dyes and synthetic dyes[5].

The use of non-allergic, non-toxic and ecofriendly natural dyes on textiles has become a matter of significant importance due to the increased environmental awareness in order to avoid some hazardous synthetic dyes. However, worldwide the use of natural dyes for the colouration of textiles has mainly been confined to artisan / craftsman, small scale / cottage level dyers and printers as well as to small scale exporters and producers dealing with high-valued ecofriendly textile production and sales[6,7]. Recently, a number of commercial dyers and small textile export houses have started looking at the possibilities of using natural dyes for regular basis dyeing and printing of textiles to overcome environmental pollution caused by the synthetic dyes[8]. Natural dyes produce very uncommon, soothing and soft shades as compared to synthetic dyes. On the other hand, synthetic dyes are widely available at an economical price and produce a wide variety of colours; these dyes however produce skin allergy, toxic wastes and other harmfulness to human body.

For successful commercial use of natural dyes, the appropriate and standardized dyeing techniques need to be adopted without scarifying required quality of dyed textiles materials. Therefore, to obtain newer shades with acceptable colour fastness behaviour and reproducible colour yield, appropriate scientific techniques or procedures need to be derived from scientific studies on dyeing methods, dyeing process variables, dyeing kinetics and compatibility of selective natural dyes. A need has also been felt to

[a]To whom all the correspondence should be addressed.
E-mail: ijt@cal2.vsnl.net.in / ijt_aksamanta@hotmail.com

reinvestigate and rebuild the traditional processes of natural dyeing to control each treatment and pre-dyeing process (preparation, mordanting) and dyeing process variables for producing uncommon shades with balanced colour fastness and eco-performing textiles.

India is rich in natural wealth and there are ample scope to explore and revive application of natural dyes on textiles, having more and more scientific knowledge base available, as is evidenced from the studies reported[9,10] with the objectives, such as to know the chemistry of dyes and interaction between mordant dyes and fibres; to get maximum yield of colourant and reproducible shades; to have commercial availability of extracted natural dyes in powder form; to improve the dyeing methods/ yields; to optimise dyeing conditions; to develop newer shades; and to improve dyeability with natural dye.

In spite of the better performance of synthetic dyes, recently the use of natural dyes on textile materials has been attracting more and more scientists for study on this due to the following reasons:

- Wide viability of natural dyes and their huge potential.
- Availability of experimental evidence for allergic & toxic effects of some synthetic dyes, and non-toxic & non-allergic effects of natural dyes.
- To protect the ancient and traditional dyeing technology generating livelihood of poor artisan/ dyers, with potential employment generation facility.
- To generate sustainable employment and income for the weaker section of population in rural and sub-urban areas both for dyeing as well as for non-food crop farming to produce plants for such natural dyes.
- To study the ancient dyeing methods, coloured museum textiles and other textiles recovered by archaeology for conservation and restoration of heritage of old textiles.
- Specialty colours and effects of natural dyes produced by craftsman and artisans for their exclusive technique and specialty work.
- Availability of scientific information on chemical characterizations of different natural colorants, including their purification and extraction.
- Availability of knowledge base and database on application of natural dyes on different textiles.

Production of synthetic dyes is dependent on petrochemical source, and some of the synthetic dyes contain toxic / carcinogenic amines which are not ecofriendly[11, 12]. Moreover, the global consumption of textiles is estimated at around 30 million tonnes, which is expected to grow at the rate of 3% per annum. The colouration of this huge quantity of textiles needs around 700,000 tonnes of dyes which causes release of a vast amount of unused and unfixed synthetic colourants into the environment. This practice cannot be stopped, because consumers always demand coloured textiles for eye-appeal, decoration and even for aesthetic purposes. Moreover, such a huge amount of required textiles materials cannot be dyed with natural dyes alone. Hence, the use of eco-safe synthetic dyes is also essential. But a certain portion of coloured textiles can always be supplemented and managed by eco-safe natural dyes[6, 7]. However, all natural dyes are not ecofriendly. There may be presence of heavy metals or some other form of toxicity in natural dye. So, the natural dyes also need to be tested for toxicity before their use.

The present paper reports the studies carried out so far on the chemistry and application of natural dyes on textiles to understand the science of natural dyeing as well as to focus the problem areas, difficulty and probable measures to overcome them.

2 Application of Natural Dyes on Textiles

2.1 Characterization and Chemical/ Biochemical Analysis of Natural Dyes

2.1.1 Macro- and Micro-chemical Analysis

Saidman *et al*.[13], Gulrajani *et al*.[14] and Mohanty[9] have reviewed the chemistry, chemical composition and chemical based classification of natural dyes having anthraquinone[13] (madder), alpha napthoquinones (henna), flavones[13,14] (weld), indigoids (indigo and tyrian purple), carotenoids (annatto, saffron), etc. which give a basic understanding of chemical nature of such colourants. Madder dyes are hydroxyl-anthraquinones which are extracted from the root bark of various *Rubiaceae*, e.g. from madder root (*Rubia tinctorum*). The root contains approximately 1.9% of dye, present in the free form or bound as the glucoside. Annato[14] pulp is rich in tannin but contains mixture of eight colourants of carotenoid group such as nor-bixin and bixin. Both these components have the properties of Vitamin A. Indigoid dyes are perhaps the oldest natural dyes used by man. It is found as the glucoside indican in the plant *Indigofera tinctoria* and has been known in India for about 4000 years. The main dyeing component of this plant is indigo. Tyrian purple is derived from the Mediterranean shell fish of the genera Purpura and Murex. Henna[14, 15] contains high proportion of coloured species other than Lawsone, as is evident from HPLC analysis of its aqueous extract, i.e 0.57% Lawsone. It is non-ionic moiety and is expected to bind with polyester through interaction, such as hydrogen bonding in addition to van der Waals forces or even dipole-dipole interactions of the Lawsone molecule with polyester fibre molecules/ chains.

