

Fabric Dye Yielding Potential of Selected Herbaceous and Arboreal Plant Species of the Kashmir Valley

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(2010-331-D)



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Thesis

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Sher-e-Kashmir
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Certificate – I

This is to certify that the thesis entitled “**Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Environmental Sciences**, to the Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, is a record of bonafide research work carried out by **Mr. Syed Maqbool Geelani (Regd. No. 2010-331-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that any help or information received during the course of investigation have duly been acknowledged.

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the Kashmir valley”**

ABSTRACT

The present investigation was carried out during 2012-13 to study the fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley. 6 plant materials of 5 species (*Quercus robura* L. (fruit cups), *Juglans regia* L. (leaves), *Juglans regia* L. (fruit hull), *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves), *Nasturtium officinale* R.Br. (leaves) and *Tagetes patula* L. (petals) were selected for dye extraction and 4 plant material of 3 species *Salix alba* L. (wood extract and wood ash), *Populus deltoides* Bartram ex Marsh. (wood ash) and *Punica granatum* L. (peel) for mordant extraction. The experimental materials for dye extraction were collected from university campus and for mordants from outskirts of Kashmir valley. Morphological attributes of plant species were recorded for characterization and identification. The extraction of the natural dyes was carried out by Soxhlet method and mordants by soaking method using distilled water as solvent. The yield of the dye powder was assessed and dye quantification was carried out. The extracted natural dye were applied on pashmina, wool, silk and cotton fabrics, adopting pre, simultaneous and post mordanting methods, including and excluding mordant. The percent absorption of different dyes were assessed and colour coordinates, colour strength and retention and fastness properties of dyed fabrics were examined as per standard test

methods. Results revealed highest value of anthocyanins in *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) and lowest in *Nasturtium officinale* R.Br (leaves). Highest carotenoid and chlorophyll content were recorded in *Juglans regia* L. (leaves) and lowest in *Quercus robura* L. (fruit cups). Leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea*. recorded highest percent yield and petals of *Tagetes patula* L. recorded lowest percent yield. Highest average percent dye absorption by pashmina, wool, silk and cotton was recorded due to *Juglans regia* L. (leaves), *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves), *Juglans regia* L. (fruit hull) and *Juglans regia* L. (leaves) respectively. Highest average percent absorption of mordants by pashmina, wool, silk and cotton was recorded due to *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood ash), *Salix alba* L. (wood extract) and *Punica granatum* L. (peel) respectively. The pre mordanting method of dyeing showed the highest average percent absorption by the pashmina and wool fabric and simultaneous mordanting recorded highest percent absorption value by silk and cotton fabric. Colour coordinates (L^* , a^* , b^* , C^* , h° and ΔE) of dyed fabrics varied in each dye, mordant and method. Different shades and colour tones were recorded with different dyes, mordants and methods. Highest colour strength (K/S) and relative colour strength value was recorded in wool, pashmina and silk due to *Juglans regia* L. (leaves) dye mordanted with *Punica granatum* L. (peel), *Salix alba* L. (wood extract) and *Punica granatum* L. (peel). In cotton fabric highest colour strength and relative colour strength was recorded due to *Nasturtium officinale* R.Br. (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant and lowest value due to *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant. The highest average colour strength (K/S) of mordants was recorded due to *Punica granatum* L. (peel) in pashmina, wool, silk and cotton fabric. The lowest value of colour strength in pashmina and wool fabric were recorded due to *Salix alba* L. (wood extract). *Salix alba* L. (wood ash) recorded lowest value in silk and cotton fabric. Simultaneous mordanting recorded highest average colour strength value in pashmina fabric, post mordanting in wool fabric, simultaneous mordanting in silk fabric and without mordanting in cotton fabric. The lowest average value of colour strength (K/S) was recorded by post mordanting in cotton and silk fabric and without mordanting in wool and pashmina fabric. All the extracted dyes and mordants recorded acceptable fastness grades. Mordants in combination with dyes and mordanting methods showed significant results of washing fastness, light fastness and rubbing fastness properties. Natural mordants in combination with most of natural dyes recorded an increase in fastness properties of the dyed fabrics. The mordanted fabric samples showed better dye quality than the unmordanted samples. The affinity of the dyes and mordants recorded best on pashmina, wool and silk fabric while as cotton fabric showed very poor affinity for the selected dyes and mordants.

From the present study it is concluded that all the extracted natural dyes and mordants recorded excellent results on selected fabrics except cotton. The natural mordants showed major influence on the properties of selected fabrics and

helped in attaining the varieties of beautiful shades which also facilitated the colour strength and colour fastness properties against washing, light and rubbing. In view of the demand of natural dyed fabrics in national and international market, these dyes and mordants can be used ecofriendly. Thus, selected plant species can be used as good and efficient source of natural dyes and mordants for the dyeing of pashmina, wool and silk fabrics.

Key words: Eco friendly, Natural dyes, Natural mordants, Mordanting, Fabrics, Pollution.

Signature of Student

Signature of Major Advisor

Dated: _____

Dated: _____

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The real value of a person is his knowledge (and the perfection of his attainments). His worth and position would be in accordance with the status of knowledge and attainment he holds. The worth of every person is according to the extent of his knowledge.

The holy Prophet (s) said: "The virtue of knowledge is more beloved with Allah than the virtue of worship"

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Place : Srinagar

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Chapter – 1

INTRODUCTION

Colour is an element which transforms the entire fabric life. It is the property that is noticed and is the first factor governing fabric choice. The importance of colour in textiles has been recognized before thousands of years (Vankar, 2000). Natural dyes, dyestuffs and dyeing are as old as textiles themselves. Dyeing was practiced during the Bronze age in Europe. Though, earliest written record of the use of natural dyes was found in China dated 2600 BC, however dyeing was known as early as 2500 BC in the Indus valley period. This knowledge is substantiated by findings of coloured garments of cloth and traces of madder dye in the ruins of the Indus valley civilization at Mohenjodaro and Harappa (3500 BC) (Roy, 1978).

Until 1856 natural materials were the only source of dyes. The commerce of natural dye was considered as a measure of economic prosperity of nations. Accidental discovery of Mauvine - coloured coal tar products by Sir Henry Perkin was the starting point for synthetic dye industry. The increasing market demand for dyes and the dwindling number of dye yielding plants forced the emergence of synthetic dyes like aniline and coal-tar, which threatened total replacement of natural dyes. Finally with the synthetic indigo blue substitute in production in 1900, the use of natural dyes became very limited (Gulrajani, 1999).

Dyeing is the art of colouring textiles in such a manner that the colour is fast and not removed by different operations like washing, rubbing, sunlight, perspiration etc, to which the textiles are usually subjected (Cowan and Jungerman, 1993). Substances with considerable colouring capacity are widely employed in the textile, pharmaceutical, food, cosmetics, plastics, photographic and paper industries (Carneiro *et al.*, 2007). The dyes can adhere to compatible surfaces by solution, by forming covalent bond or complexes with salts or metals, by physical adsorption or by mechanical retention (Bafana *et al.*, 2011).

Dyes are classified according to their application and chemical structure and are composed of a group of atoms known as chromophores, responsible for the dye colour. These chromophore containing centers are based on diverse functional groups, such as azo, anthraquinone, methane, nitro, aril methane, carbonyl and others. In addition electron withdrawing or donating substituents so as to generate or intensify colour of the chromophores are denominated as auxochromes (Arun and Bhaskara, 2010). The colour of dyed fabric depends on the nature of the chromophores as well as the substituent functional groups of the auxochromes of the dye molecular species (Siva, 2007). Chromophores and auxochromes are considered the most important chemical constituents of dyes responsible for textile colouration (Foulds, 1995).

Environmental problems from the dyeing of textiles arose after industrialization, when traditional natural dyes were replaced by synthetic dyes. Synthetic dyes are designed to resist chemicals, and improve the quality of the product but are persistent in the environment. Synthetic dyes are produced from cheap petroleum sources and generally have easy dyeing, superior fastness properties, widely available at an economical price and produce a wide variety of colours and shades (Aminoddin and Haji, 2010). The chemicals used to produce synthetic dyes are highly toxic, carcinogenic, allergic, explosive and dangerous to work with. The production of synthetic dyes involves many violent reactions, which are considered health hazardous (Wilkinson and Mcgechan, 1996).

Azo dyes are the largest group of colourants, constituting 60-70 % of all organic dyes produced in the world (Bafana *et al.*, 2011; Carliell *et al.*, 1998). The success of azo dyes is due to their ease and cost effectiveness for synthesis as compared to natural dyes, and also their great structural diversity and medium to high fastness properties in relation to light as well as to wetness (Bafana *et al.*, 2011; Seesuriyachan *et al.*, 2007). They have a wide range of applications in the textile, pharmaceutical and cosmetic industries and are also used in food, paper,

leather and paints (Chung and Cerniglia, 1992). However some azo dyes can show toxic effects, especially carcinogenic and mutagenic events (Pinheiro *et al.*, 2004).

Azo dyes constitute the largest chemical class of synthetic textile dyes. These dyes may, however, pose a health risk to humans due to the formation of mutagenic/carcinogenic aromatic amines upon reductive cleavage of their azo groups (-N=N-) (Ahlstrom, 2007). The best known aromatic amine is aniline, but another example is the potent human bladder carcinogen benzidine, which is derived from the reduction of several azo dyes (Ahlstrom, 2007; Levine, 1991). The results of some studies indicate that anaerobic conditions, present only in the intestines, are required for the degradation of azo dyes (Levine, 1991). Systemically ingested azo dyes used in food, sweets, soft drinks and as colouring agents for drugs have been blamed for provoking immediate type hypersensitive reactions such as urticaria and asthma bronchiale (Michaelsson and Juhlin, 1973). Clinical studies indicate that one azo dye, tartrazine (E102), is occasionally associated with flares of urticaria or asthma. The mechanism of sensitivity to tartrazine is obscure, and has been called “pseudo allergic” (Dipalma, 1990). Additional studies must be conducted to clarify the cause and the mechanism involved (Wuthrich, 1993). There is no convincing evidence in the literature of reactivity to other systemically ingested azo dyes (Simon, 1986). More studies must be carried out to determine the pathways of degradation of dyes and the metabolic/toxic properties of their degradation products.

Possible contact allergic reactions to synthetic textile dyes have been recognized since 1868 (Cronin, 1980; Lisboa, 1994). In 1884, the influence of new synthetic dyes was debated in *The Times* and in medical journals in England, as a result of the numerous complaints of unacceptable skin eruptions, caused by wearing, when in the state of perspiration, hosiery and flannel coloured with aniline dyes (Garfield, 2000). In 1940, nylon stockings were introduced into the American market. Soon after their introduction, cases of nylon stocking dermatitis were reported. This was originally called “nylon allergy”. Upon further

investigation, however, it was found that the dermatitis was caused by dyes and not by nylon (Hatch, 1985; Kousa, 1980). Dobkevitch *et al.* (1947) reported eczema due to cross hypersensitivity between the azo dye Disperse Yellow (DY) 3 in nylon stockings and the para-amino compound p-phenylenediamine (PPD), today mostly used as a hair dye. Starting in 1985, several authors reported patients with acute contact Dermatitis caused by dark clothes, mainly due to contact allergy to other disperse dyes such as Disperse Blue (DB) 106 and Disperse Blue (DB) 124 (Menezes, 1985; Menezes, 1987; Hausen, 1993).

It is estimated that over 10,000 different dyes and pigments are used industrially and over 7×10^5 tons of synthetic dyes are annually produced worldwide (Robinson *et al.*, 2001; Ogugbue and Sawidis, 2011). Most of these dyes escape conventional wastewater treatment processes and persist in the environment as a result of their high stability to light, temperature, water, detergents which are mostly chemicals. In textile industries, 50 % of the dyes are lost in effluents (Moreira *et al.*, 2004) are mostly toxic and carcinogenic to living organisms especially aquatic animals and humans (Young and Yu, 1997).

The release of untreated wastewater from the dyeing industry is a threat to the environment. Industries produce coloured wastewater with a high organic load, which can contribute enormously to the environmental pollution of surface water and treatment plants if not properly treated before disposal into the water resources. The ingestion of water contaminated with textile dyes can cause serious damage to the human health and of other living organisms, due to the toxicity and mutagenicity of its components (Prado *et al.*, 2004).

The textile industry consumes a substantial amount of water in manufacturing processes used mainly in the dyeing and finishing operations. In this industry, up to 200, 000 tons of dyes are lost to effluents every year during the dyeing and finishing operations, due to the inefficiency of the dyeing process (Ogugbue and Sawidis, 2011). The wastewater from textile plants is classified as

the most polluting of all the industrial sectors, considering the volume generated as well as the effluent composition (Ben *et al.*, 2012).

Recalcitrant organic, coloured, toxicant, surfactant and chlorinated compounds and salts are the main pollutants in textile effluents (Ben *et al.*, 2012). Textile wastewaters are characterized by extreme fluctuations in many parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH, colour and salinity. The discharge of highly coloured synthetic dye effluents into inland and coastal waters is an environmental problem of growing concern (Padmavathy *et al.*, 2003). Pollution by dye wastewater is becoming increasingly alarming and is of great environmental concern (Moreira *et al.*, 2004). Even presence of very small amounts of dyes (<1 mg/L for some dyes) in the water, which are nevertheless highly visible, seriously affect the aesthetic quality and transparency of water bodies like lakes, rivers leading to damage to the aquatic environment (Ibrahim, 1996; Wijetunga *et al.*, 2010). During the dyeing process loss of colourants to the environment can reach 10-50 % (Forgacs, 2004; Przystas, 2012; Ben *et al.*, 2012; Vaidya and Datye, 1982). Some dyes are highly toxic and mutagenic, and also decrease light penetration and photosynthetic activity, causing oxygen deficiency and limiting beneficial uses such as recreation, drinking and irrigation (Forgacs, 2004; Przystas, 2012; Hubbe, 2012).

The textile industries commonly utilize reactive dyes for dyeing different types of fibres, producing effluents comprising of several types of chemicals like dispersants, leveling agents, acids, alkalis, carriers etc. (Cooper, 1995). These chemicals cause different diseases like contact dermatitis, allergic dermatoses, respiratory diseases and asthma (Thoren *et al.*, 1980). Workers in the textile industry have a two-fold increased risk of contracting bladder cancer compared to workers in other occupations like aviation, agriculture and construction (Gonzales *et al.*, 1988). Different tests conducted for mutagenicity, genotoxicity, carcinogenicity and teratogenicity reported adverse effects of textile dyes (Kaisa *et al.*, 2007).

One of the most difficult tasks confronted by the wastewater treatment plants of textile industries is the removal of the colour of these compounds, mainly because dyes and pigments are designed to resist biodegradation, such that they remain in the environment for a long period of time. For example, the half-life of the hydrolyzed dye reactive blue 19 is about 46 years at pH 7 and 25°C (Hao *et al.*, 2000; Firmino *et al.*, 2010).

Textile dyeing is recognized as one of the most environmentally unfriendly industrial processes, it is of extreme importance to understand the critical points of the dyeing process so as to find alternative, ecofriendly methods. Considering the importance of the coloured products in present day societies, it is of relevance to optimize the colouring process with the objective of reducing the environmental impact of the textile industry. The increased demand for textile products and the proportional increase in their production, and the use of synthetic dyes have together contributed to dye wastewater becoming one of the substantial sources of severe pollution problems in current times (Dos *et al.*, 2007; Ogugbue and Sawidis, 2011).

As a result of the worldwide concern over the carcinogenic effects, toxicity and allergic reactions associated with synthetic dyes interest in the revival of natural dyes in textile colouration is increasing (Kulkarni *et al.*, 2011). Moreover, many countries have already imposed stringent environmental standards over synthetic dyes. Germany was the first to take initiative to put ban on numerous specific Azo dyes for their manufacturing and applications. Netherlands, India and some other countries also followed the ban. The recent ban on the use of Azo dyes by European Union has also increased the scope for natural dyes (Patel, 2011).

Nature does not produce colours that are garish or fluorescent. Man often finds his most useful chemicals in plants and then copies them. There are a vast number of colours that can be obtained from nature. Leaves, roots, flowers, barks, fruits and stems can be used. Many of them used today in the cottage textile

industry, as would have been used traditional yarns from the time that man first stopped wearing animal skins and started weaving cloth and spinning wool. The colour adopted by the fibre is heavily influenced by the chemicals (normally called mordants) added to the dye.

Natural dyes can be sorted into three categories depending upon source is dyes obtained from plants, animals and minerals. Natural dyes mostly require mordant to fix to the fabric and prevent the colour from either fading with exposure to light or washing out. These compounds bind the natural dyes to the fabrics. A mordant is an element which aids the chemical reaction that take place between the dye and the fibre, so that the dye is absorbed.

The natural dyes are clinically safer than their synthetic analogues, in handling and use because of non carcinogenic and biodegradable nature (Aminoddin and Haji, 2010). Natural dyes exhibit better biodegradability and generally have a better compatibility with the environment. They are less toxic, polluting, health hazardous, non carcinogenic, easily available and renewable (Adeel *et al.*, 2009). Though possess lower toxicity and allergic reactions than synthetic dyes however safety of natural dyes needs to be proved if they are used more widely and in commercial process (Kumar and Bharti, 1998).

The global demand for natural dyes is about 10,000 tonnes, which is equivalent to 1 % of the world synthetic dye consumption (Sachan and Kapoor, 2007). However, demand for natural dyed products is increasing in international market. Natural dyes are excellent for long endurance and retain great beauty and charm. They create very harmonious combinations with various natural mordants. Manufacturing of natural dyes offers a rich and varied source providing a source of income through sustainable harvest and sale.

In view of advancements in technology and urban development, there is dire need to assess the environmental pollution problems caused due to synthetic dyes. Considerable research work is being conducted throughout the world to

search out new cheaper dye sources and extraction methods for producing sufficient quantities of viable safe natural pigments and dyes. Kashmir valley abounds in rich plant biodiversity of great potential. To study the “Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley” present work is proposed with the following objectives:

- 1) Collection, characterization and identification of selected dye yielding plants.
- 2) Extraction, quantification and colour quality of pigments.
- 3) Impact of natural dyes and mordants on fabric properties and dye retaining attributes.

Chapter – 2

REVIEW OF LITERATURE

Colour and its various uses come over the horizon from pre historical period by all cultural groups and on all major land masses. Ever since primitive people used matter to stain hides, decorate shells and feathers, and paint their story on the walls of the ancient caves. These original natural colourants have a timeless history of application, especially as textile dyes. Almost all parts of the plants like root, bark, leaf, fruit, wood, seed, flower etc can be a good source of natural dyes. Any part of a plant which can yield 1-4 % dye, can be considered as a potential natural dye source. In India nearly 450 taxa are known to yield dyes and thus India harbour a wealth of useful resources. In India total market of herbal dyes is to the tune of US \$ 1 billion and it is tremendously growing at the rate of 12 % per annum and per capita consumption of dyes varies from 400 g to 15 kg in developed and under developed countries for their utility in paints, inks, textiles, polymers etc. (Gokhale *et al.*, 2004). India is major exporter of herbal dyes due to ban on production of some of the synthetic dyes and intermediates in developed countries due to pollution problem.

Kakati and Yadava (1990) studied seasonal changes in chlorophyll a, b and carotenoids in *Bothriochloa intermedia*/Imperata cylindrica grassland at Imphal in North East India. The total standing crop of chlorophyll was maximum (1.5 g/m^2) in September and minimum (0.12 g) in February and Carotenoids were maximum (0.23 g/m^2) in November and minimum (0.024 g) in February. Maximum chlorophyll and carotenoid concentration were found in October and November respectively. The standing crop of chlorophyll (g/m^2) showed a highly significant relationship with live biomass.