2.1.2 UV-Visible Spectroscopic Study

UV visible spectra of any colourant/dye show its peaks at predominating wavelength, indicating main hue. For natural dyes, the spectra specially indicate different peaks for mixed colourants available in their extract in both UV and visible region. UV/ Visible spectroscopic studies of different natural dyes were carried out by Bhattacharya[16] and Erica *et al*.[17] using different solvents for extraction. Neem bark[18] colourant shows two absorption maxima at 275 and 374 nm while beet sugar[19] shows three absorption bands at 220, 280 and 530 nm. The visible spectra of ratanjot[20] at acidic *p*H show maximum absorption at around 520-525 nm, but under alkaline *p*H there is a shift towards 570 nm and another peak is observed at 610-615 nm. Red sandal wood[21] shows a strong absorption peak at 288 nm and the maximum absorption at 504 and 474 nm at *p*H 10 in methanol solution. *Gomphrena globosa* flower colourant shows one major peak at 533 nm. This dye does not show much difference in the visible spectrum at *p*H 4 and 7; however the peak shifted towards 554 nm, as reported by Shanker and Vankar[22]. Bhuyan *et al*.[23] observed the dye absorption for the dyes extracted from *Mimusops elengi* & *Terminalia arjun* and reported that depending on the concentrations of dyes in the dye bath, the dye absorbed on the fibre varies from 21.94 % to 27.46 % and from 5.18 % to 10.78% respectively. The colour components isolated from most of the barks contain flavonoid moiety. Bhuyan *et al*.[24] also studied the colour component extracted from the roots of *Morinda angustifolia* Roxb using benzene extract and showed its melting point as 280°C. The compound shows UV/Vis absorption at 446, 299, 291, 265.5 and 232 nm and gives a positive Borntregar reaction, a characteristic for an anthraquinone. Extraction, spectroscopic and colouring potential studies of the dye in ginger rhizome (*Zingiber officinale*) were studied and reported by Popoola *et al*.[25]. This dye is soluble in hydroxyl based organic solvents and gives one homogenous component of 0.86 R_f value on chromatographic separation, having wavelength of maximum absorption at 420 nm.

These studies are although too scientific in nature, but are useful in understanding the UV absorbance criteria, as these are indicative of many application information, like possible fading and absorbance behavior under UV-light, sunlight, etc. Hence, these reports are also important.

2.1.3 Chromatographic Analysis

Thin layer chromatatography (TLC) was used by many workers to identify different colour components in natural dyes to be applied on textiles[26]. Dyes detected were insect dyes and vegetable dyes, viz. yellow, red and blue colours. Koren[27] also analysed the natural scale insect, madder and indigoid dyes by HPLC. Guinot *et al*.[28] used the TLC for preliminary evalution of plants containing flavonoids (flavonols, flavones, flavanones, chalcones/ aurones, anthocynanins, hydroxycinnamic acids, tannins and anthraquinones) colour compounds found in the plants.

Identification of dyes used in historic textiles through chromatographic and spectrophotometric methods as well as by sensitive colour reactions has been reported by Blanc *et al*.[29]. Szostek *et al*.[30] studied the retention of carminic acid, indigotin, corcetin, gambogic acid, alizarin flavanoid, anthraquinone and purpurin. A non-destructive method was reported for identifying faded dyes on fabrics through examination of their emission and absorption spectra. Balakina *et al*. [31] analysed quantitatively and qualitatively the red dyes, such as alizarin, purpurin, carminic acid, etc. by high performance liquid chromatography (HPLC). This technique has been used by several workers to identify different components of synthetic as well as natural dyes.

Mc Govern *et al*.[32] carried out the separation and identification of natural dyes from wool fibres using reverse phase HPLC with a C-18 column. Two quaternary solvent systems and one binary solvent system were used to obtain chromatograms of dyes, isomers and minor products present in the sample. A linear gradient elution method has been used for the HPLC analysis of plant and scale insect as well as for the red anthraquinonoid mordant, molluscan blue, red purple and indigoid vat dyes[33]. The method enables the use of the same elution programme for the determination of different chemical classes of dyes.

In addition, it significantly shortens the retention time of natural anthraquinonoid dyes over those previously reported. Cristea *et al*.[34] reported the quantitative analysis of Weld by HPLC and found that after a 15 min extraction in a methonal/water mixture, 0.448% luteolin, 0.357% luteolin 7-glucoside and 0.233% luteolin-3'7-diglucoside were obtained. Son *et al.* [35] reported HPLC analysis of indigo, showing that with the increase in the dyeing time, the structural changes of indigo component are attributed to decrease in colour strength.

Study of annatto dyestuff, nor-bixin and bixin was reported by means of derivative spectroscopy and HPLC[16]. The sample preparation involved extraction with acetone in the presence of HCl and removal of water by evaporation with ethanol. This residue was dissolved in chloroform-acetic acid mixture for derivative spectroscopy and in acetone for HPLC. Derivative spectra were recorded from 550nm to 400nm. Analysis of cochineal colour in foods utilizing methylation with diazomethane was carried out using TLC and HPLC with a mobile phase of butanol, ethanol and 10% acetic acid.

These chromatographic analyses led to separation and understanding of individual component present in natural colourants extracted by different media and methods and therefore to establish and explain different phenomena related to colouring of textiles by these natural dyes.

2.1.4 Test of Toxicity

The toxicity[36, 37] data sheet for natural dye provide evidence about the possibility of any adverse effect to human being. The irritation effects to skin and eye and the sensitization potential are the primary concern. Furthermore, possible long-term effects, such as mutagenic, carcinogenic or reproductive toxicity effects are also to be tested for any material/ natural dye before its use. The LD-50 is the best-known toxicity rating. It describes the 'lethal dose for 50% of the test animals, which is the amount of substance in kg/kg of body weight that kills half of the animals. The crude methanolic extracts of stem, root, leaves, fruit, seeds of *Artocarpus hetrophyllus*[38] and their subsequent partitioning with petrol, dichloromethane, ethyl acetate and butanol fractions exhibited a broad spectrum of antibacterial activity. The butanol fractions of the root bark and fruit were found to be the most active. None of the fraction was active against the fungi tested. Mariegold[39] showed negative test against microbiological control for *E-coli* and *Salimonella*. Dwivedi *et al*.[40, 41] and Benencia and Courreger[42] studied chemopreventative effects of red sandal wood oil on skin papillomas in mice followed by the effects of sandal wood extract to prevent skin tumor development in CD1 mice and antiviral activity against herpes simplex virus 1 and 2. The hepatoprotective[43] activity of an aqueous methnol extract of *Rubia crodifolia* (Manjistha) was investigated against acetaminophen and CCl_4-induced damage. Acetaminophen produced 100% mortality at a dose of 1 g/K in mice while pretreatment of animals with manjistha extract reduced the death rate to 30%. Singh *et al.* [44] tested *Acacia catechu, Kerria lacca, Quercus infectoria, Rubia cordifolia* and *Rumex maritimus* against pathogens like *Escherichia coli*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Proteus vulgaris* and *Pseudomonas aeruginosa*. Minimum inhibitory concentration was found to vary from 5 µg to 40 µg. Using a bioassay-directed purification scheme, the active antibacterial was isolated from *Caesalpina sappan*[45] (sappan wood or red wood) and identified to be brasilian. The trypan blue dye exclusion test showed that the brazilin lacks cytotoxicity against vero cells, it has potential to be developed as an antibiotic. Bhattacharya *et al*.[46] reported that the arjun bark, babul bark and pomegranate rind are eco-safe and contained sometimes traces amount of red listed heavy metals/chemicals but in permissible range. Shenai[47] has given a critical and realistic evalution of dyeing with vegetable dyes highlighting the metal toxicity of substances used in textile processing.

Mondhe[48] and Rao[49] made an attempt to prepare azo-alkyd dyes by the reduction of nitro alkyds, followed by diazotization of aminoalkyds and coupling with different phenolic compounds present in *Jatropha curcas* seed oil using IR spectra.

In general, it has been observed from the literature that the identification of natural dyes in textiles involves selective extraction of dyes and comparison of each dye by various characterization techniques, viz. UV-Visible and IR spectroscopy, TLC, HPLC, ecotoxicity (LD-50) and bio-assay, including methods of identification of vegetable dyes on cellulose fibres, animal fibres and man-made fibres.

The above reports are however exclusive but not exhaustive and many further analyses of colour components of natural dyes are possible by other modern techniques, like FTIR (Fourier Transform Infrared Spectroscopy), NMR (Nuclear Magnetic

Resonance), AAS (Atomic Absorption Spectrometry), DSC (Differential scanning calorimetry), TGA (Thermogravimetric Analysis) and elemental analysis of natural dyes/colourants to study the chemical functional nature, presence of heavy metals, thermal behaviour and presence of different elements for understanding the chemistry of natural dye component well.

Recently, Samanta *et al*. [50] have studied UV- Vis spectra, DSC and FTIR of six selective natural dyes (red sandal wood, jackfruit, sappan wood, mariegold, babool and manjistha) and found that the babool and mariegold show dominating UV-absorbance characteristics at 242-250 nm and 370-380nm, with the 242-250nm zone very predominant, while manjistha has no such preferential UV- absorbance peak at 242-370 nm zone except at 380 nm. DSC thermogram shows endothermic and exothermic peaks at different zones for heating the same from ambient to 500°C temperature. The FTIR study shows the types of chemical functionality and bonds present in the main colour components of each of the individual purified dyes.

2.2 Extraction and Purification of Colorants from Natural Dyes

The extraction efficiency of colourant components present in natural plant/ animal/ mineral sources depends on the media type (aqueous/ organic solvent or acids/ alkali), *p*H of the media and conditions of extraction, such as temperature, time, material-to-liquor ratio and particle size of the substrate.

2.2.1 Aqueous Extraction

Dayal and Dobhal[51] extracted colourants from the leaves of Eucalyptus hybrid, seeds of *Cassia tora* and *Grewia optiva* by using aqueous medium under varying condition. These dyes impart fast shades on silk, cotton and jute fabrics. Khan *et al*.[52] studied natural dyes extracted from biomass products, namely cutch, ratanjot and madder. The colour gamut of wool samples dyed with these dyes indicates red yellow zone. Maulik *et al*.[53] also studied the extraction of hinjal and jujube bark having *p*H 4-5 for dyeing wool and silk. The dye uptake appears to be higher in case of wool than in case of silk. Teli and Paul[54] made an attempt to extract natural dye from the coffee seed for its application on cotton and silk. Pan *et al*.[55] dyed the grey jute fabric with extracts from deodar leaf, jackfruit wood and eucalyptus leaf by soaking it in soft water and boiling for 4 h separately. Dye uptake increased with the increase in mordant concentration. Verma and Gupta[56] overnight soaked wattle bark in distilled water, boiled in pressure vessel and then filtered it to obtain a residual dye powder (15 - 20 % w/w) of the bark. Saxena *et al*.[57] initially extracted mariegold and chrysanthemum flowers by boiling their dry petals with acidified water and reported it to be the best. Sarkar *et al*.[58,59] and Deo and Paul[60] extracted colour component from three varieties of mariegold flower in aqueous medium by the addition of 5% sodium chloride in 1:2 proportion. Aqueous extraction of saffron yields a yellow dye with medium wash fastness on wool and poor wash fastness on cotton. The wash fastness can be improved by treatment with metal salts before dyeing, as studied and reported by Tsatsaroni *et al*.[61].

2.2.2 Extraction by Non-aqueous/ Organic Media / Mixed Aqueous and Organic Solvents

Vankar *et al*. [62] utilized the supercritical fluids CO_2 to extract and purify natural colourant from eucalyptus bark. Extraction of dye from food was best achieved with ethanolic 40M/oxalic acid mixture. The comparative behaviour of other red food dyes was also studied. A process developed for the extraction of natural dye from the leaves of teak plant has been carried out using aqueous methanol[63]. A brick red shade dyeing for silk/ wool using the isolated dye in presence of different mordant has also been achieved. Bhuyan *et al*.[24] studied the isolation of *Morinda angustifolia roxb,* which is a morindone type of compound containing an anthraquinone group, using ethanol in a soxhlet apparatus and observed that the silk and cotton fabrics can be dyed with this colour component with and without using different mordants. Bhattacharya *et al*.[46, 64] and Patel and Agarwal[65] made an attempt to standardize colourant derived from arjun bark, babul bark and pomegranate rind. Singh *et al*.[66] and Agarwal *et al*.[67] studied extraction of dye from well grounded henna leaves directly in a solvent assisted dyeing process, employing organic solvent:water (1: 9) mixture as the dyeing medium. Superior dyeing properties were obtained, when this dye was applied on polyester. The build-up, colour yield and wash fastness properties were found moderate to good. Vasugi and Kala[68] obtained the dye from the grape skin waste by using soxhlet extractor, and later on distilled it under vacuum to obtain the concentrated dye solution. Eom *et al*.[69] extracted colourant by using a reflux condenser for 1 h followed by filtration.