Soyza *et al.* (1990) measured the chlorophyll content in leaf discs of known area and mass from 820 leaves from 8 trees of *Sassafras albidum* growing along the floodplain of the Bronx River, New York. *Sassafras* displayed leaves of

a few discrete forms: leaves with entire margins predominated at the proximal and distal nodes of shoots while lobed leaves were most common at the intermediate nodes. In regression analysis for individual trees, leaf nodal position accounted for 30-50 % of the variance in chlorophyll content. Leaves of the intermediate nodes 6-11 (about 46 % of all leaves) accounted for 59.3 % of total leaf surface area and had the highest chlorophyll content per unit mass and per unit area. Leaf chlorophyll content was significantly greater in shade leaves in 6 trees of total 8 trees on a per unit mass basis, and lower in shade leaves in 5 trees of total 8 trees on a per unit area basis. There were no significant differences in chlorophyll content between shapes of leaves from sun or shade positions or between trees.

Kononkov *et al.* (1995) determined the contents of chlorophyll, carotenoids and beta-cyanin in leaves picked at the flowering stage from 31 specimens of *Amaranthus tricolour*, *A. caudatus* and *A. cruentus*. The colour intensity of leaves, stem and raceme of the plants formed 6 groups and 8 entries with high productivity and intense red-violet leaf colouration. Content of chlorophyll a + b was highest in *A. tricolour* accessions K49 from Kyrgyzstan (14.61 mg/g) and K99 from China (15.12 mg/g). These 2 accessions also had the highest carotenoid content (4.95 and 4.23 mg/g, respectively), while K99 reported the highest *amaranthin* content (34.2 mg/g).

Donner *et al.* (1997) investigated the occurrence of the four major anthocyanins, cyaniding 3-glucoside, cyaniding 3-laminaribioside, cyaniding 3-malonylglucoside and cyanidin 3-malonyllaminaribioside. In addition, four new minor anthocyanin pigments were isolated and characterized from red onions. Two structures were determined by chemical and spectroscopic methods. The peaks were recorded at 280 nm (flavonoids and phenolic acids) and 525 nm (anthocyanins).

Ozrenk *et al.* (2012) studied, 14 well-adapted genotypes of pistachio (*Pistachio vera* L.) grown in Diyarbakr (Southeastern Turkey) and 15 walnut (*Juglans regia* L.) genotypes grown in Erzincan (Eastern Turkey). Pistachio

genotypes contained 8.16-9.33 % palmitic acid, 0.54-0.68 % palmitoleic acid, 2.35-4.21 % stearic acid, 67.81-76.82 % oleic acid, 9.42-18.32 % linoleic acid, 0.27-0.38 % linolenic acid and 0.19-0.33 % arachidic acid. The range of selenium, alpha -tocopherol, gamma tocopherol, delta-tocopherol, alpha-tocotrienoid, gamma-tocotrienoid and total carotenoid of these promising genotypes were found to be between 11.44 and 190.71 mg/g, 1.36 and 26.93, 36.17 and 170, 0.45 and 2.61, 0.96 and 3.76, 2.33 and 37.72 and 1.01 and 4.93 mg/kg, respectively. Linoleic acid ranging from 43.19 % to 53.16 % was the most abundant fatty acid in 15 pomologically selected walnut genotypes, followed by oleic and linolenic acids (31.91 % and 11.46 %, respectively). Their selenium contents ranged between 7.25 and 57.67 mg/g gamma tocopherol was the predominant tocopherol in walnut genotypes.

Piccaglia *et al.* (1997) characterized typical chromatographic profile of pigments in petals and calyces of marigold (*Tagetes patula* and *T. erecta*) by HPLC combined with a diode array detector (DAD). Relevant quantitative differences were found among the marigold types which had a total content of pigments ranging from 17 to 570 mg : 100 g in the petals and from 0.4 to 18.6 mg : 100 g in the calyces. The petal colours were also defined by the L*, a* and b* values determined. Differences in petal colour were well related to the pigment content and good correlations between pigment concentration and L* and a* values were found.

Akca *et al.* (2001) studied the effects of gibberellic acid application on the growth and morphological characteristics of *Juglans regia* seedlings and reported significant differences in seedling characteristics between treated seedlings and control plants. The shoot growth increased as parallel to high GA3 application. But the chlorophyll content and leaf area decreased. The plant height was determined as 29.4, 37.3, 52.3, 53.1 and 64.8 cm, chlorophyll content was determined as 1.029, 0.930, 0.712, 0.335 and 0.264 mg/g in the control plant and 50, 100, 150 and 200 ppm in GA3 treated plants respectively.

Perucka *et al.* (2001) evaluated the chlorophyll and anthocyanin contents of three *Rheum rhaponticum* L. cultivars, i.e. Purpurat, Wczesny Hosera and Wisniowy. The chlorophylls and anthocyanins were isolated from fresh petioles. Differences in chlorophyll content were not significant among cultivars, however, the highest anthocyanin content (0.2 mg/100 g fresh matter) was recorded for Wisniowy.

Barzana *et al.* (2002) proposed an alternative extraction process for carotenoids from *Tagetes erecta* petals, consisting of a simultaneous enzymatic treatment and solvent extraction. The process employed milled fresh flowers directly as raw material, eliminating the inefficient silage and drying operations as well as the generation of hard to deal with the aqueous effluents present in traditional processes. The process developed was tested at the 80 L scale, where under optimal conditions a carotenoid recovery yield of 97 % was obtained.

Amubode, (2003) extracted natural dyes by boiling onion skins, cashew, mango and teak leaves (10 % w/v) in water for 30 minutes. During the dyeing process alum, potash or common salt (5 g/litre) were used as mordants. Most of the natural dyes extracted showed no affinity with textile unless with a mordant, which was applied on the fabric before dye application. The colour produced on textile was dependent on the mordant used.

Wei *et al.* (2003) studied the systematic selection and optimization of the two phase solvent system to separate lutein from the crude extract of the Marigold flower petals. They extracted 100gm petals homogenized with (1000 ml) isopropyl alcohol and the residue was extracted with a 1:1 solution of acetone: hexane (100 ml). The petals were further extracted with hexane/acetone/methanol/toluene (10:7:6:7; /V/V/V), ethanol/hexane/acetone (6:1:1; V/V/V). The filtrate obtained from vacuum filtration were combined in a separating funnel, water was added to hasten the phase separation of the hexane layer which was saved. They found the volume ratio of the solvent system of n-heptane-

chloroform-acetonitrile (10:3:7; V/V/V) was suitable for obtaining lutein. The lutein yielded 15.3 mg at over 98.5 % purity based on HPLC peaks.

Buk Gu *et al.* (2004) studied the effects of dyeing duration (5, 15, 30, 45 or 60 minutes), concentration (1, 2, 4 or 6 %), temperature (10-20, 30-40, 50-60, 70-80 or 90-100 °C) and pH (5, 7 or 9) of the dyestuff from marigold (*Tagetes erecta*) plants on the dyeability of silk fabrics. The dyestuff was extracted from marigold plants, spray-dried and made into powder. The colour strength, and a* and b* values showed an increase, whereas the L* values decreased with increasing dyestuff concentration and dyeing duration. The a* and b* values were highest after dyeing for 45 minutes. The L* value was lower (49.12-64.33) at higher dyeing temperatures (90-100 °C) than at lower dyeing temperatures (70-80 °C). The values of a* and b*, however, were higher at lower dyeing temperatures than at higher dyeing temperatures. The dyed silk recorded the highest ΔE values and the lowest L* values at pH 5. However, the b value was highest at pH 7.

Kaczynska and Chylinski (2004) investigated the pigment contents and their distribution in flowers and leaves of some cultivars in *Canna generalis* (Brillant, La Fayette and Ambassador) from Poland. Brilliant contained pelargonidin: cyanidin ratio of 1:14 and cyanidin: delphinidin ratio of 2:06; while in Ambassador, these were 4.50 and 0.90, respectively. Carotenoids (98.3 %) were responsible for the orange-red pigmentation of La Fayette flowers. Ambassador orange flowers and Brilliant red flowers contained both carotenoids and anthocyanins.

Rashmi *et al.* (2004) conducted an experiment to determine the effect of Katha leaf dye, obtained from the heartwood of *Acacia catechu*, on the yarn properties of UAS-bred sheep wool. Mordanting with different mordant concentrations showed an increase in the dye uptake by wool samples with reduced yarn strength and elongation of the wool samples by dyeing forming a vivid range of light to dark brown, olive green and green shades with different mordants and showed a positive and non-significant correlation with percentage

of dye absorption. The correlation analysis showed no significant difference among the physical properties.

Waheed and Alam (2004) carried out dyeing of silk fabric with aqueous extract of Kikar bark (*Acacia Arabica*, *A. nilotica*) and Madder bark (*Rubia cordifolia*) by using various metal sulfates as mordants. The three techniques of mordanting were used for dyeing the fabric. The fastness properties i.e. crock fastness, washing fastness and light fastness of the dyed samples were determined and comparison was made for control and samples dyed in the presence of the metal ions. The three fastness attributes of the dyed samples were found to be good to excellent. The colour of the dyed silk was investigated on computer colour matching system in terms of reflectance, K/S and CIE L*a*b* colour values.

Kant and Dutt (2005) conducted ethnobotanical survey in the Neeru catchment, Doda, Jammu and Kashmir, India, in the vicinity of lesser Himalayas and noticed some local tribes, i.e. Gaddies, Shippies and a few other professionals like weavers and shoemakers, using plant parts for dyeing hand woven threads and hides, respectively. Different plant species, i.e. *Berberis lycium*, *Geranium nepalense*, *Geranium wallichianum*, *Juglans regia*, *Macrotomia benthamii*, *Pistacia integerrima*, *Rubia cordifolia*, *Rumex nepalensis* and *Girardinia heterophylla*, were used for such purposes.

Paul *et al.* (2005) optimized various dyeing variables of *Hamelia patens* dye for dyeing of silk. Fresh leaves of the plant were used for dyeing of silk yarn. Four mordants, i.e. alum (aluminium potassium sulfate at 5, 10, 15 and 20 g/100g of material), chrome (potassium dichromate), copper sulfate and ferrous sulfate (each at 1, 2, 3, 4 and 5g/100g of material), were selected for mordanting using (pre, simultaneous and post mordanting). *H. patens* dye was extracted in acidic medium using 0.1-1 % HCl in 100 ml of water. The dye extracted with 1 % HCl gave the best shade and highest percentage absorption. The optimum dye extraction time, dyeing time and dye material concentration was 60 minutes, 30

minutes and 7g/100 ml water, respectively. The best concentration of alum, chrome, ferrous sulfate and copper sulfate was 5, 1, 2 and 1 %, respectively. The simultaneous method was the best method of mordanting for all the 4 mordants. *H. patens* dye produced various shades on silk yarns by using the different mordants and mordanting methods. With copper sulfate, it produced peach colour in pre-mordanting, and pink colour in simultaneous and post mordanting methods. Chrome produced pink colour in pre-mordanting, beige to brown colour in simultaneous and brown in post mordanting method. With alum, a pink colour was obtained in all the mordanting methods. Ferrous sulfate gave a pink colour in pre-mordanting, pink with blackish tinge in simultaneous and grey colour in post mordanting respectively.

Saleh *et al.* (2005) investigated the improvement of dyeing properties of Egyptian cotton fabrics of the cultivars Giza 83 and 89 with natural dye from a yellow pigment fraction isolated from the rhizomes of *Curcuma longa* by enzymatic pretreatment. The dyeing technique was performed by simultaneous mordanting technique (sample-dye-mordant) without enzyme, and after the enzymatic treatment. Different mordants, namely iron (II) sulfate, alum, potassium dichromate and copper sulfate, were applied using this technique. The results revealed that the simultaneous mordanting technique (sample-dye-mordant) after the enzymatic treatment resulted in an increase in dye uptake in all cases compared to the untreated or the simultaneous mordanting technique without enzymatic pretreatment samples and did not affect fastness properties. The colour strength (K/S) values, fastness properties and also the response to dyeing were higher for Giza 89 than Giza 83 due to its higher hydroxyl groups on the fabric surface causing increase in the charged sites by using the lone pair of electrons on the functional groups between the molecular structures of the reactants.

Anatoly *et al.* (2006) developed three band conceptual model capable of remotely estimating total of chlorophylls, carotenoids and anthocyanins contents

in leaves from many tree and crop species and tuned the spectral regions used in the model in accord with pigment of interest and the optical characteristics of the leaves studied and showed that the developed technique allowed accurate estimation of total chlorophylls, carotenoids and anthocyanins, explaining more than 91, 70 and 93 % of pigment variation respectively. This new technique showed great potential for noninvasive tracking of the physiological status of vegetation and the impact of environmental changes.

Goktas *et al.* (2006) derived water-based wood surface dyes extracted from different trees and herbaceous plants. Wood specimens were prepared from yellow pine (*Pinus sylvestris*) and beech (*Fagus orientalis*). The extracts for dyeing were derived from walnut (*Juglans regia*) shell skin, oleander (*Nerium oleander*), saffron (*Crocus sativus*) and madder root (*Rubia tinctorium*). The colour value of the wood surface was determined according to the ISO 2470 standard [International Commission on Illumination (CIELAB)]. Results showed that, all of the dyes generated from natural plant extracts had aesthetic properties. Thus, they could be utilized in wood-based furniture and finishing of decoration products.

Sood *et al.* (2006) performed dyeing on wool yarn with combinations of *Eupatorium adenophorum* and apricot leaf extracts (1:1, 1:2, 1:3, 1:4, 2:3, 2:1, 3:1, 3:2 and 4:1). The dyed samples were tested for their colour fastness to various agents, i.e. sunlight, washing, perspiration and crocking. Among the three extraction media (aqueous, alkaline and acidic), the alkaline medium recorded the best with 1.0 alkali concentration. The best three dye proportions found were 1:3, 1:4 and 3:1 on the basis of optical density. The optimum dye extraction time was observed 45 minutes, and the optimum pH for dyeing of wollen yarn was 4.0 with an optimum time of 45 minutes on the basis of percentage dye absorption. The best shades obtained from the three dye proportions were greenish brown, brown and green, respectively, when 5 % alum was used as the mordant. Outstanding washing and light fastness were observed. The dry and wet crocking observed

excellent to good fastness with slight colour change and colour staining. For alkaline and acidic perspiration, the samples showed excellent fastness, ranging from 5 to 4/5 grades.

Thomas *et al.* (2006) performed an experiment using wastes of pressed berries, grapes, distillation residues of liquor wastes and peels from vegetable processing and food and beverage industries for dyeing wool yarn. Colour strength, shade and fastness properties of the dyeing were tested and extracts were applied as direct dyes in the presence of iron II and alum mordants. The results proved the potential of such wastes as a source for natural dyestuff.

Alam *et al.* (2007) investigated the dyeing characteristics of Henna plant leaves (*Lawsonia inermis*) on silk. The dye up take by silk fibre was decreased with the increase of dye concentration. Similarly the absorption of dye was increased with the decrease of dye concentration. The maximum dye absorption was observed at 0.9 % dye with 10 % alum for the period of 65 minutes at 80 °C and pH 4 with an optimum condition of dye absorption of 93 %. The colour fastness of dyed silk fibre at different treatment temperature were found satisfactory. The dyeability and colour fastness of henna matured leaves was found highly applicable on dyeing of silk fibre as well as other protein fibre.

Bains and Grewal (2007) carried out dyeing of cotton with the leaves of bansa (*Uricalum indacom*) shrub by using four natural mordants, namely bark of arjun (*Terminalia arjuna*), babool (*Acacia nilotica*), eucalyptus (*Eucalyptus sp.*) and rind of pomegranate (*Punica granatum*). Pure cotton fabric was pretreated with cellulase enzyme (Neutrox BDN 100 Powder) and the enzymatic conditions were optimized based on the effect of pretreatment on physical properties. The pretreated samples were dyed with natural dyes and natural mordants. The effect of enzymatic pretreatment in dyeing cotton with natural dyes was studied by comparing the CIELAB values and the colour fastness properties. The enzymatically pretreated samples showed more dye absorption and colour fastness properties than the control.

Guinot *et al.* (2007) investigated the dyeing potential of Flavonoids extracted from marigold flowers. Patulitrin (1) and patuletin (2) were isolated and their structures were established using NMR and HPLC-MS and the compounds were identified as the main flavonoids present in the dyeing bath. The dyeing process, demonstrated that aglycone 2 bound more strongly to wool fibres than its glucoside 1.

Sachan and Kapoor (2007) extracted water soluble yellow dye from turmeric rhizomes (*Curcuma longa* L.) collected from Shillong, Lucknow and local market and reported dye content of 21.3-27.6 % in Shillong followed by Lucknow (15.5-18.9 %) and market sample (14.0-18.2 %). Shillong samples were rich in *Curcumin* (6.6 %) in comparison to others having 2.4-2.5 %.

Pilarski *et al.* (2007) determined contents of chlorophyll a and b and the sum of the carotenoids in Krakow, Poland, on the current year, 1, 2, 3 year old stems and leaves of fruit trees: cherry, sweet cherry, pear, common plum and walnut. The content of chlorophyll showed increase with the age of the stems, except for the cherry tree. Chlorophyll in the current year stems was from 1.6 to 2.2 mg dm⁻², in the 3 year old stems it was 1.6-2.8 mg dm⁻² and in leaves its amount varied from 2.7 to 4.5 mg dm⁻². The 3-year-old stems were compared to the current-year stems containing ~40-50 % more chlorophyll in common plum, walnut and pear trees and ~85 % more in sweet cherry. In the cherry, the amount of chlorophyll decreased by 15 % during the time of the experiment. The stems contained similar amounts of chlorophyll in sweet cherry and walnut trees, or smaller amounts in common plum tree by ~40 %, in pear by ~50 %, and in cherry by ~70 %. The value of the chlorophyll a/b ratio in the stems was considerably smaller in comparison to the leaves. The content of carotenoids in the current-year stems varied from 0.5 to 1.4 mg dm⁻² and with age of the stems it increased to 0.6-1.4 mg dm⁻² in the 3-year old stems, and in the leaves it amounted from 0.9 to 1.3 mg dm⁻². Compared to the leaves, the stems contained similar amounts of carotenoids in sweet cherry and common plum, whereas the amount of

carotenoids was higher in the leaves of the cherry and pear and smaller in the leaves of walnut. The ratio of the chlorophyll content to that of carotenoids oscillated from 2 to 4.

Aung and Win (2008) extracted natural mordant from guava leaves and determined compounds in the leaves of the species by phytochemical tests. Various extraction methods were used using different types of solvents and changing of the extraction time and temperature. Extracted natural mordant was applied on cotton fabrics by using natural and synthetic dyestuffs. Fastness properties on dyed cotton fabrics i.e. light, rubbing, and washing were carried out. The range of colour obtained on cotton fabric using tannin mordant was determined by CIELAB coordinates. Staining and changing in colour was assessed by using standard grey scale and the results were compared to those obtained from the dyed samples dyed by using basic dye with tannin mordant. The results obtained were satisfactory.

Bamola *et al.* (2008) evaluated natural mordants and dyes in terms of extraction time, optimum concentration, colour shades and fastness properties (light and washing). Dyes were extracted from *Myrica esculenta* (leaves and bark), *Quercus floribunda* (leaves), *Rhus parviflora* (leaves and bark) and *Berberis* sp. (root), whereas mordants were extracted from *M. esculenta* (leaves and bark), *Symplocos racemosa* (leaves), *Juglans regia* (seed coat) and *Hippophae rhamnoides* (seeds). Spectral data showed maximum absorption before and after dyeing and each sample was obtained at a wavelength of 200-400 nm. The maximum time of extraction was 1-30 h. The dye sample with mordant showed greater absorption on wool than the dye without mordant. The dye with mordant also produced colours characterized by greater brightness and fastness than the dye without mordant. *M. esculenta* (bark) registered superior percent absorption with all dyes, whereas *J. regia* (fruits) and *S. racemosa* (leaves) exhibited satisfactory absorption with the experimental dyes. Dyes with mordants also showed excellent washing and light fastness properties.

Chairat *et al.* (2008) carried out adsorption kinetics study of lac dyeing on cotton under dyeing conditions of pH 3.0, MLR 1:100 and an initial dye concentration of 480 ± 10 mg/L. Pseudo first- and second-order kinetic models were used to examine the adsorption kinetic data. The adsorption kinetics of lac dyeing on cotton with pH control was found to follow the pseudo second-order kinetic model with activation energy of 42.4 kJ/mol.

Cuoco *et al.* (2008) established an extraction method of madder (*Rubia tinctorum*) root dye and optimized the original chemical composition. A central composite design (CCD) was developed to specify the importance of the three major factors (time, temperature and solvent composition) affecting the ultrasound assisted extraction of this matrix. The identification of the constituents of *R. tinctorum* was carried out by liquid chromatography coupled with a photodiode array detector (LC-PDA). Anthraquinonic aglycone and heterosidic dye compounds were characterized by retention time and UV spectrum: alizarin (1,2-dihydroxyanthraquinone), purpurin (1,2,4-trihydroxyanthraquinone), lucidin (1,3-dihydroxy-2-hydroxymethylanthraquinone), rubiadin (1,3-dihydroxy-2-methylanthraquinone), xanthopurpurin (1,3-dihydroxyanthraquinone), pseudopurpurin (1,2,4-trihydroxy-3-carboxyanthraquinone), lucidin primeveroside, ruberythric acid (alizarin primeveroside), galiosin (pseudopurpurin primeveroside) and rubiadin primeveroside with an optimal experimental conditions at 18 min, 36 C and 37/63 MeOH/H₂O (v/v).

Jothi (2008) studied the dyeing potential of African marigold (*Tagetes erecta* L.) for dyeing of Cotton, and Silk using Alum, Ferrous sulphate, Copper sulphate and Stannous chloride as mordants. The, L*, a* and b* values of the dyed cotton fabric ranged from 20.08–70.66 for ferrous sulphate and Alum mordant, 4.21–36.68 for copper sulphate and stannous chloride and 10.01–80.08 for ferrous sulphate and Alum mordant respectively and L*, a* and b* values of the dyed silk ranged from 48.81-70.10 for Ferrous sulphate and Stannous chloride, 0.74-23.44 for Ferrous sulphate and Alum and 24.0-80.33 for Ferrous sulphate

and Stannous chloride respectively. The K/S values of dyed cotton with different mordants recorded are 0.176, 1.036, 1.1736 and 0.1770 for Alum, Ferrous sulphate, Copper sulphate and Stannous chloride respectively and K/S values of dyed silk 0.3791 for Alum, 1.2765 for Ferrous sulphate, 0.8594 for Copper sulphate and 0.1415 for Stannous chloride. The dyed fabrics showed good wash fastness and light fastness attributes. The findings revealed the usage of Marigold flower for colouration of 100 % cotton, silk, and wool fabrics.

Nilani *et al.* (2008) used Marigold (*Tagetes erecta*) petals for the extraction of the natural dye. Aloe vera juice was selected as natural mordant to standardize the dyeing effect of Marigold dye on natural and synthetic fibers. Natural dye was formulated with Marigold dye and natural mordant. Aloe vera juice, in the ratio 2:10, 5:10 and 10:10 and the effect was compared with synthetic mordants like copper sulphate, lead acetate and potassium dichromate with Marigold dye in the ratio 10:1. Natural dye with Aloe vera juice in the ratio 10:10 showed a good dyeing effect on the animal fibers as compared to plant or synthetic fibers. The natural dye with Aloe vera juice in the ratio 10:10 subjected to skin irritation study resulted in no skin irritation, erythema or edema.

Toiu *et al.* (2008) analysed the total carotenoid content in fresh and dried flowers of 7 Romanian cultivars of *Tagetes patula* and 2 Romanian cultivars of *T. erecta* by spectrophotometric method. The different cultivars of marigold showed considerable variations in their carotenoid concentrations, ranging from 5.44 to 55.05 mg/100g in fresh flowers of and 52.8 to 372.08 mg/100g in dried flowers of *T. patula* and from 7.49 to 25.71 mg/100g in fresh flowers and 36.2 to 240.25 mg/100g in dried flowers of *T. erecta*.

Vankar and Rakhi (2008) performed ultrasonic textile dyeing with natural dyes of *Acacia catechu* and *Tectona grandis*. Better and faster dye uptake was recorded after enzyme pretreatment on cotton fabric. Results of dyeing were found better than metal mordanted fabric. Marked improvement in wash-fastness and light-fastness was observed. The enzyme pretreatment was primarily used for

better absorbency, adherence and dyeability of these dyes on cotton fabric, thereby completely replaced metal mordants with enzyme. Scanning electron microscopy showed surface characteristics at different stages of dyeing and the effect of sonication on the dyeing was compared with conventional heating. The study also showed enhancement in CIELAB values.

Ali *et al.* (2009) optimized the alkaline conditions for extraction of natural dye from Henna leaves and used resulting extract to further optimize the dyeing conditions on cotton by exhaust method. Dyeings without any mordant were compared with those obtained with pre mordanting and post mordanting with alum and iron. It was found that dyeings produced with alkaline extracts of Henna leaves gave better colour strength than the dye extracts obtained in distilled water. Dyeings with alkaline extracts recorded moderate to good fastness properties and that mordanting did not result in any significant improvement in fastness properties.

Cinzia and Riccardo (2009) identified the analytical steps affecting the quantitative assessment for the determination of heavy metals in textile materials and to test the selected extraction conditions. The method was applied to a textile materials dyed with a chromium dyestuff at two different concentrations. The metals analyzed were total Cr and Cr VI. The results showed quantity of total chromium and Cr VI extracted affected principally by the temperature of the solution and by the material-to-liquor ratio extraction and less by the time of contact.

Kamel *et al.* (2009) dyed cotton fabrics with natural dye extracted from *Crocus sativus* (Saffron) using a traditional heating method and a power ultrasonic method. Factors affecting the dyeing properties such as pH values, salt concentration, temperature, duration of dyeing and ultrasonic power were studied by using environment friendly mordants by pre-mordanting, post-mordanting, and simultaneous-mordanting methods. The fastness properties including light,

washing, and perspiration of dyed and mordanted fabrics showed very good results.

Vankar *et al.* (2009) using sonicator dyeing with *Malus* extract along pretreatment with 1-2 % metal mordant, 5 % of plant extract (owf) and reported very good hue colours for cotton, wool and silk dyed fabrics. They also used sonication in conjunction with metal mordanting and reported synergistic effect on better dye uptake, dye adherence and eventually on good fastness properties of the dyed swatches of cotton, silk and wool.

Xiang *et al.* (2009) estimated chlorophyll, carotenoid and anthocyanin contents and leaf colour parameter of four year old grafted seedlings of *Prunus cerasifera* var. *atropurpurea*, *P. cistenena*, *P. blireana*, *P. cerasifera* var. *nigra* were determined to explore the relationship between leaf colour parameters (L^* , a^* , b^*) and pigment contents. The pigment content of the four species showed a similar trend as the season changed. The anthocyanin content of *P. cerasifera* var. *nigra* which was stable in the year was significantly higher than the three species, but the chlorophyll and carotenoid contents of *Prunus blireana* 'Meirenmei', which was stable in the year, were significantly lower than the other three species. The leaves of *P. cerasifera* 'nigra' whose anthocyanin content was the highest in the season kept mauve and the ratio was stable, but the opposite was observed for *Prunus blireana* Meirenmei, and the change in the leaf colour was red-green-red. Positive correlations were observed between chlorophyll content, anthocyanin content and leaf colour parameter of the four species, and the correlations between L^* and b^* values and three pigments varied with species. Results show that the pigment contents and ratio of the four *Prunus* species varied with seasons. The change in the leaf colour was red-green-red because the anthocyanin content showed seasonal variation. The quantity of anthocyanin and chlorophyll decides a^* value, but not the L^* and b^* values.

Goodarzian and Ekrami (2010) extracted the red pigment from Madder plant by solvent extraction method and dyed woolen fabrics with both raw and

extracted Madder. After carrying out the spectrophotometric and colourimetric evaluations, they reported best colour strength of extracted Madder dye than that of raw Madder. The colour fastness of the dyed samples was recorded 4 for crocking fastness, 4-5 for laundering fastness and 4-5 for light fastness with all dye concentrations.

Haji (2010) extracted Berberine a functional colourant from *Berberis vulgaris* wood and dyed on wool fiber using the extract of roots of *Rumex hymenosepolus* as biomordant and reported increased light, rub and wash fastness of dyed samples.

Kavak *et al.* (2010) investigated the usage of willow extract as a natural mordanting agent for dyeing of cotton, wool, feathered-leather and wood samples with onion (*Allium cepa*) dyestuff. The extraction of dyestuff was performed by soxhlet apparatus in distilled water. Pre mordanting, together mordanting and last mordanting methods were followed during dyeing at pH value of pH-4.5 to 5 in the presence of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ and $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ mordants. The fastness and brightness of the dyed samples were reported to be enhanced by the usage of willow extract.

Kazimierz and Jadwiga (2010) addressed the role of non ionic surfactants on the sorption of C.I. Reactive Blue 217 by cellulose fibers, focusing on the influence of the surfactant concentration and type on the spectroscopic properties of the dye. It was found that surfactants in dyeing baths change the spectroscopic properties of dye solutions, resulting in the decomposition of aggregates and agglomerates to form a surfactant-dye complex. Changes in the electro kinetic potential of the dyeing bath were also examined. It was found that nonionic surfactants retard the sorption processes of dye from the dyeing bath and improve dyeing quality.

Maria *et al.* (2010) carried out dyeing of cotton and wool fabrics with nine natural dyes obtained by aqueous extraction of the original plants/insect in an

attempt to reconstruct traditional textile dyeing receipes. Cochineal, madder, alkanna, henna, brazilwood, red sandal wood, safflower, indigo and logwood were used for the dyeings, carried out directly and after mordanting of the textile material. A variety of mordants i.e. aluminium potassium sulphate, potassium dichromate, copper sulphate, zinc chloride, iron (III) chloride, iron (II) sulphate and tin chloride, is anticipated to meet both early and recent requirements and options. The dyeings were evaluated through colour measurements and standard wash, light and rub fastness tests. The mordanting process with the textile dyeing resulted in an improvement in dye absorption and fastness properties mainly for the cotton samples.

Mishra and Patni (2010) evaluated the susceptibility of Oaks (*Quercus* sp.) to a wide diversity of gall-forming insects and usage of gall as a dyestuff. Kalamkari unit's method (India) was followed for the extraction of dye and dark brown dye was obtained from the leaf gall of *Quercus leucotrichophora* caused by *Eriophyes* sp. Three different types of cloths and three different types of yarns were used to observe the strength of dye. Cotton-Jute (C-3) sample showed dark brown colour with myrobalan and ferrous sulphate, yellowish, cream and purplish colour with potassium dichromate, stannous chloride and aluminium sulphate respectively.

Qiao *et al.* (2010) conducted preliminary experiments on dyeing technology of bamboo veneer for black walnut by orthogonal test L9 (34). Tests on effect of dyeing time, temperature and liquor ratio on dyeing uptake, surface result and permeability showed, pretreated bamboo veneer of 2-3 mm could have higher dye uptake and permeability rate with slight colour difference under the conditions of dyeing time of 25 hours, dyeing temperature at 90 °C, liquor ratio of 1:10, dye concentration of 0.25 %.

Suitcharit *et al.* (2010) studied the effect of chitosans molecular weights (Mw) on mangosteen dye fixation on cotton using chitosans with Mw of 226 kDa (CTS-Mw I; native chitosan), 10.8 kDa (CTS Mw II), and 7.2 kDa (CTS-Mw III).

The preparation of chitosan with different Mws was carried out using sodium nitrite in acid media (depolymerization process). The effect of chitosan concentrations on fixation and fastness properties of mangosteen dye extract was studied. The results showed increase in concentrations of depolymerized chitosans (CTS-Mw II and III) yielded an increase in N % contents. Chitosan-cotton fabrics obtained by three application methods were dyed with mangosteen dye extract and evaluated for K/S value (colour strength). Pre-dyeing method showed higher K/S values in all cases.

Tiwari *et al.* (2010) carried out ultrasound, enzyme and enzyme-mediated ultrasound assisted extraction processes for the extraction of dye from pomegranate rind. Optimum parameters for dye extraction were found to be pH 10, extraction time 40 min and temperature 50 °C and the yields for ultrasound, enzyme, enzyme-mediated ultrasound assisted and solvent extraction were found to be 29.2, 26.5, 35.6 and 8.8 % respectively. The dye obtained was used for dyeing wool and cotton, keeping the optimum dye bath concentration as 10 % and 8 % (w/v) respectively. The fastness properties of wool was found to be very good while that of cotton was only satisfactory evaluated using the tests ISO-105-X12 for colour fastness to rubbing, ISO-105-C02 for colour fastness to washing and ISO-105-B02 for colour fastness to light.

Vinod *et al.* (2010) identified Baicalein, a trihydroxy flavone from the bark of *Terminalia bellerica* as a natural colourant and tested the potential of the natural colourant on silk yarn. The properties of colour fastness with regard to light, washing and crocking were investigated and found to be satisfactory. Thermodynamic parameters were evaluated. The positive value of free energy confirms the affinity between the dye molecules and the protein content of silk. Further, adsorption studies carried out to determine the best fit isotherm model for the present dyeing system showed *Terminalia bellerica* bark as an good potential source of natural dye for silk.

Ahmad *et al.* (2011) carried out boiling and solvent extraction methods to extract the natural dyes from the waste of *Gluta aptera* wood (Rengas), for its application on silk and cotton fabrics and their comparison in term of colours and shades on substrates, method of extractions as well as their ability to withstand washing, light and perspiration were compared. Wash fastness results for dyed silk indicated colour change ranging from moderate to good results with the rating from 2/3 to 4 with good staining rating from 4 to 5, same results were obtained from colour fastness perspiration which gave rating from 3 to 3/4 for change in colour and good staining results as well. Colour fastness for rubbing gave excellent results with rating from 4 to 5 in both dry and wet rub. Poor to moderate results were obtained for light fastness test which gave ratings from 2 to 4. Cotton dyed results for wash fastness rating for change in colour is from 3 to 4 which indicate good fastness, staining indicates good to excellent results which gave rating from 4 to 5. Colour fastness to perspiration results gave 3 to 4 rating for change in colour which indicated moderate to good results thus the good result is continued for staining on both cotton and wool. Rubbing fastness showed rating from 4 to 5 which indicate excellent fastness in both dry and wet rubs. The darkest colour (brown) was obtained by dyed cotton without mordant ($L^*=75.15$) and the lightest Colour, light brown ($L^*=55.93$) was achieved by dyeing with powder (methanol) and rice husk ash as mordant.

Akbarzadeh *et al.* (2011) examined the process of dyeing polyester/cotton fabrics with a highly effective fiber-reactive and a disperse dyestuffs namely, (E)-4-hydroxy-5-(4-(2 sulfophenyl) amino)-1,3,5-triazin-2-yl) amino)-3-(2-sulfophenyl) diazenyl) naphthalene-2,7 sulfonic acid and (E)-5-(4- nitrophenyl) diazenyl) pyridin-2(1H)-one, respectively in one pot processes of printing and dyeing. The disperse and fiber-reactive dyes were formulated by pigmented printing paste in a specified styrene-acrylic as a polymeric matrices, in two different concentrations of 3 and 5 % and printed and dyed on cotton fabric, polyester fabric, dried at 95 °C in 2 min and fixed at 150 °C in 3 min. The

characteristics of cured prints such as paste add-on, fastness to washing and dry/wet rubbing were evaluated, together with fabrics stiffness. The highest K/S was obtained and the fastness properties range between good and excellent for samples printed using styrene-acrylic matrices. The lowest K/S was obtained in the case of styrene thylacrylate used as a standard commercial binder. Using styrene-2-ethyl hexyl acrylate gave K/S better than styrene-butyl acrylate for two types of printed fabrics. Dyed textiles were characterized by good dry-rubbing and washing fastness but medium wet-rubbing fastness properties.

Atayde *et al.* (2011) evaluated and compared colourimetric characteristics of three anatomical sections (transverse, tangential and radial) of 'muirapiranga' bloodwood (*Brosimum* sp.) by International Commission on Illumination (CIELAB) using 10 samples obtained from furniture traders in the municipality of Cruzeiro do Sul (AC) and determined colourimetric parameters: lightness (L^*), red-green axis (a^*), blue-yellow axis (b^*), chrome (C^*) and hue angle (h°) on an average of 34 readings per specimen in each of the planes. Colorimetric parameters derived for *Brosimum* sp. showed: $L^*=42.13$, $a^*=18.87$, $b^*=15.05$, $C^*=24.23$ and $h^\circ=37.86$ with variations in colour, indicated significant differences among the three sections in question. The reflectance and transverse section (6-28 %) was found to reflect less light than the tangential (6-43 %) and radial sections (7-49 %), depending on which anatomical plane was chosen.

Na Bin *et al.* (2011) carried out dyeing treatment of the veneer from fast-growing poplar using heat-infusing and cold-pressing methods. The influences of dye-liquor concentration, dyeing time, dyeing temperature and auxiliaries on the effect of dyeing were studied using ultraviolet-visible spectrophotometer. Both methods showed an increased rate of dye uptake, and the effect of heat-infusing was better than that of cold pressing.

Chang *et al.* (2011) Surveyed Berry skin colour OIV index, anthocyanin composition and content of 78 grape cultivars using a CIELAB system and high-performance liquid chromatography (HPLC)-mass spectrometry (MS) coupled

with photodiode array detection and reported high correlations between L^* , b^* , and colour, while a^* was not a representative parameter. L^* and b^* values declined as berry skin colour OIV became darker and a^* increased as berry skin colour OIV became darker in pink and red grape cultivars only. The composition and content of anthocyanins varied widely among the cultivars. Total anthocyanins and types of anthocyanins were significantly correlated with colour OIV parameters. Through multiple linear regression analysis, cyanidin derivatives showed positive effect on values of L^* and b^* and Delphinidin derivatives resulted positive effects on the value of a^* . The CIELAB system gave good results for differentiation of grape berry skin colour OIV.

Ekrami *et al.* (2011) assessed fastness properties and colourimetric evaluations of wool samples dyed with Olive fruit waste and reported quite good fastness properties and different shades with different mordanting agents.

Hadi *et al.* (2011) investigated colourimetric and fastness properties of Nylon samples dyed with Saw wood of Red alder tree and reported reddish, brownish and yellowish shades with changing mordanting agents having quite good fastness properties.

Ibrahim *et al.* (2011) studied different samples of *Brassica oleraceae* anthocyanin in aqueous solutions at various pH levels between 1.0 to 14.0 at a period of 10 days and expressed their colours by the CIELAB coordinates, colour tone, colour intensity and colour lightness. Powdered anthocyanin exhibited more stable compared to liquid anthocyanin at most pH values, no changes in colour intensity and colour tone and little changes in colour lightness were reported. The variation in the results suggested that further developments of anthocyanin as a potential pH colour indicator in food packaging system are required.

Kamel *et al.* (2011) carried out dyeing of cationized cotton fabric with 69 % 3-chloro-2-hydroxy propyl trimethyl ammonium chloride (Quat, 188) using Cochineal dye by conventional and ultrasonic techniques. Factors affecting dye

extraction and dye bath exhaustion were investigated. Dye extraction by ultrasound at 300 W was reported more effective at lower temperatures and than conventional extraction. The colour strength values obtained were found to be higher with ultrasound than with conventional techniques, however the fastness properties of the dyed fabrics with ultrasound were similar to those of the conventional dyed fabrics.

Kulkarni *et al.* (2011) extracted natural dyestuff from the peel of *Punica granatum* by Solvent extraction method. The dye was used for dyeing of scoured cotton cloth using copper sulphate and ferrous sulphate as mordants in the ratios 1:1, 1:3, 3:1. Dyeing along with mordanting techniques included premordanting, simultaneous mordanting and post mordanting. Large range of shades were obtained because of varying mordant ratios and combinations. The fastness tests of the dyed fabrics reported good rub fastness and good light fastness.