2.2.3 Extraction by Acid and Alkali

Dixit and Jahan[70] extracted euphorbia leaves under acidic *p*H by adding hydrochloric acid, under alkaline *p*H using sodium carbonate and under aqueous medium. It was observed that the silk fabric dyed under acidic medium produced best shades. Sudhakar *et al.*[71] extracted colourants using alkali from nuts of *Areca catechu* for colouration of silk fabric. Dye extracted from jatropha seed gave a range of bright, even and soft colours on silk fabric when extracted under acidic condition[72]. Samanta *et al.*[73] studied the extraction of the dye from jackfruit wood under various *p*H conditions and reported that the optimum conditions for extraction of colour component from jackfruit is achieved at *p*H 11, giving absorbance of colour component at 2.77 λ_{628} nm. Samanta *et al.* [74] studied the extraction of red sandal wood under various *p*H condition and reported that the optimum conditions for extraction of colour component is achieved at *p*H 4, giving absorbance of colour component at 2.63 $\lambda_{603.0}$ nm.

2.3 Different Mordants and Mordanting Methods

Mordanting is the treatment of textile fabric with metallic salts or other complex forming agents which bind the natural mordantable dyes onto the textile fibres. Mordanting can be achieved by either pre-mordanting, simultaneously mordanting and post-mordanting. Different types and selective mordants or their combination can be applied on the textile fabrics to obtain varying colour/ shade, to increase the dye uptake and to improve the colour fastness behaviour of any natural dye. Extensive work has been reported[75-83] in this area of study.

Dayal *et al.* [84] studied the effect of copper sulphate and potassium dichromate on colour fastness properties of silk, wool and cotton fibres. The wool treated with metal ions, such as Al(III), Cr (VI), Cu (II), Fe (II) & Sn (II) and rare earths such as La (III) & Sn (III) was used to dye with beet sugar colourant and it was found that this dyeing can withstand the requirement of BIS fastness standards[19]. Agarwal *et al.* [85] optimized the various concentrations of mordant and reported that the best shades could be produced by 0.15% alum, 0.08% copper sulphate and stannous chloride, 0.04% ferrous sulphate and 0.06% potassium dichromate on mulberry silk fabric. Natural dye extracted from the leaves of teak plant by using aqueous methanol produced brick red shade on silk and wool in the presence of different mordants[63]. Irrespective of mordanting methods, silk[86] treated with potash alum showed increase in colour fastness when subjected to sunlight exposure test and those treated with potassium dichromate, copper sulphate and ferrous sulphate showed excellent to good all around fastness properties. Wool yarns dyed with turmeric[18], when subjected to different concentrations of natural mordant (a petaloid of banana flower) and chromium under identical mordanting conditions, showed similar colour fastness. Tulsi leave extract when applied on textiles with or without using metallic salts, produced pale to dark green and cream to brown shades with adequate fastness as studied by Patel *et al.*[87]. Silk[88] fabric when mordanted with magnesium sulphate produced lower depth of shade, whereas copper sulphate produced highest depth. Bhattacharya *et al.*[89] studied the effect of various metal sulphates as mordants and reported that the depth of dyeing can be improved by using different metal salt mordants. Das *et al.*[90] observed that the pre-mordanting and post-mordanting employing ferrous sulphate and aluminium sulphate improve the colour uptake, light fastness and colour retention on repeated washing. The use of such mordants, however, does not improve wash fastness property of dyed textile substrate with pomegranate. Das *et al.*[91] reported that the ferrous sulphate and aluminium sulphate improve colour retention on washing and the fastness properties further for dyed textile substrate with tea leaves. Chan *et al.*[92] studied dyeing of wool with four varieties of tea. Coloured protein fibres became blackish, when ferrous sulphate was employed as mordanting agent. Tsatsaroni *et al.*[61] reported that the saffron yields a yellow shade on wool and cotton when mordanted with aluminium sulphate, iron sulphate, sodium potassium tartrate and zinc chloride. The use of a mordant in dyeing alpha-crocin results in some darkening and dulling of yellow colour.

Tin (as mordant) imparts good wash fastness to cotton dyed with golden rods. Chromium for mariegold dyeing and alum and tin for dyeing with onion skins also impart good wash fastness as reported by Vastrad *et al.*[93]. Turmeric dye[94] can be applied on cotton fabric using different mordants like tannic acid, alum, ferrous sulphate, stannous chloride and potassium dichromate to obtain various shades of colour. The use of gluconic acid as a ligand for complexing iron (II) salts and for vat dyeing of cotton has been studied earlier. Chavan and Chakraborty[95] reported the use of iron (II) salts complexed with such ligands as tartaric acid and citric acid for the reduction of indigo at room temperature for subsequent cotton dyeing. Wash fastness[96] and light fastness[97] can be increased by the use of metal salts or tannic acid on cotton fabrics. Cotton yarns, when treated with Acalypha[98] dye after pre-mordanting with potash alum, potassium dichromate, copper sulphate and ferrous sulphate, showed excellent colour fastness properties.

Pre-mordanting route favours dyeing of jute[99] fabric with direct type of natural dyes in the presence of aluminium sulphate as a mordant, while simultaneous mordanting route gives better results for madder on cotton with the same mordant. It has also been proposed that alum[100] and aluminium sulphate should be used as mordants in dyeing with natural dyes, as their environmental toxicity is almost nil. Samanta *et al.*[73,74] also studied and reported the effect of different natural and chemical mordants (with or without mordant assistants) like aluminium sulphate, tartaric acid and cetrimide on bleached jute fabric. As the mordant concentration and dye concentration are increased, there is improvement in the light fastness by 1-2 grades.

Different types of mordant and method of mordanting significantly affect the rate and extent of photofading. The use of copper or ferrous sulphate gives high resistance to fading, whereas stannous chloride or alum do not. On the other hand, light fastness improves when post-mordanting is conducted with copper or ferrous ion, but pre-mordanting is superior in the case of stannous chloride or alum, as investigated and reported by Gupta *et al.*[101].

Harda-tartaric acid combination is found to be the best followed by tannic acid-harda and tartaric acid – tannic acid combinations for cotton. Samanta *et al.*[74] reported that the combination of harda and aluminium sulphate as double mordants is best suited for jute fabric for red sandal wood natural dye. Synergistic effect of mordant was observed while using the binary combinations of mordants. Meta-mordanting gave the best results for harda-tartaric acid and tartaric acid-tannic acid combinations, while pre-mordanting gave the best results for tartaric acid-harda combination, as studied by Deo and Paul[102,103]. The colour fastness properties of goldendrop root dyed wool[104] were studied using combinations of mordants, such as alum: chrome, alum: copper sulphate, alum: ferrous sulphate, chrome: copper sulphate, chrome: ferrous sulphate and copper sulphate : ferrous sulphate in the ratio of 1:3, 1:1 and 3:1 respectivly. Bains *et al.*[105] studied the effects of combination of mordants on colour fastness properties of cotton dyed with peach.

There is lot of literature available on the mordanting prior to normal dyeing and the effects of mordants on colour fastness properties, shade development and other physical properties when applied individually[106,107] or in combination[108] on cellulosic, protenic and synthetic fibres.

However, it is felt that the fibres with integrated and synthetic works necessarily show the different shades being developed for combination of different ecofriendly mordants and natural dyes as well as their colour fastness behaviors. Computerized database/ electronic shade card in regard to this will be a more preferred choice for future requirement.

2.4 Conventional and Non-conventional Methods of Natural Dyeing

2.4.1 Conventional Dyeing

Dyeing can be carried out in an alkaline bath, acidic bath or in a neutral bath, depending on the chemical nature of natural dyes. There are various reports available on different methods of mordanting as well as different methods of dyeing of different fibres, such as cellulosics, lingo cellulosics, protenic and synthetics. These studies are widely available in different literature[9, 109-112]. Mohanty *et al.*[9] reported dyeing of cotton and silk with babool, tesu, manjistha, heena, indigo, mariegold, etc. with different mordants. Various kinds of shades, like black to brown and green to yellow to orange, can be obtained by the application of different mordants. However, before dyeing, the clothes need to be scoured, bleached or treated chemically by different methods. Thus, source-wise and state-wise, different artisan dyers are performing natural dyeing of silk, cotton and wool from long time and have derived some special techniques and processes for individual dye-fibre combination to get a particular shade. Some conventional dyeing practices followed in various states of India are reported here.

In Maharashtra, Gujarat and Rajasthan[9], the general process followed in preparing a cotton cloth for natural dyes includes dunging, washing, bleaching and steaming followed by steeping in alkaline lye and rinsing. Then the cloth is usually soaked in a solution of harda/myrobolan and then dried. The cloth is then pre-mordanted by dipping it in a solution of alum and water. In some places, gum or a paste of tamarind seed (tamarind kernel powder) is added to make it sticky. For dyeing, the cloth is generally boiled with an aqueous extracted solution of specific natural dye until all the colouring matter is absorbed by the cloth.

The dyed fabric is then washed and spread out to dry gradually in air under the sun. Water is sprinkled at certain interval over the cloth so as to brighten the colour; this process is continued for 2-4 days. If required, the cloth is finally starched by dipping it in a paste of rice or wheat flour, or in a solution of babool gum and then dried.

In Bengal[9], the most common natural dyes used are haldi, babool, madder (manjistha), pomegranate rind, palash, mariegold, saw dust, red wood, besides al-root, garan wood, etc. Sappan wood is either cut into small pieces or pounded into powder and then boiled in water for 6 h for its extraction in aqueous medium. The textile material is then dipped into this solution for 1 h with or without alum at boil. At Burdwan, the dunged cotton cloth is generally boiled in water along with the powdered bark of the Al-root and then left steeped in this solution until it is cooled. In Bengal, manjistha (Indian madder) is extracted mainly from stem, occasionally from the roots of the plant. The dye extract is prepared by boiling the dried manjeet stem with water, but sometimes merely left to steep for few hours in cold water. In Malda, alum, manjistha alum and *Caesalpinia sappan* are boiled together with water for mixed dye extraction. The textile material is then dyed in this solution, which is thus a single bath mordanting cum dyeing process. In Chittagong (now in Bangladesh) and Malda, sawdust of wood (*Artocarpus indegrifola*) is also used as a source of yellow natural dye. This is boiled with a little alum till the water is reduced to half of its original volume. The cotton yarn is then dyed yellow by steeping in this solution for 2 h.

In Cuttack (Orrisa), the sappan wood chips are generally boiled with alum and turmeric and then cooled. After cooling the textile material is dipped in the boiled extracts of sappan wood for 3 h. At Cuttack, aqueous extract of powdered Al-root is prepared at room temperature (25°C) with sufficient quantity of water and then the cloth is steeped for 24 h. Finally, the whole material is boiled gently for 2 h.

Two different types of indigo vat are prepared in most of the places, particularly in UP, which are known to be a khari-mat or alkaline-vat and a mitha-mat or sweet-vat. Khari –mat is prepared by taking 40 gallon water in earthen vessel, into which 2 lbs of indigo, 2 lbs of lime, 2 lbs of sajji mati and one ounce of gur (molasses) are generally added. The liquor is now ready for dyeing within 24 h in hot weather, but in winters it took four days for the fermentation to get completed. Mitha-vat is prepared by taking 60 gallon water and 4 lbs lime. On the next day, 4 lbs lime is again added. At the end of 4th - 5th day, about 60 lbs of tali (taken from the old vat already running) is mixed into the new sweet vat. The liquid is then stirred twice a day for 4 days.

The dyeing with Al-root[9] does not require boiling and therefore called as 'cold dyeing'. The cotton yarn was washed in plain water, dried and then steeped in a mixture called Khuranii (prepared by mixing castor oil, carbonate of soda and water). The yarn was then soaked in this mixture overnight and dried without washing. It was then exposed to sun for 7 h, steeped in a small quantity of fresh water and then kept in the moist state for one night. The next morning, it was again exposed to the sun drying. The operation was repeated for seven days. Lastly, the yarn was washed and dried. The next step was the preparation of Al-root solution. Finally, the yarn was steeped in the mixture, soaked for 24 h, and again washed thoroughly. These operations continued for 4 days. Finally, the yarn was dipped in alkaline solution of sodium carbonate and dried. To produce a lemon yellow colour, kesuda (*Betea frondosa*) was boiled in water with haldi, and the material was dyed in it. Finally, the material was dipped in lime juice. This practice of dyeing is generally used in Gujarat.

In many other states of India, different traditional methods are known to be available for natural dyeing of textiles[9,10].

2.4.2 Non-conventional Dyeing

Customer's demand for ecofriendly textiles and ecofriendly dyes led to the revival of natural dyes for textiles, with the newer energy efficient dyeing process and more reproducible shade developing processes.