Kulkarni *et al.* (2011) carried out investigation to extract natural dye from green chili (*Capsicum annum*) in which the main colouring component is oleoresin. The dye was extracted using solvent extraction method. Two mordants - copper sulphate and ferrous sulphate were used in ratios 1:1, 1:3, 3:1 and 100 % scoured cotton cloth was used as dyeing substrate. Three different techniques-pre mordanting, simultaneous mordanting and post mordanting showed different shades of yellow from a single dye using the two mordants in different ratios. Colour fastness studies on the dyed cloth were reported good light fastness, good rub fastness and moderate wash fastness.

Kumaresan *et al.* (2011) assessed colour fastness properties of Silk dyed with *Spathodea campanulata* extract using combination of mordants - Myrobolan: Ferrous sulphate, Nickel sulphate, Aluminium sulphate, Potassium dichromate and Stannous chloride in 1:3, 1:1, 3:1 ratio and reported fair to excellent rubbing and light fastness grades.

Kumaresan *et al.* (2011) studied colour fastness properties of the flower of *Cordia sebestena* dyed on silk using combination of mordants such as myrobolan:nickel sulphate, myrobolan: aluminium sulphate, myrobolan: potassium dichromate, myrobolan: ferrous sulphate, myrobolan:stannous chloride in the ratio of 1:3, 1:1, 3:1. The washing, rubbing and light fastness of the dyed samples, reported fair to excellent fastness grades.

Lal *et al.* (2011) investigated chloroform fraction of the aqueous extract of the rind of *Punica granatum* and afforded seven already reported compounds viz. 1-O-Isopentyl-3-O-octadec-2-enoyl glycerol (I), 1-O-trans, cis, trans-9,11,13-octa deca trienoyl glycerol (II), β -Sitosterol laurate (III), β -Sitosterol myristate (IV), Punicanolic Acid (V), Luteolin (VI) and Tricetin (VII). The structures of isolated compounds were ascertained using various spectral (IR, ¹H, ¹³C NMR, MS) techniques. Compounds I, II, VI and VII were found to be coloured in nature and tested as dye substances on Cashmere (Pashmina) wool and showed promising dyeing properties.

Chaggaan *et al.* (2011) subjected shade dried fruit coat husk powder of *Juglans nigra* to column chromatographic separation which yielded 7 fractions and carried different spectral (IR, ¹H NMR and MS) and chemical analysis. Nine compounds including two 1, 4 naphthoquinones derivatives, juglone (I) and plumbagin (II), one α -tetralone derivative, (-)- regiolone (III), two sterols, stigmasterol (IV) and β -sitosterol (V), four flavonoids, taxifolin (VI), kaempferol (VII), quercetin (VIII) and myricetin (IX) were isolated from chloroform fraction of aqueous extract of test species. These extracted compounds were subsequently used for dyeing of pashmina shawls, which gave promising results and the experiment inferred the combined effect of Juglone and Plumbagin responsible for the dyeing behaviour of *Juglans nigra* nut husk powder.

Manhita *et al.* (2011) evaluated the efficiency of eight different procedures used for extraction of natural dyes using contemporary wool samples dyed with cochineal, madder, woad, weld, brazil wood and logwood and based on the LC-

DAD peak areas of the natural dyes compared main components extracted from the wool samples. Among the tested methods, extraction procedure with Na₂ EDTA in water/DMF (1:1, v/v) proved to be the most suitable for the extraction of the studied dyes.

Muradoglu and Gundogdu (2011) compared the stomata frequency, stomata size, chlorophyll content and leaf characteristics (leaf length, width & leaf area) of 11 cultivars of walnuts. The stomata frequency, stomata size (stomata length and width) of all 11 cultivars were in the range 183-335 stomata/mm², 17.21-30.10 and 10.65-20.06 µm, respectively. The total chlorophyll and leaf area in all cultivars were in the range 0.34-2.37 mg/g and 26.77-86.92 cm². The largest chlorophyll content was measured in Pedro.

Naz *et al.* (2011) used Eucalyptus (*Eucalyptus camaldulensis*) bark powder (un-irradiated and irradiated) as natural colourant for dyeing un irradiated and irradiated cotton fabric using different doses of Co-60 gamma irradiation to study the effect of radiation treatment on the colour strength of dyed fabrics. For the evaluation of un- irradiated and irradiated dyed cotton using Spectra Flash (SF-650) in CIELAB system the data colour report was used. Pre and post mordanting was also carried out using chrome alum, potassium dichromate, copper sulphate, ferrous sulphate and stannous chloride as mordants. Gamma irradiation was reported to have potential to improve the fastness properties such as washing, light and rubbing of cotton dyed with *Eucalyptus* powder.

Patel (2011) dyed cotton yarn with dye extracted from dry roots of *Rubia cordifolia* with Alum, CuSO₄, FeSO₄ and Myrobolan mordants, adopting pre and different mordanting techniques and obtained pinkish and grayish pink shades and reported good rubbing, washing and light fastness with poor to fair perspiration fastness properties of dyed samples.

Periyasamy *et al.* (2011) performed dyeing of cellulosic/regenerated blended fabrics with reactive dyes requiring a large amount of salt, polluting fresh water courses. Pretreated samples were dyed without using salt as an electrolyte. The influence of pretreatment on K/S value, wash fastness, rubbing fastness, tensile strength, flexural rigidity and crease recovery were determined. The pretreatment of Lyocell/cotton fabrics with polyvinylamine chloride increased dye uptake and showed good wash fastness and rubbing fastness. Polyvinylamine chloride was found to be effective for pretreatment in salt-free dyeing of Lyocell/cotton fabrics.

Saravanan and Chandramohan (2011) revived the old art of dyeing with natural dye obtained from barks of *Ficus religiosa*. L, commonly known as peepal tree. Bleached silk fabrics were dyed with chemical and natural mordants and dyeing was carried out by pre-mordanting, post mordanting and simultaneous mordanting. The dyed samples showed good washing, light and rubbing fastness properties. The various colour changes were measured by computer colour matching software and heavy metals like antimony, arsenic, cadmium and lead present in the extract were determined by Inductive Coupled Plasma Mass Spectrometer.

Sharma and Grover (2011) performed dyeing of cotton yarn with Walnut (*Juglans regia* Linn.) bark dye and tested the colour fastness of dyed material against light, crocking, perspiration and washing. It has been found that walnut dye can be successfully used for dyeing of cotton and may be useful in imparting number of fast shades on cotton using common mordants like Alum, FeSO₄, CuSO₄ and Chrome with good fastness properties.

Suabjakyong *et al.* (2011) investigated the extraction of natural dye from black plum fruit (*Syzygium cumini*) using various solvents and its staining property on the rat hepatic tissue. Both fresh and dry black plums were extracted with either distilled water or 45 % glacial acetic acid at 100 °C for 60 minutes. Proportion of fresh black plum was 1:2 and 1:5 respectively whereas the dried

plum as 1:5 and 1:10 respectively (black plum: solvent, w/v). The sections were stained with black plum dye at 10, 15 and 20 minutes with/without 1 % ferric arum as mordant. The results showed good stain from fresh and dry black plums on the nucleus and cytoplasm of hepatic cells with violet colour. The level of the stain was not significantly different among various conditions (proportion solvents, staining period and with/without mordant). The finding suggested usage of black plum fruit as an alternative dye for histological staining and cytotoxicity testing in cosmetic and others.

Temani and Shakyawar (2011) standardized dyeing condition of Cochineal extract on pashmina yarn, using natural colourant characterized for dye bath exhaustion, K/S value and fastness properties. The colourant was exhausted between 80 and 95 % with K/S value ranging from 0.526 to 0.816 with very good washing (4-5) and light fastness (6-7) at standard condition.

Tutak and Benli (2011) studied the waste parts of the walnut as a natural dye for dyeing textile fibres. The dyeing properties of leaves, husk and shell of the walnut were examined on various textile fibres (wool, cotton and viscose) by using different metal salts of potassium dichromate, copper sulphate, iron sulphate and aluminium sulphate. Colour performance and fastness properties suggested walnut based products as a good source of natural textile dyes.

Venkatasubramanian *et al.* (2011) Studied influence of ultrasound on natural colourant extraction from Green wattle bark, Marigold flowers, Pomegranate rind, 4'O clock plant flowers and Cock's comb flowers and performed UV-VIS Spectrophotometry and gravimetry analysis on the extracts. The results indicated significant (13-100 %) improvement in the extraction efficiency due to use of Ultrasound.

Arora *et al.* (2011) conducted an experiment to extract natural dye from Ratanjot (*Arnebia nobilis* Rech.f) for application on cotton, nylon, silk, polyester, aryl. The sensitivity of the dye extract to pH and temperature was also studied.

Acute sensitivity to pH in terms of its solubility and colour was reported and was found to be thermally stable upto 80 °C. The dyed polyster showed pink colour, nylon shows blue and all other substrates acquired a purple Hue under similar dyeing conditions. The fastness properties of the dyed fabrics showed excellent wash, rub and perspiration fastness, however light fastness was found to be poor.

Merdan *et al.* (2012) studied the usability of the flowers of the *Papaver rhoeas* L. as natural dye in dyeing the wool fibres through the conventional and ultrasonic methods mordanted with the common mordanting agents. CIE L*a*b* values of the materials were measured and compared by using the CIE L*a*b* colour space system. Washing and light fastness properties of the dyed materials were examined and increase in colour yield with natural dyestuff and ultrasonic energy was recorded.

Raja *et al.* (2012) carried out extraction of natural dye from petal part of the Saffron flower for application on the pashmina shawl. The natural dye was extracted by aqueous method at boiling conditions and extracts were applied on pashmina wool at two different pH i.e. pH 4-5 and pH 7-8 with and without the use of mordant. The results showed best dyeing ability of the Saffron flower waste to dye the pashmina shawls with very good washing and light fastness properties. Saffron flower extract dyed fabric at acidic pH without mordant showed zone of inhibition for the growth against *Staphylococcus aureus*.

Singh and Purohit (2012) studied the colour fastness properties of the flowers of *Erythrina suberosa* dyed on wool using combination of mordants such as lemon juice: copper sulphate, lemon juice: potassium dichromate; lemon juice: ferrous sulphate and lemon juice: stannous chloride in the ratio of 1:3, 1:2 and 3:1. Dyeing along with mordanting techniques included pre-mordanting, simultaneous mordanting and post mordanting. Large range of shades were obtained with varying mordant ratios and combinations. The washing, rubbing, light and perspiration fastness of the dyed samples gave fair to excellent fastness grades.

Sundrarajan *et al.* (2012) studied enzymatic and chitosan modification on woven cotton fabric. Chitosan bio polymer present as chitin in crab shell was prepared and cross linked with the fabric using citric acid and sodium hypophosphite at 110°C. Modifications were evidenced by morphological changes inferred from SEM analysis. FTIR studies confirmed the fixation of chitosan on fabric. Unmodified and modified fabrics were dyed with natural dye *Curcuma longa* (turmeric). Dye uptake, Washing fastness and K/S values of dyed fabric were evaluated. The ecofriendly modifier enzyme and chitosan enhanced the dyeability and washing fastness of dyed fabric.

Rahman *et al.* (2013) demonstrated ultrasonic cleaner as a technique to extract colourant from a selected plant, i.e. *Xylocarpus moluccensis* species found abundantly in peninsular Malaysia. Colourant from combination of heartwood and bark of *Xylocarpus moluccensis* were extracted at different ultrasonic volumes, time and temperature. The colour strength of the dye was analyzed by using Lab Scan XE UV-visible spectrophotometer. Results showed the highest percentage of total dye yield extract at optimum condition (extraction time: 80 minutes, extraction temperature: 49 °C and sonic volume: medium) with 80 ml of 0.1 M sodium hydroxide as the solvent. The yield produced was found higher than that of boiling method and thus gave higher intensity of red crude extract.

Abdou *et al.* (2013) studied the effect of chitosan on the printing properties of different fabrics (natural, blends and synthetic fabrics) using *Curcuma tinctora* as natural dye. Increase in the colour strength value (K/S) 3.88 with sod. Alginate to 9.61 with 4 % starch in case of cotton, 1.91 with sod. Alginate to 11.42 with 4 % starch in case of Cotton/Polyster, 0.98 with sod. Alginate to 5.12 with 5 % starch in case of Polyster, 4.24 with sod. Alginate to 8.15 with 3 % starch in case of Viscose/Polyster, 1.44 with sod. Alginate to 7.94 % with 5 % starch in case of Polyamide and 2.01 with sod. Alginate to 8.12 with 4 % starch in case of wool respectively was reported, giving darker colour and increase in dye uptake on fabrics. Fastness properties of the printed fabrics to

washing, rubbing, perspiration and light also improved. The treated fabrics were reported to have antimicrobial property.

Kumaresan *et al.* (2013) determined the colour fastness and colour strength properties of cotton fabric dyed with flowers of *Spathodea campanulata* and *Cordia sebestena*. Three dyeing methods using, 1, 2 and 3 % mordant concentrations of Nickel sulphate, Aluminium sulphate, Pottasium dichromate, Ferrous sulphate, Stannous chloride and Myrobolan were used. The mordants ferrous sulphate and aluminium sulphate showed excellent colour values. Better results were reported of *Spathodea campanulata* in simultaneous mordanting with 3 % mordant combination as compared to the natural dye obtained from the flowers of *Cordia sebestena*. The results showed better light fastness, rub fastness and perspiration fastness values of *Cordia sebestena* as compared to *Spathodea campanulata* dyed cotton fabrics.

Lokesh and Kumara (2013) performed extraction of natural dye using *Spathodea campanulata* different solvent extracts. They carried out dyeing of the silk fabric and 100 % cotton fabric using combination of mordants (harda/metallic salts) such as 0.15 % alum, 0.08 % CuSO₄, 0.04 % FeSO₄, 0.06 %, K₂Cr₂O₇, Myrobolan, 0.08 % SnCl₂, Myrobolan: K₂Cr₂O₇ (1:1), Myrobolan : SnCl₂ (1:1). Washing and rubbing with detergent for 30 minutes at 60 °C showed negligible effect on dye fastness. The extracts obtained from 0.1 N NaOH along with Myrobolan: SnCl₂ (1:1) as mordant produced the better results and the stability studies before dyeing showed appreciable results.

Charu *et al.* (2013) explored dyeing material from *Trichoderma* spp. for the dyeing of silk and wool fabrics. Dyed fabrics were evaluated for percent absorption, colour values and fastness properties, which reported higher values in wool than that of silk fabric. Percent absorption of wool and silk fabric reported values to the tune of 48.37 and 44.58. L*, a*, b* and K/S reported values of 85.27, -2.23, 21.81 and 0.90 in silk fabric and 82.91, -4.07, 35.18 and 2.00 in wool fabric respectively.

Fastness properties revealed good (4) to excellent (5) fastness for washing, excellent (5) dry and wet rub fastness.

Narayanaswamy *et al.* (2013) extracted natural dye from *Casuarina equisetifolia* bark for the dyeing of silk fabric using Alum, Tannic acid and Tartaric acid mordants. Dye uptake was calculated at different dye concentrations. Values of 33, 62, 79, 90 and 86 at 0.5, 1, 5, 10, and 15 dye % concentrations with K/S value of 0.98, 1.15, 1.67, 3.95 and 3.86 respectively were reported. 51.21, 09.80, 7.02, 56.41 and 67.06 L*, a*, b*, C* and h° values of without mordant dyed silk fabric. 46.50, 11.02, 5.78, 57.92 and 59.75 with Alum, 48.01, 12.67, 5.06, 58.93 and 57.26 with Tannic acid and values of 48.99, 9.92, 3.29, 58.65 and 56.51 with Tartaric acid were reported. Poor fastness of without mordanted dyed sample and improved fastness of mordanted samples with reference to light, washing and rubbing were also reported.

Ali *et al.* (2014) carried out dyeing of cotton fabric with red calico (*Alternanthera bittzickiana*) leaf extract at 60 °C for 50 min using dye bath of pH 7.0 and copper sulphate and tannic acid (1 %) mordants. The pre and post-mordanting methods were reported showing the best and improved colour strength and colour fastness properties.

Catia *et al.* (2014) studied the spectrophotometry and fluorimetry of yellow and red extracts of *Carthamus tinctorius* L. in solution and on dyed textiles. Dyestuffs were directly extracted from dried petals of *Carthamus* flowers and quinochalcone dyes (hydroxysafflor yellow A, safflor yellow A, anhydro safflor yellow B and carthamin) were separated and isolated through both analytical and preparative methods. The red reference samples were reported having peculiar relevance for the non-invasive identification of Carthamin, whose specific absorption and emission features were clearly detected on a 16th century tapestry fragment.

Eunmi and Kyung (2014) treated wool and cotton fabrics with the gallnut extract using a pad-dry-cure process for developing multi-functional clothing material with no harmful effects. Surface appearance, mechanical properties, antimicrobial ability, and antioxidant performance of gallnut extract-treated wool and cotton fabrics were investigated. Gallnut extract treatment were reported to impose the antimicrobial and antioxidant properties on the wool and cotton fabrics.

Hanan (2014) carried out printing of wool, wool/polyester and polyester fabrics with rhubarb natural dye using green mordant (tartaric acid) and a metal mordant (potassium dichromate) adopting pre mordanting method. Dye nanoparticles were incorporated with urea in printing pastes at acidic pH value. Results showed enhanced K/S values and fastness properties of the prints. The K/S values of Blank pretreated wool with tartaric acid, pretreated wool with tartaric acid, Blank pretreated wool with potassium dichromate and pre treated wool with potassium dichromate were reported 1.55, 5.58, 4.59 and 9.10 respectively. Washing staining, alteration and dry, wet rubbing of blank pre treated wool with tartaric acid were reported 4, 4 and 4, 3, pretreated wool with tartaric acid 4-5, 4-5 and 4-5, 3-4, blank pretreated wool with potassium dichromate recorded 4-5, 4-5 and 3, 2-3 and pretreated wool with potassium dichromate reported 4-5, 4-5 and 4, 3.

Arun and Yogamoorthi (2014) treated cotton cloth with 4 mordants viz. alum, ferrous sulphate, copper sulphate and stannous chloride using *Tecoma stans* flower extract. Results revealed three important features viz. flowers of *Tecoma stans* possesses fast colour yellow colourant -a carotenoid group of pigments – Zeaxanthin., secondly during dyeing process, pre-mordanting with stannous chloride yielded better colour fastness., fluorescence decay profile of zeaxanthin in Dichloro methane (DCM) exhibited Excitation (λ) at 420 nm and emission (λ) at 650 nm strongly supported the self-quenching property of zeaxanthin. Flowers of *Tecoma stans* was reported a potential source of yellow colourant with striking

spectroscopic characteristics. Pre mordanted with stannous chloride and alum resulted better result than post mordanting. Among the four mordants, stannous chloride yielded better shade and hue.

Mustafa (2014) investigated the usage of industrial waste rose flowers (*Rosa damascena*) for dyeing of wool yarn using herbal pulps as natural dyes. Colour strength and fastness properties (washing, rubbing and light properties) of the yarn were tested. Wool was dyed without mordant, with Alum (5 gm/L) and Na_2CO_3 mordants. The L^* , a^* and b^* values of without mordant, Alum (5 gm/L) and Na_2CO_3 mordants reported values to the tune of 54.85, 5.80 and 32.12 respectively; 66.75, 5.28 and 5.70 and 59.12, 4.10 and 26.97. Washing, light and dry, wet rubbing values of without mordant, Alum (5 gm/L) and Na_2CO_3 mordants reported grades of 5, 4 and 5, 4/5 respectively, 4/5, 3 and 4/5, 4 and 5, 4 and 5, 4.

Sarvana *et al.* (2014) carried out dyeing of wool fabric using bark of *Odina wodier* with different mordant combinations adopting pre, post and simultaneous mordanting methods. L^* , a^* , b^* and K/S values of dyed wool with Alum, Tannic acid, Myrobolan and Cow dung mordants reported values to the tune of 54.56, 0.654, 7.51 and 24.36 respectively; 68.27, 1.94, 5.59 and 14.94; 69.13, 1.734, 6.89 and 12.84 and 69.62, 1.852, 6.34 and 11.97 respectively. Washing, Light and dry, wet rubbing fastness with Alum reported grades of 3-4, 5 and 3-4/5, 3-4, Tannic acid 3-4, 4 and 4,3, Myrobolan 4-5, 4 and 4,4 and with Cow dung grades of 3-4, 3 and 3-4, 3-4 were reported.