It is reported that the ultrasonic energized dyeing conditions for neem leaves give better dye uptake, uniform dyeing, and better light and wash fastness on cotton fabric, as studied by Senthilkumar *et al.* [113]. However, Ghorpade *et al.* [114] and Tiwari *et al.* [115] reported ultrasound energy dyeing of cotton with sappan wood. Tiwari *et al.*[116] also reported dyeing of cotton fabrics by tulsi leaves extract using ultrasonic dyeing technique. Dyeing under ultrasonic conditions is advantageous because it consumes less heat than normal dyeing for the same shade. Lokhande *et al.* [117] dyed nylon with three different natural dyes using various mordants by two different techniques [open bath and high temperature high pressure (HTHP dyeing methods)], of which HTHP dyeing was found to be better as compared to open bath. Battacharya and Lohiya[118] also used the HTHP technique for dyeing cotton and polyester fibres with pomegranate rind, catechu, nova red and turmeric.

Tiwari and Vankar[119,120] studied unconventional natural dyeing using microwave and sonicator with alkanet root bark. Vankar *et al.*[121] studied and reported ecofriendly sonicator dyeing of cotton with *Rubia cordifolia* Linn using biomordant. Use of biomordant replaces metal mordants, thus making natural dyeing more ecofriendly. Vankar *et al.*[122] also studied conventional and ultrasonic methods of dyeing cotton fabric with aqueous extract of *Eclipta alba*. The effects of dyeing show higher colour strength values obtained by the latter. Beltrame *et al.*[123] studied and reported the dyeing of cotton in supercritical carbon dioxide fluid as newer solvent system. The advantages of *supercritical fluid extraction* as compared to aqueous liquid extraction and dyeing are that it is relatively rapid process because of the low viscosities and high diffusivities associated with supercritical CO_2 fluids. Kamal *et al.*[124] studied the mixture dyeing of *Terminilla arjun* fruit and chochineal with aqueous extract on wool fabric. Neetu and Shahnaz[125] studied the dyeing with combination of natural dyes obtained from onion skin and kilmora root. Samanta *et al.*[99] reported the application of mixture of turmeric and madder on cotton and reported that it yields some synergistic effect for enhancing colour strength.

However, these methods are still in research laboratory stage. None of them has yet commercialized due to many reasons, including high cost, ignorance about the process to the small scale dyers, etc.

2.5 Physico-chemical Studies on Dyeing Process Variables and Dyeing Kinetics

It is felt essential to develop a knowledge base on dye chemistry and effects of dyeing process variables as well as rate of dyeing and chemical kinetics of dyeing for different natural dyes and fibres combinations to manipulate the processes of natural dyeing efficiently in order to get maximum colour yield in economical way.

2.5.1 Dyeing Process Variables

Source-wise, the natural dyes have variable chemical compositions, which are influenced by a number of physical and chemical factors, besides the compositions of vegetal part of the plant from where the natural dye extracts are obtained. This again depends on conditions and place of growing, harvesting period, extraction methods and conditions, application method and technological process followed. Many workers have reported some of the most significant experimental results on laboratory trials regarding dyeing conditions, techniques and achievable best parameters for extraction and application of natural dyes, including observations on variation in extraction parameters, such as extraction temperature[126], extraction time, extraction solvent, vegetal material and liquor ratio, type of media or solvent used and also on observations of varying mordanting agent and technique as well as dyeing parameter.

The effects of dye extraction medium, optimum concentrations of dye source material, extraction time, dyeing time, mordant concentration and methods of mordanting on silk dyed with natural dyes has been reported by Grover *et al.*[127] and Dixit and Jahan[70]. The acidic media exhibited maximum per cent absorption for jatropha, lantana, hamelia and euphorbia dyes, while kilmora and walnut showed good results in alkaline medium. The result obtained from different experiments leads to the optimization of a standard recipe for a particular dye-mordant-fibre combination. Srivastava *et al.*[128] studied the optimum dyeing technique for dyeing wool by determining the optimum wavelength, dye material concentration, extraction time, dyeing time, *p*H, concentration of mordant, etc. Das *et al.*[91] reported colouring of wool and silk textiles with tea extracts, which have highest affinity for both wool and silk at *p*H 2 - 4 in presence and absence of either of the ferrous sulphate and aluminium sulphate as mordants. Optimization of dyeing process variables for wool with natural dyes obtained from turmeric has been studied and reported by Agarwal *et al.*[129]. Bansal and Sood[130] studied the optimum conditions for development of vegetable dye on cotton from *Eupatorium* leaves. The optimization of dyeing of wool by *Rhododendron arboretum* as a natural dye source was reported by Sati *et al.* [131]. Rose *et al.*[132], Maulik and Bhowmik[133], Siddiqui *et al.*[134] and Samanta *et al.*[74] studied the effect of process variables on dyeing with selective natural dyes. The standardization and optimization of dyeing conditions are essential for effectively colouring any textile in a particular shade in techno-economic way to produce maximum colour yield.

Gupta *et al.*[135] studied and reported the kinetics and thermodynamics of dyeing with Juglone for different fibres. The isotherm for wool, human hair, silk, nylon and polyester was linear, indicating a partition mechanism of dyeing. The slope of isotherms was found to increase with the increasing temperature in all the cases. ΔH and ΔS values were positive for all these dyeings. The apparent diffusion coefficient was highest for wool and lowest for silk. Gulrajani *et al.*[136] studied the kinetics of annatto and reported that it has high affinity for both nylon and polyester fibres. The process of dyeing is endothermic as the dye uptake increases at higher temperature. Mahale *et al.*[137] investigated the conditions of extraction and application of African mariegold on silk yarn. The optimum conditions were found to be 60 min dye extraction time, 30 min mordanting, 30 min dyeing using mixtures of 5% potash alum, 1% potassium dichromate and 1% copper sulphate as mordants. Samanta *et al.*[74] has studied the dyeing absorption isotherm, heat of dyeing, free energy and entropy of dyeing for red sandal wood[74] and jackfruit wood[138]. Study with red sandal wood revealed that this dyeing process follows a linear Nernst absorption isotherm for jute; while study on jackfruit wood revealed that Nernst absorption isotherm is followed in most of the cases, except jute-$FeSO_4$ –jackfruit combination of natural dyeing[138], where it follows Langmuir adsorption isotherm.

These studies are notably important for understanding the dyeing theory and physico-chemical dyeing parameters of different natural dye-fibre combinations. These are also important for practically manipulating dyeing conditions to get maximum colour yield from particular natural dyes.