Adem *et al.* (2014) worked on the dyeing of wool and cotton fabrics with dye extracted from *Vitis vinifera* leaves. Solutions of 0.1 M $\text{K}_2\text{Cr}_2\text{O}_7$ and $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ were used as mordants. Dyeing was carried out adopting pre, simultaneous and post mordanting methods. Fastness properties of cotton fabric were found better than that of wool fabric. Washing, light and dry, wet rubbing of wool and cotton fabrics without mordant reported were 2, 3; 5, 3 and 3, 4 and 5, 3 respectively. Grades of washing fastness using $\text{K}_2\text{Cr}_2\text{O}_7$ and $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$

mordants ranged between 1-2 to 5 with $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ and $\text{K}_2\text{Cr}_2\text{O}_7$. Light fastness ranged between 3 to 6-7 with $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ and $\text{K}_2\text{Cr}_2\text{O}_7$. However, grades of dry and wet rubbing ranged between 5 and 2-5 with $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ and $\text{K}_2\text{Cr}_2\text{O}_7$ respectively.

Chapter – 3

MATERIALS AND METHODS

3.1 Locations

The present study entitled “Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley” was carried out during the period 2012-2013 at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar, Srinagar (J&K). This chapter refers to the research procedure and techniques used in the light of objectives. The detailed classification of materials and methods involved in the experiment are listed under the following sub-headings :

3.2 Experimental material

The experimental material comprised of 6 plant materials of 5 species for dye extraction, 4 plant materials of 3 species for mordant extraction and 4 fabrics for dye application as mentioned in Tables-1 to 3.

All the plant material for dye extraction was collected from the University Campus of Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar, Srinagar and outskirts (J&K).

All the materials for the dye and mordant extraction were collected from different regions of Budgam and Srinagar district of Kashmir, India.

Table-1 : Plant material for dye extraction

S. No.	Scientific name	Common name	Parts used for extraction
1.	<i>Quercus robura</i> L.	English Oak	Fruit cups
2.	<i>Juglans regia</i> L.	Walnut	Leaves
3.	<i>Juglans regia</i> L.	Walnut	Fruit hull
4.	<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i>	Purple leaf Plum	Leaves
5.	<i>Nasturtium officinale</i> R.Br.	Watercress	Leaves
6.	<i>Tagetes patula</i> L.	French Marigold	Petals

Table-2 : Test crops used as mordants

S. No.	Scientific name	Common name	Parts used for extraction
1.	<i>Salix alba</i> L.	Willow	Wood extract
2.	<i>Salix alba</i> L.	Willow	Wood ash
3.	<i>Populus deltoides</i> Bartram ex Marsh.	Poplar	Wood ash
4.	<i>Punica granatum</i> L.	Pomegranate	Peel

Table-3 : Test fabrics (substrates) used for dye application

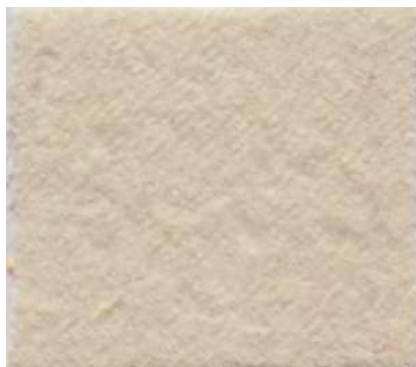
S. No.	Fabric	Source
1.	Wool	Poshish (J&K State Handloom Development Corporation Ltd.)
2.	Cotton	Poshish (J&K State Handloom Development Corporation Ltd.)
3.	Silk	Silk showroom, Government Silk weaving factory, Rajbagh, Srinagar, Kashmir, J&K
4.	Pashmina	F.S. Shawls, Eidgah, Srinagar, J&K

3.3 Observations

Plant species collected from different locations were identified after Bentham and Hooker (1872) in conformity with recent literature and were tagged for recording the observations.

3.3.1 Morphological attributes

Morphological attributes of plant species were recorded for characterization and identification of plant species.



Wool fabric



Cotton fabric



Silk fabric



Pashmina fabric

Plate-1 : Test fabrics for dyeing

3.3.1.1 Field observations

3.3.1.1.1 Habitat

Habitat of the plant species was recorded by observing the natural environment in which the plant species normally occurred.

3.3.1.1.2 Plant habit

Plant habit was recorded by observing whether the plant is erect, sub-erect, climbing, creeping, herbaceous or arboreal etc.

3.3.1.1.3 Plant and flower/inflorescence colour

Plant colour was recorded throughout growth season and flower and inflorescence. Colour during flowering stage.

3.3.1.2 Vegetative features

3.3.1.2.1 Stem type

In this parameter the stem type was recorded by observing whether the plant stem is erect, sub-erect, climbing, creeping etc.

3.3.1.2.2 Macro and micro morphological leaf characteristics

The macro morphological characteristics of leaves were recorded by observing the leaf type, leaf margins, leaf venation type, leaf arrangement, etc. The micro morphological features of the leaves were recorded by observing the leaf surface, presence or absence of trichomes, etc.

3.3.1.3 Reproductive features

3.3.1.3.1 Inflorescence/floral features

The inflorescence/floral features of the plant species were recorded at the flowering stage by recording floral arrangement, the number of sepals, petals, stamens and pistils of the flowers of the selected plant species.

3.3.1.3.2 Fruit type

The fruit type whether berry, drupe, pome, etc. was recorded by observing the fruit of each plant species at maturity.

3.4 Quantification and colour quality of pigments (anthocyanins, carotenoids and chlorophyll)

The quantification and colour quality of pigments (anthocyanins, carotenoids and chlorophyll) were carried out following the below mentioned methods. The experiments were carried out in the Research laboratory of the Division of Environmental Sciences, SKUAST-K, Shalimar campus. The optical density of the samples was recorded by using UV VIS spectrophotometer.

3.4.1 Total anthocyanin content (mg/100 g)

Anthocyanins were calculated by following the method of Fuleki and Francis (1968). One gram of sample was taken and diluted to 100 ml with ethanolic HCl (95 % Ethanol + 1.5 N HCl) and kept in refrigerator overnight at 4°C. Then it was filtered using Whatman filter paper No.1. Filtrate was taken and optical density was measured at 535 nm using spectrophotometer against ethanolic HCl as blank.

Calculations

The total anthocyanin content was calculated using following equations:

$$\text{Total Optical density (100 g}^{-1}\text{)} = \frac{\text{Absorbance at 535 nm} \times \text{Volume made of the extract used for Colour measurement} \times \text{Total Volume} \times 100}{\text{ml of extract used} \times \text{Weight of sample taken}}$$

$$\text{Total anthocyanin content (mg 100 g}^{-1}\text{)} = \frac{\text{Total O.D}}{98.2}$$

3.4.2 Total Chlorophyll and Carotenoids (mg g⁻¹ fw)

Chlorophylls and carotenoids content were estimated by following Hiscox and Israelstam (1979) and Arnon (1949). 250 mg of sample was taken and ground into pieces using 5 ml of 80 % acetone. The homogenate was filtered using whatman filter paper No.1 and washed 3-4 times with 5 ml of 80 % acetone. Final volume of 25 ml of filtrate was made. Filtrate was taken and optical density was measured at 663 nm, 645 nm and 480 nm using spectrophotometer by keeping 80 % acetone as blank.

Calculations

The total chlorophyll content was calculated using following equations:

$$\text{Total Chlorophyll 'a' + 'b' (mg g}^{-1}\text{fw)} = \frac{[(8.02 \times \text{O.D at 663 nm}) + (20.2 \times \text{O.D at 645 nm})] \times \text{Final volume of 80 \% acetone}}{1000 \times \text{Weight of Sample}}$$

The total carotenoid content was calculated using the following equations given by Kirk and Allen (1965):

$$\text{Total Carotenoids (mg g}^{-1}\text{fw)} = \frac{[\text{O.D at 480 nm} + (0.144 \times \text{O.D at 663 nm}) - (0.638 \times \text{O.D at 645 nm})] \times \text{Final volume of 80 \% Acetone}}{1000 \times \text{Weight of Sample}}$$

3.5 Preparation, extraction and application of natural dyes and mordants.

All the experiments were carried out at the Department of Chemical Engineering and Technology, Indian Institute of Technology, IIT (BHU), Varanasi.

3.5.1 Preparation of plant material

The shade dried fresh plant material was washed with water to remove dirt and other adhering materials and then dried in tray drier at 80 °C for 2 hours and finely powdered with the help of a grinding machine. The material was then passed through a standard test sieve (BSS-14).

3.5.2 Preparation of Mordants

3.5.2.1 Willow (*Salix alba* L.) wood extract mordant

To prepare the mordant solution, the stem of willow (*Salix alba* L.) was cut into small pieces and soaked in distilled water for 30 days. 10 L of distilled water were used for 1 kg of Willow stem wood. The solution was filtered and kept under refrigeration for future usage (Kavak *et al.*, 2010).

3.5.2.2 Willow (*Salix alba* L.) wood ash mordant

To prepare the mordant solution, the stem of willow (*Salix alba* L.) was burnt completely to ash and soaked in distilled water for 10 days. 1 L of distilled water was used for 100 g of willow stem ash. The solution was filtered and kept under refrigeration for future usage.

3.5.2.3 Poplar (*Populus deltoides* Bartram ex Marsh) wood ash mordant

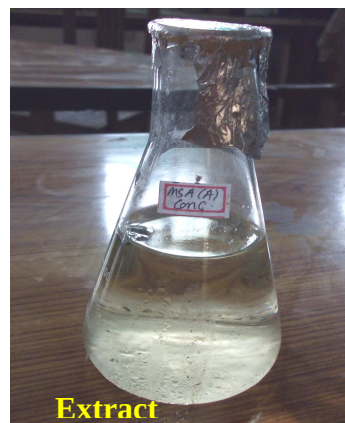
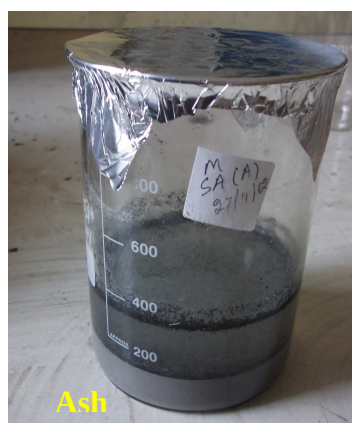
Natural mordant solution of Poplar (*Populus deltoides* Bartram ex Marsh) was prepared by burning the stem completely into ash and soaked in distilled water for 10 days. 1 L of distilled water was used for 100 g of the ash. The solution was filtered and kept in refrigeration for future use.

3.5.2.4 Pomegranate (*Punica granatum* L.) peel extract mordant

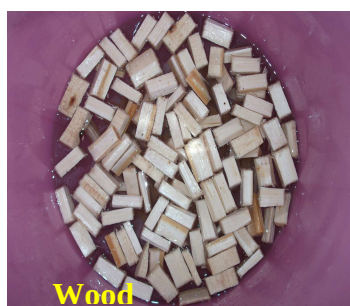
To prepare the mordant solution, the peel of Pomegranate (*Punica granatum* L.) was cut into small pieces and soaked in distilled water for 4 days. 1 L of distilled water was used for 100 g of Pomegranate (*Punica granatum* L.) peel. The solution was filtered and kept under refrigeration for future usage.

3.5.3 Extraction of dyes

Extraction of dyes was performed by Soxhlet apparatus using distilled water as solvent. 1 L of distilled water was used for 100 g plant material. The material was kept for reflux for about 8 hrs at 80-85 °C. The liquid extract was evaporated at 65 °C in a rotary vacuum evaporator to one fourth of its original volume to get the final extract for dyeing, Lokesh and Kumara, (2013).



Salix alba L.



Salix alba L.



Populus deltoides Bartram ex. Marsh



Punica granatum L.

Plate-2 : Mordants used



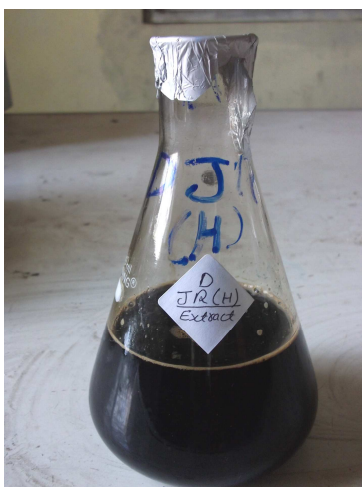
***Quercus robura* L. (Fruit cups)
(Leaves)**



***Tagetes patula* L. (Petals)**



***Nasturtium officinale* R.Br.**



***Juglans regia* L. (Fruit hull)**



***Juglans regia* L. (Leaves)**



***Prunus cerasifera* Ehrh. var.
atropurpurea (Leaves)**

Plate-3 : Dye extracts of different test species

3.5.4 Spray drying

To estimate the percent yield of the natural colourant, 50 g of the plant materials were used for extraction. The concentrated dye extract was spray dried in Spraymate (Jay instruments and systems Pvt. Ltd. TTC Industrial area, Turbhe, Navi Mumbai). The inlet and outlet temperatures of Spray drier were maintained at 140 and 80 °C respectively and aspiration speed was maintained at 1200 rpm, while flow rate was maintained at 35 ml/min with slight changes made as per the different plant materials. The dried powder was collected, stored in a desiccator and used for estimation of the percent dye yield by applying the following formula (Bulda *et al.*, 2008).

$$\text{Percent yield of dye powder} = \frac{\text{Dye powder obtained (g)}}{\text{Amount of plant material used (g)}} \times 100$$

(Bulda *et al.*, 2008)

3.5.5 Scouring of fabrics

The scouring process is required to remove the naturally present grease, acquired impurities like oils, dirt etc. The fabrics were washed with 2 % non-ionic soap (Labolene) at 50 °C for 20 min, maintaining the material-to-liquor ratio at 1:80. The scoured material was thoroughly washed with plenty of tap water and dried at room temperature. The scoured material was soaked in distilled water for 30 minutes prior to dyeing. All the fabrics were cut and sized into 5×6 cm and used for dyeing experiments (Tiwari *et al.*, 2010).

3.5.6 Mordanting and dyeing procedures

The concentrated dye extract of the different plant materials were used for the dyeing of the selected fabrics (wool, cotton, silk and pashmina). All the selected dye extracts were treated with different mordants individually and applied on each fabric samples.

3.5.6.1 Dyeing of Fabrics

Dyeing was carried out in a water bath, keeping suitable material to liquor ratio. The scoured and washed fabric samples were introduced in 250 ml beaker containing 100 ml of dye solution and 4 % dye (owm) at room temperature. The temperature was increased to 85-90 °C with gentle stirring. The process of dyeing was continued for 1 hour. The material was then removed from the dye bath and washed 2-3 times with 1 % of detergent and water. The dyed samples were squeezed and dried at room temperature. The dyeing of the wool, silk and pashmina was done at acidic pH by adding acetic acid (CH_3COOH) while as dyeing of cotton fabric was carried at basic pH by adding sodium chloride (Na_2CO_3) using the following the receipe. (Tiwari *et al.*, 2010; Lal *et al.*, 2011; Wang *et al.*, 2012).

3.5.6.2 Dyeing receipe

Dye	4 %
Acetic acid (CH_3COOH) (Wool, Silk and Pashmina)	0.5-1 %
Sodium carbonate (Na_2CO_3) (Cotton)	0.5-1 %
Temperature	85-90 °C
Material to Liquor ratio (MLR) Wool fabric & Pashmina	1:60
Material to Liquor ratio (MLR) Cotton fabric	1:40
Material to Liquor ratio (MLR) Silk fabric	1:100
Time (hrs)	1-2
pH (wool, silk and pashmina)	Acidic
pH (Cotton)	Alkaline

3.5.6.3 Mordanting

The mordanting was carried out by the following three methods.

1. Pre mordanting.
2. Simultaneous mordanting.
3. Post mordanting.

3.5.6.3.1 Pre mordanting of the fabrics

In this method mordanting was carried out prior to dyeing. The required amount (i.e. optimum concentration) of mordant was dissolved in 100 ml of distilled water in a beaker. Fabric sample was placed in the beaker and the dye bath was gradually brought to boiling point. The sample was stirred from time to time and the mordanting was continued for 1 hour. The sample was squeezed lightly after cooling and dyed immediately after mordanting (Jothi, 2008; Suitcharit *et al.*, 2010; Wang *et al.*, 2012).

3.5.6.3.2 Simultaneous mordanting of the fabrics

The optimized concentration of mordant was dissolved in 10 ml of boiled distilled water and transferred to a beaker containing 90 ml of dye liquor prepared by using optimum dyeing variables. The solution was warmed and stirred prior to addition of presoaked fabric. The presoaked fabric samples were added to the dye bath and the temperature was raised to optimum, and dyeing was carried out for 1 hour. The dyed sample was allowed to cool and then removed from the dye bath and washed 2-3 times with 0.5 % of detergent and water. The dyed samples were squeezed gently and dried at room temperature. Similar procedure was followed for all the natural mordants (Jothi, 2008; Suitcharit *et al.*, 2010; Wang *et al.*, 2012).

3.5.6.3.3 Post mordanting of the fabrics

Pre soaked fabric samples were placed in beakers containing 100 ml of dye solution. The dyeing was carried out for optimum time. The samples were

removed from the dye bath. The weighed amount of each mordant was dissolved in 10 ml of boiling water separately. The dyed samples were removed from the dye bath and added to the solution of the each mordant. Mordanting was carried out for 1 hour at 60 °C. Then the samples were removed from the dye bath, squeezed gently and dried at room temperature. Similar procedure was followed for all the natural mordants, (Jothi, 2008; Suitcharit *et al.*, 2010; Wang *et al.*, 2012) (Table-4).

Table-4 : Receipe of mordanting of selected fabrics

Mordant	<i>Punica granatum</i> L. (peel)	<i>Salix alba</i> L. (wood ash)	<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)	<i>Salix alba</i> L. (wood extract)
Concentration (%)	4	4	4	15
Temperature (°C)	60-75	60-75	60-75	60-75
Time (hrs)	1	1	1	1
Material to Liquor ratio (MLR)				
1:60 Wool	1:40 Cotton	1:100 Silk	1:60 Pashmina	

3.6 Determination of percent absorption of dye

The percent absorption of the natural dye by the different fabrics was carried out by recording the optical density of the dye solution both before and after dyeing process. The ultraviolet-visible adsorption spectra (UV-VIS) was recorded on PC based double beam spectrophotometer (Systronics 2202) over the range of 200-800 nm. The per cent absorption of natural dye was calculated by using the following equation (Kumar and Sinha, 2004; Vinod *et al.*, 2010) :

$$\text{Per cent absorption} = \frac{\text{O.D before dyeing} - \text{O.D after dyeing}}{\text{O.D before dyeing}} \times 100$$

3.7 Evaluation of CIE L*, a*, b*, C*, h° and ΔE values of dyed fabrics

After dyeing colour strength and fastness strength were carried out to have an idea about the colour of the dyed fabric. CIELAB values of dyed and undyed fabrics were determined by Chromometer (Model CR-2000, Minolta, Osaka, Japan) equipped with 8 mm measuring head and AC illumination (6774 K) based on CIE system (International Commission on Illumination). The meter was calibrated using the manufacturer's standard white plate. The reference illuminant was D65 (standard daylight), expressed as L*, a* and b* which representing lightness (L*) or darkness and ranges from black = 0 to white = 100, redness (+a*), greenness (-a*), yellowness (+b*), and blueness (-b*). From the L*, a* and b* coordinates, Chroma (C*) and hue angle (h°) values were calculated by the following equations (Aung and Win 2008; Vankar *et al.*, 2008; Atayde *et al.*, 2011).

$$\text{Chroma} = (a^{*2} + b^{*2})^{1/2}$$

$$\text{Hue} = (h = \tan^{-1} b^*/a^*)$$

Chroma measures the intensity or saturation of the colourant while hue angle (h°) is expressed on 360° grid to show the tonality of the colour. Hue angle (h°) represents red at 0° (or 360°), blue at 270° (or -90°), yellow at 90° and green colour at 180° (or -80°).

3.8 Total Colour change (ΔE)

The total Colour change of the dyed fabrics was calculated from the L*, a* and b* coordinates by applying the following equation.

Total Colour change (ΔE):

$$(\Delta E) = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Where,

$$\Delta L^* = L^* \text{ sample} - L^* \text{ standard}$$

$$\Delta a^* = a^* \text{ sample} - a^* \text{ standard}$$

$$\Delta b^* = b^* \text{ sample} - b^* \text{ standard}$$

3.9 Determination of colour strength (K/S) value

The colour strength (K/S) test was conducted at Division of Textile manufacture and Textile chemistry, Central Sheep and wool Research Institute, Avikanagar, Jaipur, Rajasthan.

The colour strength (K/S values) of the undyed and dyed fabric samples was evaluated (Kumaresan *et al.*, 2011) using a JAYPAK 4802 colour matching system (Jay Instruments Ltd, Mumbai, India) at D65 illuminate/10 Deg observer, (Jothi, 2008). The reflectance of the samples was measured at 360-760 nm. The colour strength value in the visible region of the spectrum (400-700 nm) was calculated based on the Kubelka-Munk equation :

$$\frac{K}{S} = \frac{(1-R_{\lambda})^2}{2 \times R_{\lambda}}$$

Where, K is the coefficient of absorption, S is the scattering coefficient and R is the surface reflectance value of the sample at a particular wavelength, where maximum absorption occurs for a particular dye/colour component.

3.10 Relative colour strength

The Relative colour strength (K/S values at maximum wavelength) were determined using the following equation adopted by, Goodarzian and Ekrami (2010).

$$\text{Relative strength} = \frac{(K/S) \text{ Extracted}}{(K/S) \text{ Raw}}$$

3.11 Evaluation of colour fastness properties

The fastness tests were conducted at the Division of Livestock products and Technology, Faculty of FVSc & AH, Shuhama, SKUAST-K, under the National Agricultural Innovation Project (NAIP) sub project entitled “A Value Chain on Enhanced Productivity and Profitability of Pashmina Fibre”.

Evaluation of the fastness properties of the dyed fabrics was done as per ISO standard test methods by measuring light, washing and rubbing fastness

values. The colour fastness is usually rated either by loss of depth of colour in original sample or is expressed by staining scale, Samanta and Agarwal, (2009). The fastness rating was assessed using grey scale as per ISO-105-A02 (loss of shade depth) and ISO-105-A03 (extent of staining). Methods for evaluating these properties are as follows.

3.11.1 Fastness to light (ISO 105-B02)

Samples of the dyed material were exposed simultaneously to a light source of Xenon arc lamp using a Xenon test chamber (Model Xe-1-S, Q-SUN) under specified conditions for 10 hours. The colour fastness to light of the specimen was evaluated by comparing the colour change of the exposed portion to the masked control portion of the test specimen using Grey scale for colour change. The fastness rating was assessed using grey scale as per ISO-05-A02 (loss of shade depth), (Kiumarsi *et al.*, 2009; Kulkarni *et al.*, 2011; Kumaresan *et al.*, 2013).

3.11.2 Fastness to Rubbing (ISO 105 X-12)

Colour fastness to rubbing (dry and wet) was assessed as per ISO-105-X12 method using a manually operated PROLIFIC Crock Meter with finger of 1.6 cm diameter moving to and fro in a straight line over a 10 ± 0.30 cm track on specimen, with downward force of 9 N. Dry crocking test was performed by a 5 x 13 cm piece of dyed sample placed on the base of Crockmeter with its long dimension in direction of rubbing. A white test cloth square was mounted over the end of finger projected downward weighted sliding arm. The dyed test specimen was rubbed with white crock test cloth for 10 completions. Colour transferred to the white test cloth and change of colour in dyed fabric was assessed by comparing with the Grey scale for staining and colour change and grades were assigned (Kiumarsi *et al.*, 2009; Kulkarni *et al.*, 2011; Kumaresan *et al.*, 2013).

3.11.3 Fastness to washing (ISO 105-C01)

A 10 × 4 cm swatch of the dyed fabric was taken sandwiched between two adjacent undyed white fabric and stitched round the edges. The soap solution contained 5 gm of soap per litre of distilled water. The solution was heated at 60°C for 30 minutes. The liquor ratio was 1:50 i.e 0.5g/25 ml. After soaping treatment, the specimen was removed, rinsed in cold and hot water respectively. Squeezed and dried at room temperature. The dried sample was assessed for the change in colour and staining on adjacent fabric with the help of Grey scale, (Kiumarsi *et al.*, 2009; Kulkarni *et al.*, 2011; Kumaresan *et al.*, 2013).

3.12 Grading on Grey scale

Grey scale consists of pairs of standard grey chips. The pairs represent progressive differences in colour or contrast corresponding to numerical colour fastness grades. The result of a colour fastness test is rated by visually comparing the difference in colour or the contrast between the untreated and treated specimens with the differences represented by the Scale. The colour fastness grade is equal to the grey scale step which is judged to have the same colour or contrast difference, (Kiumarsi *et al.*, 2009; Kulkarni *et al.*, 2011; Kumaresan *et al.*, 2013).

3.12.1 Grey scale for colour change (ISO 105-A02)

A change in colour of any kind whether in lightness, hue or chroma, or any combination of these, discernible by comparing the test specimen with a corresponding untested specimen. This evaluation procedure describes the use of a Grey scale for visually evaluating changes in colour of textiles resulting from colour fastness test.

3.12.2 Grey scale for staining (ISO 105-A03)

The unintended pickup of colourant by a substrate due to exposure to a coloured or contaminated liquid medium, or direct contact with dyed or pigmented material, from which colourant transfers by sublimation or mechanical



Colour attributes by Chromometer (Model CR-2000, Minolta, Osaka, Japan)



Light fastness by Xenon test chamber (Model Xe-1-S, Q-SUN)



Rubbing fastness by PROLIFIC Crock Meter



Washing fastness

Plate-4 : Fastness tests of dyed fabrics

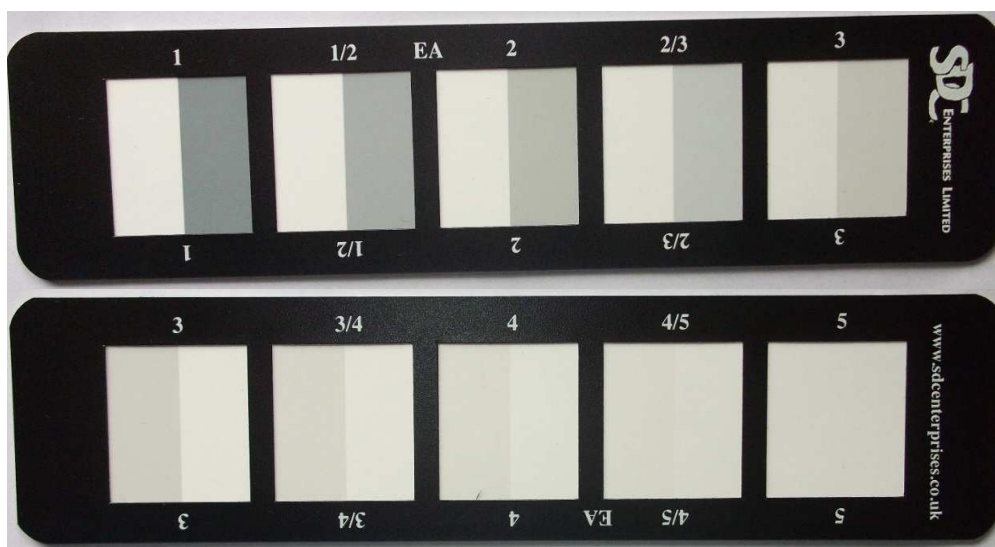
action (as in crocking). This evaluation procedure describes the use of the Grey Scale for evaluating staining of textiles resulting from colour fastness tests. The result of staining from a colour fastness test is rated by visually comparing the difference in colour or the contrast between the stained and unstained specimens with the differences represented by the scale (Table-5).

Table-5 : Colour fastness grading index

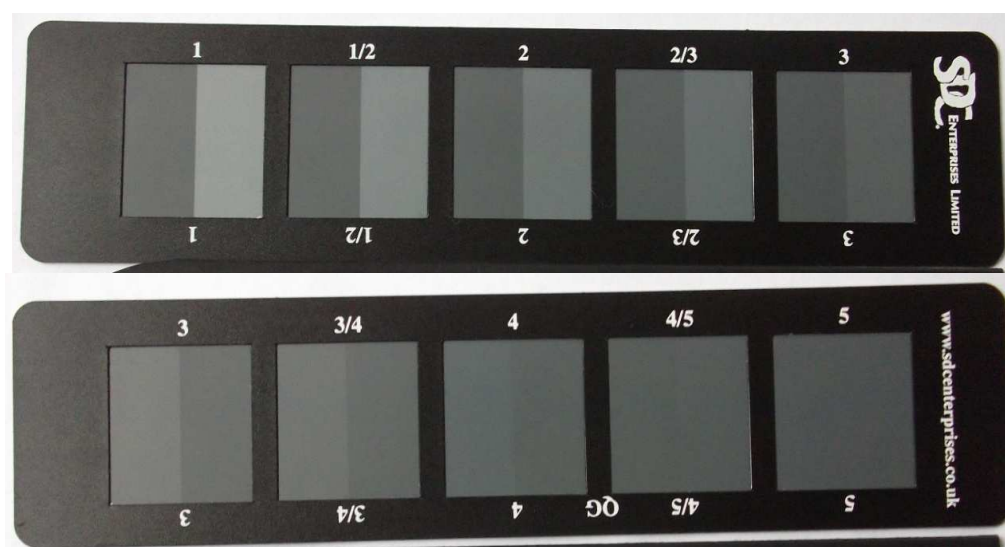
Grade No.	Remarks
5	Negligible, no change (Excellent)
4/5	Change in colour equivalent to grey scale step 4-5 (Good to Excellent)
4	Slightly change (Good)
3/4	Change in colour equivalent to grey scale step 3-4 (Fair to Good)
3	Noticeable changed (Fair)
2/3	Change in colour equivalent to grey scale step 2-3 (Poor to Fair)
2	Considerably changed (Poor)
1/2	Change in colour equivalent to grey scale step 1-2 (Very poor to Poor)
1	Much changed (Very poor)

3.13 Statistical analysis

The data generated from various experiments were subjected to factorial statistical analysis in a completely randomized design (CRD).



Grey scale for staining



Grey scale for colour change

Plate-5 : Grey scales used for conformation of fastness tests

Chapter – 4

EXPERIMENTAL FINDINGS

The present investigation entitled “Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley” was carried out with a series of experiments with the various variables during the year 2012-2013 at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar, Srinagar (J&K). Keeping in view the objectives the results obtained and observations recorded are presented under the following headings and sub-headings:

4.1 Characterization of selected plant species

Characters of the eight (8) selected plant species from different regions of Kashmir valley are presented in (Table-6).

4.2 Pigment estimation (Anthocyanins, carotenoids and chlorophyll)

Estimation of the pigments was carried out for two consecutive years (2011 and 2012). The amount of pigments of all the test species varied significantly.

4.2.1 Anthocyanins

The data presented in the Table-7 revealed that during the year 2011, the highest anthocyanin content (219.80 mg/100 gm) was recorded in the leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea*, followed by fruit hull of *Juglans regia* L. (173.97 mg/100 gm), petals of *Tagetes patula* L. (124.31 mg/100 gm), fruit cups of *Quercus robura* L. (117.96 mg/100 gm), leaves of *Juglans regia* L. (leaves) (115.42 mg/100 gm) and lowest (69.29 mg/100 gm) was recorded in the leaves of *Nasturtium officinale* R.Br. During the year 2012, the highest value of anthocyanin (211.20 mg/100 gm) was recorded in *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) followed by *Juglans regia* L. (fruit hull) (185.43 mg/100 gm), *Juglans regia* L. (leaves) (126.80 mg/100 gm), *Quercus robura* L. (fruit

Table-6 : Characterization of the selected plant species

S. No.	Plant species	Characterization
A) Test species for dye extraction		
1. <i>Prunus cerasifera</i>. Ehrh. var. <i>atropurpurea</i>		
	Common name	: Purple leaf plum
	Habitat	: Cultivated at dry places
	Habit	: Small tree
	Flower/inflorescence colour	: Flowers Pink
Morphological attributes		
a) Vegetative features		
	Stem	: Slender erect
	Leaves	: Ovate to obovate, rich purple
b) Reproductive features		
	Floral attributes	: Flowers born singly in twos or threes
	Fruit	: Fruits drupe, small, globular, red to purple
2. <i>Quercus robura</i> L.		
	Common name	: English oak
	Habitat	: Grows in shady ravines
	Habit	: Deciduous tree
	Flower/inflorescence colour	: Ament greenish yellow
Morphological attributes		
a) Vegetative features		
	Stem	: Erect, Strong
	Leaves	: Ovate to obovate, deeply lobed, terminal lobe long and narrow
b) Reproductive features		
	Floral attributes	: Flowers unisexual
	Fruit	: Nut hard, involucre cup shallow

Contd.....

Table-6 Contd.....

3. <i>Tagetes patula</i> L.	
Common name	: French Marigold
Habitat	: Cultivated at dry places
Habit	: Annual herb
Flower/inflorescence colour	: Reddish yellow or orange coloured
Morphological attributes	
a) Vegetative features	
Stem	: Erect bushy
Leaves	: Pinnately dissected; Segments linear-lanceolate, Serrate
b) Reproductive features	
Floral attributes	: Flowers in solitary heads
Fruit	: Achenes blackish to brownish
4. <i>Juglans regia</i> L.	
Common name	: Walnut
Habitat	: It grows at dry places
Habit	: Large deciduous tree
Flower/inflorescence colour	: Greenish
Morphological attributes	
a) Vegetative features	
Stem	: Trunk strong, Shoots tomentose
Leaves	: Pinnate, Leaflets, Sub sessile
b) Reproductive features	
Floral attributes	: Flowers unisexual, Petals 4 minute, Linear-lanceolate
Fruit	: Nut ellipsoid, green, thick shelled
5. <i>Nasturtium officinale</i> R.Br.	
Common name	: Watercress
Habitat	: Found near or in aquatic habitats
Habit	: Erect herb
Flower/inflorescence colour	: Flowers white

Contd.....

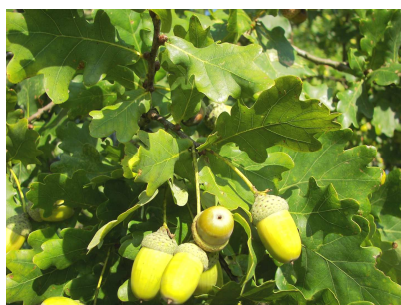
Table-6 Contd.....

Morphological attributes	
a) Vegetative features	
Stem	: Stem much branched, glabrous, creeping or floating
Leaves	: Pinnate, the upper with 3-7 pinnules, the lower cut into three repand segments
b) Reproductive features	
Floral attributes	: Flowers small in short racemes, petals white
Fruit	: Pods stalked, spreading or bent upwards
B) Test species for mordants	
6. <i>Punica granatum</i> L.	
Common name	: Pomegranate
Habitat	: Cultivated at dry places
Habit	: Large shrub
Flower/inflorescence colour	: Flowers orange red
Morphological attributes	
a) Vegetative features	
Stem	: Branchlets, round, rarely armed
Leaves	: opposite-sub opposite or clustered, oblong or obovate, obtuse, entire
b) Reproductive features	
Floral attributes	: Flowers axillary, solitary or clustered, showy, ovary inferior
Fruit	: Berry, globose, many seeded
7. <i>Populus deltoides</i> Bartram ex Marsh.	
Common name	: American poplar (Cotton wood)
Habitat	: Found in dry places
Habit	: Broad crowned tree
Flower/inflorescence colour	: Catkins greenish

Contd.....

Table-6 Contd.....

Morphological attributes	
a) Vegetative features	
Stem	: Long shoots angular, ribbed, young shoots cylindrical, slightly reddish
Leaves	: Triangular–ovate to rhombic, coarsely serrate
b) Reproductive features	
Floral attributes	: Male catkins flowers with 40-60 stamens
Fruit	: Capsule 3-4 valved
8. <i>Salix alba</i> L.	
Common name	: European willow, white willow
Habitat	: Usually found at moist places
Habit	: A large tree
Flower/inflorescence colour	: Catkins yellowish green
Morphological attributes	
a) Vegetative features	
Stem	: Trunk strong, branches, olive green or yellowish
Leaves	: Narrowly lanceolate, grey, silky
b) Reproductive features	
Floral attributes	: Flowers in male and female catkins
Fruit	: Capsule ovoid- conic



***Quercus robura* L.**



Fruit cups



Powder



***Juglans regia* L.**



Leaves



Powder



***Juglans regia* L.**



Fruit hull



Powder



***Prunus cerasifera* Ehrh.
var. *atropurpurea***



Leaves



Powder

Plate-6 : Plant species used for extraction of dyes and mordants

Contd.....

Plate-6 : Contd....



***Nasturtium officinale* R.Br.**



Leaves



Powder



***Tagetes patula* L.**



Petals



Powder



***Salix alba* L.**



Wood



Extract



Ash



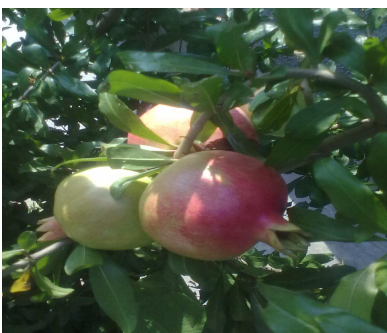
***Populus deltoides* Bartram
ex Marsh.**



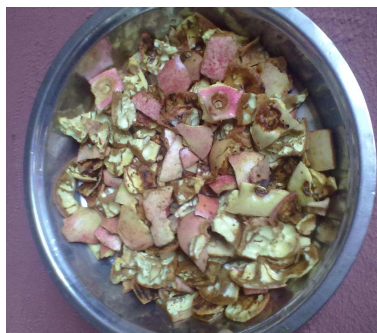
Wood



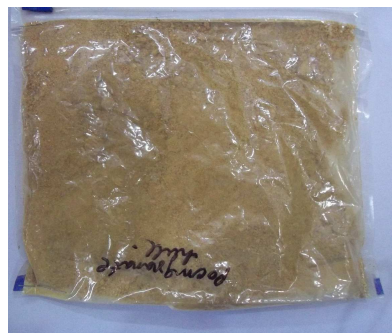
Ash



***Punica granatum* L.**



Peel



Powder

Table-7 : Quantification of pigments of selected test species

S. No.	Plant material	Parts used	Anthocyanins (mg/100 g)			Carotenoids (mg g ⁻¹ fw)			Total Chlorophyll (mg g ⁻¹ fw)		
			2011	2012	Pooled	2011	2012	Pooled	2011	2012	Pooled
1.	<i>Quercus robura</i> L.	Fruit cups	117.96 (2.07)	122.31 (2.08)	120.13 (2.07)	0.05	0.05	0.05	0.10	0.14	0.12
2.	<i>Juglans regia</i> L.	Leaves	115.42 (2.06)	126.80 (2.10)	121.11 (2.08)	0.16	0.21	0.18	0.51	0.65	0.58
3.	<i>Juglans regia</i> L.	Fruit hull	173.97 (2.24)	185.43 (2.26)	179.70 (2.25)	0.07	0.08	0.08	0.33	0.39	0.36
4.	<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> .	Leaves	219.80 (2.34)	211.20 (2.32)	215.50 (2.33)	0.10	0.14	0.12	0.42	0.48	0.45
5.	<i>Nasturtium officinale</i> R.Br.	Leaves	69.29 (1.84)	73.32 (1.86)	71.30 (1.85)	0.07	0.06	0.06	0.39	0.40	0.39
6.	<i>Tagetes patula</i> L.	Petals	124.31 (2.09)	120.17 (2.07)	122.24 (2.08)	0.08	0.06	0.07	0.31	0.37	0.34
C.D (p≤0.05)			0.01	0.03	0.02	0.03	0.01	0.03	0.08	0.05	0.07

*Values in parenthesis are log transformed values



Anthocyanin estimation



Carotenoid and chlorophyll estimation

Plate-7 : Processing of test species for pigment estimation

cups) (122.31 mg/100 gm), *Tagetes patula* L. (petals) (120.117) and lowest (73.32 mg/100 gm) was recorded in leaves of *Nasturtium officinale* R.Br.