2.6 Newer Shade Development, Colour Interaction Parameters and Dye Compatibility

Newer shades can be achieved by applying mixture of compatible natural dyes or by using sequential dyeing technique with two or three natural dyes. For the use of mixture of natural dyes, the dyers must know whether the natural dyes are compatible with each other or not. Reports are available on dyeing of different textiles with selective mixtures of natural dyes. According to one report[139] it is observed that the use of a mixture of turmeric and madder on cotton in case of simultaneous mordanting shows a synergistic effect in colour development than that for single dye application; 50:50 ratio of turmeric and madder gives the best results. For the combined dye application, it is observed that in case of simultaneous mordanting method, turmeric when combined with either madder or red sandal wood gives better colour strength, while myrobolan shows the reverse trend. Such studies using mixture of natural dyes on jute or cotton or any other textiles are rare and scanty. Several studies have been reported on compatibility[140-144] of binary and tertiary mixture of synthetic dyes, however such studies on natural dyes are still rare and sporadic.

Sakata and Kataryama[145], Patel *et al.* [146] and Sudhaker and Gowda[147] analyzed the different colour parameters of silk fabric dyed with dry Indian madder by L^*, a^* and b^* values. The colour of jute[148] dyed with aqueous extract of tea was investigated on computer aided colour measuring system in terms of K/S and CIE Lab colour difference values. CIE $L^*C^*H^*$ values were studied for cotton and woollen textiles dyed with yellow natural dye and it was found that the H^* values for cotton and wool were 74.19 and 75.15. This indicates the predominance of yellow hue with different mordants and high ΔE values, Iron (II) sulphate mordant with high ΔC^* and ΔH^* values shows change in shade towards grey to black, as studied by Tastsaroni and Eleftheriadis[149]. Mishra *et al.* [150] studied dyeing of silk fabric for reddish shade with natural lac dye of different concentrations and then measured the K/S values. Sarkar and Seal[151] studied the influence of different mordanting systems on colour strength and colour fastness of flax fabrics dyed with selective natural colourant. Results obtained were then analyzed and correlated with colour strength and related colour interaction parameters. Recently, Samanta *et al.*[152-154] have studied the compatibility of binary combinations of jackfruit wood with manjistha, red sandal wood, mariegold, sappan wood and babool applied on jute fabric. In this work, a newer and simple method of assessing relative compatibility rating (RCR) of pairs of natural dyes has been proposed with compatibility rating of 0-5 scale, (0 indicates completely non-compatible and 5 indicates highest order of compatibility), based on determination of newer colour difference index (CDI) values.

There are some recent reports for application of natural dyes even on synthetic fibres. According to one report[155], 100% nylon fabric does not pick up dyes such as heena and turmeric, but if it is pre-treated for 5 min with heat or / and acetic acid it readily picks up colour. Gupta *et al.*[156] reported few spectral curves confirming the behaviour of purpurin as a mordantable dye and showing the colour change with the mordant due to the characteristic of metal – dye interactions. Thus, for producing variety of shades and variations in L^*, C^*, H^* values, the use of different mordant-natural dye combination and mixture of natural dyes are the two important routes.

2.7 Effects of Chemical Pretreatments and Modification of Textile Materials

The primary objective in chemical modification of a polymer/ fibre material is normally to preserve its original chemical structure and related favourable properties. Such chemical modifications may involve incorporation of new functional groups with or without large scale chain rupture or chain degradation. This however involves addition of some newly built-in property criteria, favouring development of the modified material for improved dyebility with or without affecting some other property criteria.

There are many reports on the dyeing of unmodified and modified jute [157-160] and cotton[161] textiles with different classes of synthetic dyes. However, such studies are sporadic and scanty with natural dyes. There are only few reports available on the chemical modifications of cotton textiles for the improvement of their dyeability with natural dyes [99,161-163]. There is only one report[99] available on chemical modification of jute substrate with acrylamide monomer using $K_2S_2O_8$ initiation and cetyl trimethyl ammonium bromide (CTAB) for investigating their effects on subsequent dyeing with natural dyes like turmeric and madder. Treatment of textile materials with chitosan[164] obtained from the waste products of crab and prawn fishing is a possible route for the chemical modification of textile polymers to develop a variety of effects in textile dyeing and finishing applications. Bandhpoadhyay *et al*.[165] reported that the pre-treatment of cotton textiles with chitosan can reduce the amount of electrolyte addition during dyeing with reactive dyes and enhance fixation, but such studies using natural dyes are yet not reported.

Sorption behaviour of shellac, a natural thermosetting resin, on wool[164] fibres and enzymatic degradation of shellac-modified wool fibres has also been investigated. With the use of methanol as solvent, the amount of sorbed shellac is found to be maximum (about 0.03g/g of wool), which is decreased with the increase in molecular weight of the alcohol from methanol to *t*-butanol.

Shin *et al*.[166] studied the antimicrobial finishing of polypropylene nonwoven fabric by treatment with chitosan which has gained improved dyeability as well. Effect of low temperature plasma treatment[167] on colouring of wool and nylon-6 fabrics increases the dye uptake and saturated dye exhaustion for acid dye, despite the increased electro-negativity of the fibre surface. Pascual and Julia[168] reported that the pre-treatment with hydrogen peroxide improves the effectiveness of chitosan, Alkali pre-treatment followed by chitosan application increases the rate of dyeing and alters the physico-chemical parameters of dyeing kinetics and causes a reduction in hydrophobicity and shrinkage. However, a high concentration of chitosan can produce a rough hand and uneven dyeing, increasing the viscosity as well as resistance to shrink. Davarpanah *et al*.[169] studied and reported the surface modification of silk fibre using anhydrides to graft the polysaccharide chitosan and to improve dyeing ability of the grafted silk. The physical properties show acceptable changes, regardless of weight gain. Scanning electron microscopy (SEM) analysis shows the presence of foreign materials firmly attached to the surface of silk. FTIR spectroscopy provided evidence that the chitosan is grafted onto the acylated silk through the formation of new covalent bonds. The dyeing of the chitosan grafted acylated silk fibre indicated the higher dyeability in comparison to the acylated and degummed silk samples.

However, specific chemical modification is required to suit different purposes and the same has many odd effects too, i.e. increasing yellowing, variation in shades and colour fastness properties. These effects are not always favorable and hence one can use this judiciously with specific knowledge and study.

2.8 Colour Fastness Properties of Natural Dyed Textiles

Colour fastness is the resistance of a material to change any of its colour characteristics or extent of transfer of its colourants to adjacent white materials in touch. The colour fastness is usually rated either by loss of depth of colour in original sample or it is also expressed by staining scale, i.e. the accompanying white material gets tinted or stained by the colour of the original fabric. However, among all types of colour fastness, light fastness, wash fastness and rub fastness are considered generally for any textiles; perspiration fastness is considered specifically for apparels only.