4.2.2 Carotenoids

The highest value of carotenoid ($0.16 \text{ mg g}^{-1} \text{ fw}$) during the year 2011 was recorded in the leaves of *Juglans regia* L., followed by leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea* ($0.10 \text{ mg g}^{-1} \text{ fw}$), petals of *Tagetes patula* L. ($0.08 \text{ mg g}^{-1} \text{ fw}$), fruit hull of *Juglans regia* L. ($0.07 \text{ mg g}^{-1} \text{ fw}$) and leaves of *Nasturtium officinale* R.Br. ($0.07 \text{ mg g}^{-1} \text{ fw}$) and lowest ($0.05 \text{ mg g}^{-1} \text{ fw}$) was recorded in the fruit cups of *Quercus robura* L. During, 2012 highest carotenoid content ($0.21 \text{ mg g}^{-1} \text{ fw}$) was recorded in *Juglans regia* L. leaves, followed by *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves ($0.14 \text{ mg g}^{-1} \text{ fw}$), *Juglans regia* L. fruit hall ($0.08 \text{ mg g}^{-1} \text{ fw}$), *Nasturtium officinale* R.Br. leaves and *Tagetes patula* L. petals ($0.06 \text{ mg g}^{-1} \text{ fw}$), whereas the lowest content ($0.05 \text{ mg g}^{-1} \text{ fw}$) of carotenoid was recored in *Quercus robura* L. (fruit cups) (Table-7).

4.2.3 Chlorophyll

During the year 2011, highest chlorophyll content to the tune of $0.51 \text{ mg g}^{-1} \text{ fw}$ was recorded in the leaves of *Juglans regia* L., followed by leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea*, leaves of *Nasturtium officinale* R.Br., fruit hull of *Juglans regia* L., petals of *Tagetes patula* L with the values to the tune of $0.42 \text{ mg g}^{-1} \text{ fw}$, $0.39 \text{ mg g}^{-1} \text{ fw}$, $0.33 \text{ mg g}^{-1} \text{ fw}$ and $0.31 \text{ mg g}^{-1} \text{ fw}$ respectively. Lowest chlorophyll content ($0.10 \text{ mg g}^{-1} \text{ fw}$) was recorded in the fruit cups of *Quercus robura* L. As depicted in (Table-7), highest chlorophyll content ($0.65 \text{ mg g}^{-1} \text{ fw}$) during the year, 2012 was recorded in *Juglans regia* L. (leaves) followed by *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) ($0.48 \text{ mg g}^{-1} \text{ fw}$), *Nasturtium officinale* R.Br. (leaves) ($0.40 \text{ mg g}^{-1} \text{ fw}$), *Juglans regia* L. (fruit hull) ($0.39 \text{ mg g}^{-1} \text{ fw}$), *Tagetes patula* L. (petals) ($0.37 \text{ mg g}^{-1} \text{ fw}$) and lowest value ($0.14 \text{ mg g}^{-1} \text{ fw}$) was recorded in *Quercus robura* L. (fruit cups) respectively.

4.3 Percent yield of natural colourant

The yield of the dye powder from selected plant material is shown in (Table-8). The highest percent yield of dye powder (5.114) was recorded in leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea* followed by *Juglans regia* L. leaves (3.666), *Quercus robura* L. fruit cups (2.406), *Juglans regia* L. fruit hull (2.162), *Nasturtium officinale* R.Br. leaves (2.108) and lowest percent yield of dye powder (2.026) was recorded in *Tagetes patula* L. (petals) respectively.

4.4 Percent absorption of different dyes by selected fabrics

4.4.1 Percent absorption of dye by the wool fabric

The highest value of percent absorption (26.79) of the dye from *Quercus robura* L. (fruit cups) was recorded using *Populus deltoides* Bartram ex Marsh. (wood ash) as mordant. Values to the tune of 26.54, 26.51 and 26.20 were recorded using *Salix alba* L. (wood ash), *Punica granatum* L. (peel) and *Salix alba* L. (wood extract) respectively adopting pre mordanting method (Table-9).

Juglans regia L. (leaves) dye recorded highest percent absorption (27.89) with mordant *Salix alba* L. (wood extract) adopting simultaneous mordanting method. Using *Punica granatum* L. (peel), *Populus deltoides* Bartram ex Marsh (wood ash) and *Salix alba* L. (wood ash) as mordants, the values of 26.66, 26.49 and 26.44 were obtained respectively by adopting the pre mordanting method.

Juglans regia L. (fruit hull) dye recorded the highest percent absorption (28.50) with *Salix alba* L. (wood ash) followed by *Salix alba* L. (wood extract), *Populus deltoides* Bartram ex Marsh (wood ash) and *Punica granatum* L. (peel) with the values of 27.89, 27.78 and 27.55 respectively. The highest values of the percent absorption with all the mordants were observed by following the pre mordanting method.

Highest percent absorption (28.90) of the dye from *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) was recorded highest with *Punica granatum* L. (peel) adopting pre mordanting method. Values to the tune of 27.97, 27.52 and

Table-8 : Percentage yield of dye powder

S. No.	Plant material	Part used	Yield (g/50 g)	Yield of colorant (%)
1.	<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> .	Leaves	2.557	5.114
2.	<i>Quercus robura</i> L.	Fruit cups	1.203	2.406
3.	<i>Tagetes patula</i> L.	Petals	1.013	2.026
4.	<i>Juglans regia</i> L.	Fruit hull	1.081	2.162
5.	<i>Juglans regia</i> L.	Leaves	1.833	3.666
6.	<i>Nasturtium officinale</i> R.Br.	Leaves	1.054	2.108

Table-9 : Percent absorption of natural dyes and mordants by wool fabric

Mordants →		Salix alba L. (wood extract)				Mean	Salix alba L. (wood ash)				Mean	Populus deltoides Bartram ex Marsh. (wood ash)				Mean	Punica granatum L. (peel)				Mean	Factor mean	
Dye Source ↓	-----						-----					-----					-----					-----	
	M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		Dye	Method	
Quercus robura L. (fruit cups)	25.01	26.20	25.97	25.32	25.62	25.01	26.54	26.25	25.88	25.92	25.01	26.79	26.5	25.35	25.91	25.01	26.51	26.11	25.19	25.70	25.79	25.63	
Juglans regia L. (leaves)	25.37	27.37	27.89	26.78	26.85	25.37	26.1	26.44	25.75	25.91	25.37	26.49	26.12	25.65	25.90	25.37	26.66	26.34	25.92	26.07	26.18	27.07	
Juglans regia L. (fruit hull)	26.08	27.89	27.37	26.77	27.02	26.08	28.5	27.59	27.58	27.43	26.08	27.25	27.78	26.54	26.91	26.08	27.2	27.55	26.55	26.84	27.05	26.97	
Prunus cerasifera Ehrh. var. atropurpurea. (leaves)	26.27	27.19	27.52	27.09	27.01	26.27	27.6	27.97	27.5	27.33	26.27	26.41	26.85	26.34	26.46	26.27	28.9	28.33	27.75	27.81	27.15	26.13	
Nasturtium officinale R.Br. (leaves)	25.21	26.67	26.96	25.74	26.14	25.21	26.8	26.51	25.6	26.03	25.21	26.33	26.81	25.65	26.00	25.21	26.68	26.44	25.78	26.02	26.05		
Tagetes patula L. (petals)	25.85	27.22	26.44	25.17	26.17	25.85	27.18	26.88	25.14	26.26	25.85	27.86	28.18	27.07	27.24	25.85	27.48	26.7	25.22	26.31	26.49		

Mean	25.63	27.09	27.02	26.14	26.47	25.63	27.12	26.94	26.24	26.48	25.63	26.85	27.04	26.10	26.40	25.63	27.23	26.91	26.06	26.46			

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.12
Mordants (M)	:	0.09
Methods (Me)	:	0.11
Dye x Mordant	:	0.14
Dye x Method	:	0.13
Mordant x Method	:	0.11
Dye x Mordant x Method	:	0.16

26.85 were observed using *Salix alba* L. (wood ash), *Salix alba* L. (wood extract) and *Populus deltoides*. Bartram ex Marsh (wood ash) respectively by adopting simultaneous mordanting method.

The highest value of percent absorption of dye (26.96) from *Nasturtium officinale* R.Br. (leaves) was recorded with *Salix alba* L. (wood extract) adopting simultaneous mordanting followed by *Populus deltoides* Bartram ex Marsh. (wood ash), *Salix alba* L. (wood ash) and *Punica granatum* L. (peel) with the corresponding values of 26.81, 26.80 and 26.68 respectively by following the simultaneous, pre mordanting and pre mordanting method.

Tagetes patula L. (petals) recorded highest absorption of dye (28.18) using *Populus deltoides* Bartram ex Marsh. (wood ash) adopting simultaneous mordanting followed by *Punica granatum* L. (peel), *Salix alba* L. (wood extract) and *Salix alba* L. (wood ash) with values of 27.48, 27.22 and 27.18 respectively adopting pre mordanting, pre mordanting and simultaneous mordanting method.

Pre mordanting method of the dyeing showed the best dye absorption among all the mordanting methods with highest average mean dye absorption of 27.07 followed by the simultaneous mordanting 26.97, Post mordanting 26.13 and the lowest value of the dye absorption was observed in the unmordanted samples 25.63 (Table-9).

4.4.2 Percent absorption of dye by the cotton fabric

Quercus robura (fruit cups) recorded highest percent absorption with *Salix alba* (wood ash) (15.17) adopting pre mordanting method followed by *Salix alba* (wood extract), *Punica granatum* (peel) and *Populus deltoides* (wood ash) with the values of 15.05, 14.94 and 13.73 following simultaneous mordanting, simultaneous mordanting and without mordant respectively (Table-10).

The highest value of percent absorption (16.09) of the dye from *Juglans regia* (leaves) was recorded using *Salix alba* (wood extract) as mordant following simultaneous mordanting. Values to the tune of 15.96, 15.96 and 15.94 were

Table-10 : Percent absorption of natural dyes and mordants by cotton fabric

Mordants →	Salix alba L. (wood extract)				Mean	Salix alba L. (wood ash)				Mean	Populus deltoides Bartram ex Marsh. (wood ash)				Mean	Punica granatum L. (peel)				Mean	Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		Dye	Method
Quercus robura L. (fruit cups)	13.73	14.31	15.05	14.04	14.28	13.73	15.17	14.76	14.00	14.41	13.73	13.63	13.41	13.23	13.50	13.73	14.88	14.94	13.97	14.38	14.14	14.92
Juglans regia L. (leaves)	15.39	15.80	16.09	15.21	15.62	15.39	15.57	15.96	15.28	15.55	15.39	15.38	15.94	15.31	15.51	15.39	15.80	15.96	15.33	15.62	15.57	15.18
Juglans regia L. (fruit hull)	15.44	15.25	15.83	14.92	15.36	15.44	15.62	15.34	15.30	15.42	15.44	15.61	15.96	15.11	15.53	15.44	15.74	15.56	15.23	15.49	15.45	15.29
Prunus cerasifera Ehrh. var. atropurpurea. (leaves)	14.97	14.84	14.48	14.69	14.74	14.97	14.85	15.27	14.68	14.94	14.97	14.90	14.55	14.76	14.8	14.97	15.80	16.16	14.71	15.41	14.97	14.74
Nasturtium officinale R.Br. (leaves)	14.90	14.77	15.11	14.80	14.89	14.90	14.86	15.17	14.70	14.90	14.90	14.72	14.96	14.59	14.79	14.90	15.92	15.77	14.89	15.37	14.99	
Tagetes patula L. (petals)	15.11	15.02	15.67	14.80	15.15	15.11	15.65	15.20	14.86	15.20	15.11	14.94	14.59	14.74	14.85	15.11	15.45	15.23	14.62	15.10	15.07	
Mean	14.92	14.99	15.37	14.74	15.00	14.92	15.28	15.28	14.80	15.07	14.92	14.86	14.90	14.62	14.83	14.92	15.59	15.60	14.79	15.22	15.03	

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.15
Mordants (M)	:	0.10
Methods (Me)	:	0.12
Dye x Mordant	:	0.14
Dye x Method	:	0.13
Mordant x Method	:	0.11
Dye x Mordant x Method	:	0.18

recorded using *Salix alba* (wood ash), *Punica granatum* (peel) and *Populus deltoides* (wood ash) mordant respectively adopting simultaneous mordanting method.

Juglans regia (fruit hull) dye recorded highest Percent absorption (15.96) with mordant *Populus deltoides* (wood ash) adopting simultaneous mordanting. Using *Salix alba* (wood extract), *Punica granatum* (peel) and *Salix alba* (wood ash) the values of 15.83, 15.74 and 15.62 were obtained respectively by adopting the simultaneous mordanting, pre mordanting and pre mordanting method.

Highest percent absorption (16.16) of the dye for *Prunus cerasifera* (leaves) was recorded with *Punica granatum* (peel) mordant adopting simultaneous mordanting. Values to the tune of 15.27, 14.97 and 14.97 were observed using *Salix alba* (wood ash), *Salix alba* (wood extract) and *Populus deltoides* (wood ash) respectively by adopting simultaneous and pre mordanting method.

The highest value of percent absorption of dye (15.92) from *Nasturtium officinale* (leaves) was recorded with *Punica granatum* (peel) adopting pre mordanting. *Salix alba* (wood ash), *Salix alba* (wood extract) and *Populus deltoides* (wood ash) with the corresponding values of 15.17, 15.11 and 14.96 respectively by following the simultaneous mordanting method.

Tagetes patula L. (petals) recorded highest absorption of dye (15.67) using *Salix alba* (wood extract) as mordant following simultaneous mordanting method followed by *Salix alba* (wood ash), *Punica granatum* (peel) and *Populus deltoides* (wood ash) with corresponding values of 15.65, 15.45 and 15.11 respectively adopting pre mordanting method.

Simultaneous mordanting method of the dyeing showed the best dye absorption among all the methods with highest average mean dye absorption of (15.29) followed by the pre mordanting (15.18), without mordanting (14.92) and

the lowest value of the dye absorption (14.74) was recorded in the post mordanting method (Table-10).

4.4.3 Percent absorption of dye by the silk fabric

Quercus robura (fruit cups) recorded highest absorption of dye (26.92) using *Punica granatum* (peel) adopting simultaneous mordanting followed by *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Salix alba* (wood ash) with values of 26.83, 26.80 and 26.76 respectively by following simultaneous mordanting, simultaneous mordanting and pre mordanting method (Table-11).

The highest value of percent absorption of dye (27.98) from *Juglans regia* (leaves) was recorded with *Populus deltoides* (wood ash) adopting simultaneous mordanting followed by *Salix alba* (wood extract), *Punica granatum* (peel) and *Salix alba* (wood ash) with the corresponding values of 27.93, 26.97 and 26.80 respectively by following the simultaneous, simultaneous and pre mordanting method.

Highest percent absorption (27.21) from the dye for *Juglans regia* (fruit hull) was recorded highest with *Salix alba* (wood ash) following simultaneous mordanting. Values to the tune of 27.03, 26.98 and 26.89 were recorded using *Populus deltoides* (wood ash), *Punica granatum* (peel) and *Salix alba* (wood extract) mordant by adopting pre mordanting, simultaneous mordanting and without mordanting method.

Prunus cerasifera (leaves) dye recorded the highest percent absorption with *Salix alba* (wood extract) (27.89) followed by *Punica granatum* (peel), *Populus deltoides* (wood ash), and *Salix alba* (wood ash) with the values of 26.87, 26.86 and 26.78 respectively. The highest values of the percent absorption in all the mordants were observed by following simultaneous mordanting method.

Nasturtium officinale (leaves) dye recorded highest percent absorption (27.16) with mordant *Punica granatum* (peel) adopting simultaneous mordanting. Using *Populus deltoides* (wood ash), *Salix alba* (wood ash) and *Salix alba* (wood

Table-11 : Percent absorption of natural dyes and mordants by silk fabric

Dye Source ↓	Mordants → <i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
					Mean					Mean					Mean					Mean		
	M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		Dye	Method
<i>Quercus robura</i> L. (fruit cups)	25.26	26.10	26.83	25.54	25.93	25.26	26.76	26.47	25.3	25.94	25.26	26.22	26.80	25.20	25.87	25.26	26.37	26.92	25.75	26.07	25.95	25.87
<i>Juglans regia</i> L. (leaves)	26.24	27.49	27.93	26.31	26.99	26.24	26.8	26.28	26.15	26.36	26.24	27.84	27.98	26.42	27.12	26.24	26.78	26.97	26.19	26.54	26.75	26.66
<i>Juglans regia</i> L. (fruit hull)	26.89	26.52	26.71	26.77	26.72	26.89	26.94	27.21	26.58	26.90	26.89	27.03	26.92	26.75	26.9	26.89	26.57	26.98	26.82	26.81	26.83	26.92
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	26.33	27.55	27.89	26.51	27.07	26.33	26.46	26.78	26.4	26.49	26.33	26.54	26.86	26.42	26.54	26.33	26.45	26.87	26.45	26.52	26.65	25.97
<i>Nasturtium officinale</i> R.Br. (leaves)	24.4	25.86	25.43	24.91	25.15	24.4	25.94	25.32	24.91	25.14	24.4	25.48	26.03	24.6	25.13	24.4	26.12	27.16	24.16	25.46	25.22	
<i>Tagetes patula</i> L. (petals)	26.13	27.33	27.99	26.24	26.92	26.13	26.8	26.92	26.28	26.53	26.13	27.31	27.94	26.35	26.93	26.13	26.76	26.89	26.46	26.56	26.73	
Mean	25.87	26.81	27.13	26.04	26.46	25.87	26.61	26.49	25.93	26.23	25.87	26.73	27.08	25.95	26.41	25.87	26.50	26.96	25.97	26.33	26.36	

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.06
Mordants (M)	:	0.11
Methods (Me)	:	0.13
Dye x Mordant	:	0.11
Dye x Method	:	0.12
Mordant x Method	:	0.15
Dye x Mordant x Method	:	0.18

extract) as mordants the values of 26.03, 25.94 and 25.86 were obtained respectively by adopting the simultaneous, pre mordanting and pre mordanting method.

The highest value of percent absorption (27.99) of the dye from *Tagetes patula* (petals) was recorded using *Salix alba* (wood extract) as mordant following the simultaneous mordanting. Values to the tune of 27.94, 26.92 and 26.89 respectively were recorded using *Populus deltoides* (wood ash), *Salix alba* (wood ash) and *Punica granatum* (peel) adopting simultaneous mordanting method.

Dyeing with simultaneous mordanting method recorded the highest dye absorption value among all the mordanting methods with an highest average mean dye absorption (26.92) followed by the pre mordanting, post mordanting and without mordanting with the corresponding values of 26.66, 25.97 and 25.87 respectively (Table-11).

4.4.4 Percent absorption of dye by the pashmina fabric

Quercus robura (fruit cups) dye recorded the highest percent absorption with *Salix alba* (wood ash) (28.43) adopting pre mordanting followed by *Punica granatum* (peel), *Salix alba* (wood extract) and *Populus deltoides* (wood ash) with the values of 28.24, 27.95 and 27.64 respectively by following pre, simultaneous and simultaneous mordanting method (Table-12).