2.8.1 Light Fastness

Light fastness of many natural dyes, particularly which are extracted from flower petals are found to be poor to medium. So, an extensive work has been carried out to improve the light fastness properties of different natural dyed textiles. Cook[170] has reported a comprehensive review on different attempts made for improving colour fastness properties of dyes on different textile fibres by different means. The study includes tannin-related after-treatments for improving the wash fastness and light fastness of mordantable dyes on cotton; some of these treatments might be applicable to specific natural dyes.

Most of the natural dyes have poor light stability as compared to the best available synthetic dyes, and hence the colours in museum textile are often different from their original colours. The relative light stability of a range of dyes was reviewed by Padfield and Landi[171] who also studied changes in qualitative fashion. These changes in colour were studied quantitatively by Duff *et al.*[172], who expressed the changes in terms of the Munsell scale and also in CIE colour parameters. Wool dyed with nine natural dyes was exposed in Microscal MBTF fading lamp. The fastness ratings were similar to those observed by Padfield and Landi[171] in day light fading. After rating by the blue wool standards for light fastness (LF) rating, yellow dyes (old fustic, Persian berries) showed poor light fastness (1-2) ; reds [(cochineal (tin mordant)], alizarin (alum and tin mordant) and lac (tin mordant) showed better light fastness (3-4); indigo showed light fastness rating of 3-4 or 5-6 depending on the mordant used; and logwood black (chrome mordant) showed light fastness rating of 4-5 or 6-7 using other mordants. Gupta[173,174] reported the effects of chemical structure of natural dyes on light fastness and other colour fastness properties.

A large proportion of natural dyes is, of course, mordant dyes. There is strong influence of nature, type and concentration of mordants on wash and light fastness grades. The influences of different mordants were found to play important role in fading of 18 yellow natural dyes[175]. Wool dyed with different natural dyes specimens was exposed to a xenon arc lamp for assessing its light fastness upto 8 AATCC fading units equivalent to BS-8B blue wool standards. The corresponding colour change after exposure to xenon arc lamp was also assessed in each case.

Turmeric, fustic and mariegold dyes faded significantly more than any of the other yellow dyes. However, the use of tin and alum mordants causes significantly more fading than that with the use of chrome, iron, or copper mordant. Thus, the type of mordant is found to be more important than the dye itself in determining the light fastness of natural coloured textiles.

Oda [176,177] reported effects of various additives on the photofading of carthamin in cellulose acetate film. The rate of photofading was remarkably suppressed in the presence of nickel hydroxyl arylsulphonates, while the addition of UV absorbers afforded little retardation in the rate of fading. Cristea and Vilarim[178], Lee *et al.*[179], Micheal and Zaher[180] and Gupta *et al.*[181] made various attempts to improve the light fastness of different fabrics dyed with natural dyes. Samanta *et al.*[154] have recently reported the improvement in light fastness to one to half unit for natural dyed jute textiles by application of 1% benztriazole in specific conditions. The corresponding mechanism of action of benztriazole on jute has also been studied and reported by them.

2.8.2 Wash Fastness

Duff *et al.*[182] studied the light fastness and wash fastness [172,173] under standard condition (50°C) and also at 20°C with a washing formulation used in conservation work for restoration of old textiles. Some dyes undergo marked changes in hue on washing due to the presence of even small amounts of alkali in washing mixtures, highlighting the necessity to know the *p*H of alkaline solutions used for the cleaning of textiles dyed with natural dyes. As a general rule, natural dyes show moderate wash fastness on wool, as assessed by the ISO II test. Logwood and indigo dyes are found to be much faster. Duff *et al.*[182] studied the wash fastness of dyeing from native Scottish and imported dyes. In the ISO II test, the fastness of the indigo and logwood was superior to that of the native natural dyeing, such as presian berries and water-lilly root respectively. But in comparison of native and imported yellow, reds, red/purples, greens and browns, there was little difference between the two groups. Samanta *et al.*[154] recently reported that the treatment with 2%CTAB or sandofix-HCF improves the wash fastness to nearly 1 unit.

2.8.3 Rub Fastness

In general, rub fastness of most of the natural dyes is found to be moderate to good and does not require any after-treatment. Samanta *et al.*[73,152.183] reported that the jackfruit wood, manjistha, red sandal wood, babool and mariegold have good rub fastness on jute and cotton fabrics. Sarkar[58, 59] also reported good rub fastness for mariegold on cotton, silk and wool. Mahale *et al*.[86] studied the dry and wet rub fastness of silk dyed with *Acalypha*. It also has good rub fastness property. Khan *et al*.[52] reported that the cutch and ratanjot show moderate to good dry rub fastness but the wet rub fastness is found to be average.

Samanta *et al*.[184] studied the dye colour strength related parameters and compatability for dyeing cotton fabrics with binary mixture of jackfruit wood and other nature dyes.

However, it must be remembered that the colour fastness of natural dyes not only depends on chemical nature and type of natural colourants, but also on chemical nature and type of mordants being used. So, a dyer must know the use of proper combinations of fibre-mordant to achieve best colour fastness. More research is required on exploring about the use of natural after- treatment agents to improve both wash and light fastness of natural dyes.

3 Conclusions

It has been found that the required scientific studies and systematic reports on dyeing of textiles with natural dyes are still insufficient. There are lots of natural products still untouched. Though natural colouration is known from ancient time as artisanal practice for handicrafts, paintings and handloom textiles, the chemistry of interaction of such colourants with textile materials is of relatively recent interest for producing ecofriendly textiles. Thus, there are needs of many more active researches to build a knowledge base and database with production of appropriate shade cards for different textiles. It will help to popularize the use of natural dyes by solving some of its problems relative to application methods, reproducibility and colour fastness. Improving the computerized colour matching for use of synthetic dyes has now become a regular practice in most of the textile industry (except jute industry). It has still not become possible mainly due to the essential two dependant factors (dye and mordant) and colour development mechanism of natural colours applied to textiles. Whether pre-mordanted or simultaneous mordanted or post-mordanted, the colour depends not only on the natural colourant but also on the mordant and mordanting assistants used. The prediction of match by controlling these two variables simulataneously is not possible by the latest technology known so far. However, for specific pre-mordanting method, colour matching database for natural dyeing of any particular textile material and match prediction are possible with computerized programe.

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