The highest value of percent absorption (29.28) of the dye from *Juglans regia* (leaves) was recorded using *Punica granatum* (peel) as mordant following pre mordanting. Values to the tune of 28.88, 28.86 and 28.78 were recorded using *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Salix alba* (wood ash) respectively adopting simultaneous, pre and simultaneous mordanting method.

Juglans regia (fruit hull) dye recorded highest percent absorption (29.12) with mordant *Populus deltoides* (wood ash) adopting simultaneous mordanting. Using *Salix alba* (wood ash), *Punica granatum* (peel) and *Salix alba* (wood

Table-12 : Percent absorption of natural dyes and mordants by pashmina fabric

Mordants →	Salix alba L. (wood extract)					Mean	Salix alba L. (wood ash)					Mean	Populus deltoides Bartram ex Marsh. (wood ash)					Mean	Punica granatum L. (peel)					Mean	Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	M ₁		M ₂	M ₃	M ₄	M ₁	M ₂		M ₃	M ₄	M ₁	M ₂	M ₃		M ₄	Dye	Method					
Quercus robura L. (fruit cups)	26.06	27.78	27.95	26.00	26.94	26.06	28.43	27.60	26.18	27.06	26.06	37.43	27.64	26.27	29.35	26.06	28.24	27.97	26.02	27.07	27.60	26.77				
Juglans regia L. (leaves)	27.18	28.78	28.88	27.04	27.97	27.18	28.37	28.78	27.14	27.86	27.18	28.86	28.77	27.11	27.98	27.18	29.28	28.72	27.19	28.09	27.97	28.66				
Juglans regia L. (fruit hull)	27.14	27.18	27.32	27.22	27.21	27.14	28.93	28.16	27.04	27.81	27.14	28.23	29.12	27.2	27.92	27.14	28.87	28.48	27.07	27.89	27.71	28.17				
Prunus cerasifera Ehrh. var. atropurpurea. (leaves)	27.22	28.97	28.58	27.18	27.98	27.22	28.89	28.44	27.20	27.93	27.22	28.45	28.62	27.31	27.90	27.22	28.84	28.41	27.14	27.90	27.93	26.77				
Nasturtium officinale R.Br. (leaves)	25.98	26.87	26.96	26.03	26.46	25.98	26.93	26.52	25.87	26.32	25.98	26.88	27.04	26.07	26.49	25.98	26.72	26.96	25.84	26.37	26.41					
Tagetes patula L. (petals)	27.08	28.79	28.95	27.17	27.99	27.08	28.94	28.82	27.17	28.00	27.08	28.41	28.61	27.00	27.78	27.08	28.86	28.98	27.22	28.03	27.95					
Mean	26.77	28.06	28.10	26.77	27.43	26.77	28.41	28.05	26.76	27.50	26.77	29.71	28.30	26.82	27.90	26.77	28.46	28.25	26.74	27.56	27.59					

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.03
Mordants (M)	:	0.11
Methods (Me)	:	0.07
Dye x Mordant	:	0.12
Dye x Method	:	0.10
Mordant x Method	:	0.14
Dye x Mordant x Method	:	0.16

extract) as mordants the values of 28.93, 28.87 and 27.32 were obtained respectively by adopting the pre mordanting, pre mordanting and simultaneous mordanting method.

Highest percent absorption (28.97) of the dye from *Prunus cerasifera* (leaves) was recorded highest with *Salix alba* (wood extract) adopting pre mordanting. Values to the tune of 28.89, 28.84 and 28.62 were observed using *Salix alba* (wood ash), *Punica granatum* (peel) and *Populus deltoides* (wood ash) as mordants by adopting pre mordanting, pre mordanting and simultaneous mordanting method.

Nasturtium officinale (leaves) recorded highest absorption of dye (27.04) using *Populus deltoides* (wood ash) as mordant adopting simultaneous mordanting followed by *Salix alba* (wood extract), *Punica granatum* (peel) and *Salix alba* (wood ash) with values of 26.96, 26.96 and 26.93 respectively following simultaneous, simultaneous and pre mordanting method.

The highest value of percent absorption of dye (28.98) was recorded from *Tagetes patula* (petals) with *Punica granatum* (peel) as mordant following simultaneous mordanting followed by *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) with the corresponding values of 28.95, 28.94 and 28.61 respectively by following the simultaneous, pre and simultaneous mordanting method.

Pre mordanting method of dyeing recorded the highest (28.66) average mean dye absorption among all the mordanting methods whereas simultaneous mordanting, post mordanting and without mordanting recorded values of 28.17, 26.77 and 26.77 respectively (Table-12).

4.5 CIE L*, a*, b*, Hue angle (h°), Chroma (C*) and Total colour change ΔE of dyed fabrics

4.5.1 Colour coordinates of fabrics dyed with *Quercus robura* L. fruit cups using *Salix alba* L. wood extract as mordant

Mordant type and method of mordanting showed significant difference in colour coordinates of fabrics. Highest L* (85.09) was recorded in cotton fabric using pre mordanting method. Values to the tune of 2.82, 18.35, 18.57, 81.30 and 13.99 were recorded for a*, b*, C*, h° and ΔE respectively. However in wool, silk and pashmina fabrics highest L* values recorded are 73.07, 71.00 and 61.57 respectively in dyeing without mordanting, post mordanting and pre mordanting with a* values to the tune of 4.37, 5.78 and 4.97, b* 31.22, 24.62 and 26.62, C* 31.53, 25.29 and 27.08, h° 82.00, 76.80 and 79.40 and ΔE 31.16, 15.05 and 22.42 respectively. Lowest L* (55.71) was recorded by pashmina fabric dyed without mordanting with a*, b*, C*, h° and ΔE values of 4.34, 25.53, 25.90, 80.30 and 26.95 respectively followed by wool, silk and cotton with L* to the tune of 59.47, 62.17 and 80.44, a* 5.70, 9.28 and 4.50, b* 19.84, 23.80 and 19.73, C* 20.64, 25.55 and 20.24, h° 74.00, 68.70 and 77.10, ΔE 28.73, 30.42 and 18.17 following post mordanting, pre mordanting and without mordant (Table-13).

4.5.2 Colour coordinates of fabrics dyed with *Quercus robura* L. fruit cups using *Salix alba* L. wood ash as mordant

Highest L* (84.62) was recorded by cotton fabric adopting pre mordanting method with a*, b*, C*, h° and ΔE values to the tune of 3.01, 16.15, 16.43, 79.40 and 12.61 respectively. However in wool, silk and pashmina fabrics highest L* values recorded 73.07, 68.04 and 60.48 respectively in dyeing without mordanting, pre mordanting and pre mordanting with a* values to the tune of 4.37, 7.44 and 7.23, b* 31.22, 25.65 and 29.41, C* 31.53, 26.71 and 30.29, h° 82.00, 73.80 and 76.20 and ΔE 31.16, 26.25 and 24.98 respectively (Table-14). Lowest L* (47.94) was recorded by pashmina fabric following post mordanting with a*, b*, C*, h° and ΔE values of 3.20, 23.74, 23.96, 82.30 and 33.79 respectively followed by silk, wool and cotton with L* to the tune of 60.70, 61.84

Table-13 : Average colour coordinates of different fabrics treated with *Quercus robura* L. fruit cups dye using *Salix alba* L. wood extract as mordant

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		73.07	4.37	31.22	31.53	82.00	31.16
Pre mordanting		72.04	4.53	26.21	26.60	80.2	25.64
Simultaneous mordanting		64.66	6.07	28.36	29.00	77.90	27.72
Post mordanting		59.47	5.70	19.84	20.64	74.00	28.73
Cotton Fabric							
Without Mordant		80.44	4.505	19.73	20.24	77.10	18.17
Pre mordanting		85.09	2.82	18.35	18.57	81.30	13.99
Simultaneous mordanting		80.76	3.13	16.95	17.24	79.50	16.03
Post mordanting		80.55	3.25	14.89	15.24	77.70	15.04
Silk Fabric							
Without Mordant		65.81	4.84	28.98	29.39	80.50	30.03
Pre mordanting		62.17	9.28	23.8	25.55	68.70	30.42
Simultaneous mordanting		67.45	7.06	24.16	25.14	73.70	25.72
Post mordanting		71.00	5.78	24.62	25.29	76.80	23.05
Pashmina Fabric							
Without Mordant		55.71	4.34	25.53	25.9	80.30	26.95
Pre mordanting		61.57	4.97	26.62	27.08	79.40	22.42
Simultaneous mordanting		57.34	6.87	27.65	28.49	76.00	26.72
Post mordanting		57.55	4.57	27.32	27.7	80.50	26.00

Table-14 : Average colour coordinates of different fabrics treated with *Quercus robura* L. fruit cups dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		73.07	4.375	31.22	31.53	82.00	31.16
Pre mordanting		68.20	3.46	28.63	28.84	83.10	24.73
Simultaneous mordanting		64.59	4.58	27.41	27.79	80.50	27.00
Post mordanting		61.84	6.04	28.95	29.58	78.20	30.34
Cotton Fabric							
Without Mordant		80.44	4.505	19.73	20.24	77.1	18.17
Pre mordanting		84.62	3.01	16.15	16.43	79.4	12.61
Simultaneous mordanting		79.53	3.87	17.96	18.37	77.8	26.25
Post mordanting		80.47	3.71	18.87	19.24	78.9	17.51
Silk Fabric							
Without Mordant		65.81	4.84	28.98	29.39	80.5	30.03
Pre mordanting		68.04	7.44	25.65	26.71	73.8	26.25
Simultaneous mordanting		60.7	4.87	24.61	25.09	78.8	31.28
Post mordanting		61.73	5.85	18.84	19.65	73.5	28.10
Pashmina Fabric							
Without Mordant		55.71	4.34	25.53	25.9	80.3	26.95
Pre mordanting		60.48	7.23	29.41	30.29	76.2	24.98
Simultaneous mordanting		55.54	4.45	22.38	22.82	78.8	26.22
Post mordanting		47.94	3.20	23.74	23.96	82.3	33.79

and 79.53 respectively a^* 4.87, 6.04 and 3.87, b^* 24.61, 28.95 and 17.96, C^* 25.09, 29.58 and 18.37, h° 78.80, 78.20 and 77.80, ΔE 31.28, 30.34 and 26.25 adopting simultaneous mordanting, post mordanting and simultaneous mordanting (Table-14).

4.5.3 Colour coordinates of fabrics dyed with *Quercus robura* L. fruit cups using *Populus deltoides* Bartram ex Marsh. wood ash as mordant

Highest L^* (91.15) was recorded in cotton fabric following post mordanting method. Values to the tune of 2.78, 10.35, 10.72, 74.90 and 3.95 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in wool, silk and pashmina fabrics highest L^* values 73.07, 66.26 and 55.71 recorded respectively in dyeing without mordanting, pre mordanting and without mordanting with a^* values to the tune of 4.37, 6.56 and 4.34, b^* 31.22, 25.70 and 25.53, C^* 31.53, 26.52 and 25.90, h° 82.00, 75.70 and 80.30 and ΔE 31.16, 27.47 and 26.95 respectively. Lowest L^* (37.24) was recorded by pashmina fabric adopting post mordanting with a^* , b^* , C^* , h° and ΔE values of 5.24, 18.97, 19.68, 74.50 and 43.86 respectively followed by wool, silk and cotton with L^* to the tune of 56.25, 66.26 and 55.71 respectively, a^* 3.31, 8.03 and 4.50, b^* 16.45, 28.42 and 19.73, C^* 16.79, 29.54 and 20.24, h° 78.60, 74.40 and 77.10, ΔE 30.92, 37.19 and 18.17 adopting simultaneous mordanting, post mordanting and without mordanting (Table-15).

4.5.4 Colour coordinates of fabrics dyed with *Quercus robura* L. fruit cups using *Punica granatum* L. peel as mordant

Highest L^* (83.79) was recorded in cotton fabric following post mordanting method. Values to the tune of 0.48, 23.41, 23.41, 88.80 and 18.87 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in wool, silk and pashmina fabrics highest L^* values recorded are 73.07, 68.29 and 61.73 respectively in dyeing without mordanting, pre mordanting and pre mordanting with a^* values to the tune of 4.37, 6.51 and 5.51, b^* 31.22, 21.58 and 37.60, C^* 31.53, 22.54 and 38.01, h° 82.00, 73.20 and 81.70 and ΔE 31.16, 23.54 and 28.97 respectively (Table-16). Lowest L^* (41.47) was recorded by pashmina fabric dyed

Table-15 : Average colour coordinate values of different fabrics treated with *Quercus robura* L. fruit cups dye using *Populus deltoides* Bartram ex Marsh wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		73.07	4.375	31.22	31.53	82.00	31.16
Pre mordanting		56.83	5.26	25.36	25.91	78.30	32.91
Simultaneous mordanting		56.25	3.31	16.45	16.79	78.60	30.92
Post mordanting		61.00	7.08	21.76	22.88	72.00	28.14
Cotton Fabric							
Without Mordant		80.44	4.505	19.73	20.24	77.1	18.17
Pre mordanting		81.76	3.04	14.06	14.38	77.8	13.57
Simultaneous mordanting		88.64	3.1	25.86	26.05	83.2	19.35
Post mordanting		91.15	2.78	10.35	10.72	74.9	3.95
Silk Fabric							
Without Mordant		65.81	4.84	28.98	29.39	80.5	30.03
Pre mordanting		66.26	6.56	25.7	26.52	75.7	27.47
Simultaneous mordanting		60.69	4.17	20.37	20.79	78.4	29.40
Post mordanting		56.52	8.03	28.42	29.54	74.4	37.19
Pashmina Fabric							
Without Mordant		55.71	4.34	25.53	25.9	80.3	26.95
Pre mordanting		52.67	4.34	28.22	28.55	81.2	30.76
Simultaneous mordanting		55.26	3.92	25.86	26.16	81.4	27.45
Post mordanting		37.24	5.24	18.97	19.68	74.5	43.86

Table-16 : Average colour coordinate values of different fabrics treated with *Quercus robura* L. fruit cups dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		73.07	4.375	31.22	31.53	82	31.16
Pre mordanting		64.4	7.72	27.42	28.49	74.3	27.80
Simultaneous mordanting		60.97	6.95	36.86	37.51	79.3	29.32
Post mordanting		48.94	4.29	20.76	21.20	78.3	34.97
Cotton Fabric							
Without Mordant		80.44	4.505	19.73	20.24	77.1	18.17
Pre mordanting		78.88	1.86	25.6	25.67	85.8	23.54
Simultaneous mordanting		73.82	0.21	33.33	33.35	89.6	32.61
Post mordanting		83.79	0.48	23.41	23.41	88.8	18.87
Silk Fabric							
Without Mordant		65.81	4.84	28.98	29.39	80.5	30.03
Pre mordanting		68.29	6.51	21.58	22.54	73.2	23.54
Simultaneous mordanting		48.68	3.72	24.74	25.02	81.4	42.59
Post mordanting		54.48	5.29	26.16	26.69	78.6	37.73
Pashmina Fabric							
Without Mordant		55.71	4.34	25.53	25.9	80.3	26.95
Pre mordanting		61.73	5.51	37.60	38.01	81.7	28.97
Simultaneous mordanting		42.09	5.56	29.78	30.29	79.4	41.27
Post mordanting		41.47	4.39	26.45	26.81	80.6	40.78

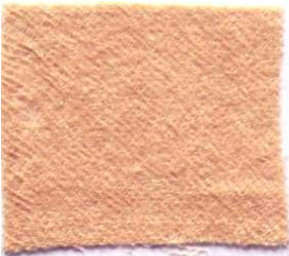
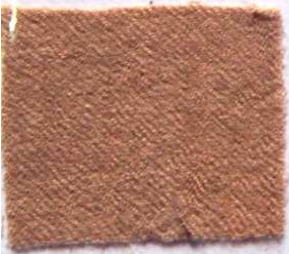
Method → Mordant ↓	Pre-mordanting	Simultaneous mordanting	Post-mordanting
<i>Salix alba</i> L. (Wood extract)			
<i>Salix alba</i> L. (Wood ash)			
<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
<i>Punica granatum</i> L. (Peel)			

Plate-8: Wool samples dyed with *Quercus robura* L. (fruit cups) in combination with different mordants

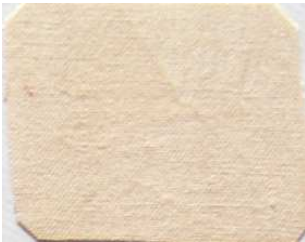
		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-9 : Cotton samples dyed with *Quercus robura* L. (fruit cups) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-10 : Silk samples dyed with *Quercus robura* L. (fruit cups) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓	<i>Salix alba</i> L. (Wood extract)	Pre-mordanting	Simultaneous mordanting	Post-mordanting
				
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-11 : Pashmina samples dyed with *Quercus robura* L. (fruit cups) in combination with different mordants

post mordanting with a^* , b^* , C^* , h° and ΔE values of 4.39, 26.45, 26.81, 80.60 and 40.78 respectively followed by silk, wool and cotton with L^* to the tune of 48.68, 48.94 and 73.82 respectively, a^* 3.72, 4.29 and 0.21, b^* 24.74, 20.76 and 33.33, C^* 25.02, 21.20 and 33.35, h° 81.40, 78.30 and 89.61, ΔE 42.59, 34.97 and 32.61 following simultaneous mordanting, post mordanting and simultaneous mordanting (Table-16).

4.5.5 Colour coordinates of fabrics dyed with *Juglans regia* L. leaves using *Salix alba* L. wood extract mordant

Highest L^* (80.53) was recorded in cotton fabric adopting simultaneous mordanting method. Values to the tune of 2.12, 20.82, 20.93, 84.20 and 18.83 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 73.33, 64.24 and 58.85 respectively in dyeing post mordanting, post mordanting and pre mordanting with a^* values to the tune of 1.40, 3.98 and 2.06 respectively, b^* 32.39, 32.01 and 32.89, C^* 32.43, 32.26 and 32.95, h° 87.50, 82.90 and 86.40 and ΔE 27.11, 29.97 and 27.58. Lowest L^* (52.11) was recorded by pashmina fabric dyed simultaneous mordanting with a^* , b^* , C^* , h° and ΔE values to the tune of 3.52, 34.16, 34.34, 84.10 and 33.93 respectively followed by silk, wool and cotton with L^* 59.17, 60.07 and 71.66 respectively, a^* 3.74, 3.04 and 3.15, b^* 32.36, 32.93 and 22.29, C^* 32.58 and 33.08, 22.51, h° 83.40, 84.70 and 81.90, ΔE 36.71, 33.69 and 26.53 following pre mordanting, simultaneous mordanting and without mordanting (Table-17).

4.5.6 Colour coordinates of fabrics dyed with *Juglans regia* L. leaves using *Salix alba* L. wood ash as mordant

Highest L^* (80.22) was recorded in cotton fabric following pre mordanting method. Values to the tune of 2.29, 19.23, 19.37, 83.20 and 17.93 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 65.62, 64.12 and 57.69 respectively in dyeing simultaneous mordanting, without mordanting and simultaneous mordanting with a^* values to the tune of 3.07, 2.68 and 3.34, b^*

Table-17 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. leaves dye using *Salix alba* L. wood extract as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		64.12	2.68	33.50	33.61	85.40	30.93
Pre mordanting		66.19	2.33	32.01	32.10	85.80	28.38
Simultaneous mordanting		60.07	3.04	32.93	33.08	84.70	33.69
Post mordanting		64.24	3.98	32.01	32.26	82.90	29.97
Cotton Fabric							
Without Mordant		71.66	3.15	22.29	22.51	81.90	26.53
Pre mordanting		80.33	2.27	18.33	18.47	82.90	17.25
Simultaneous mordanting		80.53	2.12	20.82	20.93	84.20	18.83
Post mordanting		78.74	1.93	2.43	22.51	85.10	21.24
Silk Fabric							
Without Mordant		64.15	2.85	33.26	33.38	85.10	33.60
Pre mordanting		59.17	3.74	32.36	32.58	83.40	36.71
Simultaneous mordanting		60.75	3.89	33.17	33.40	83.30	36.08
Post mordanting		73.33	1.40	32.39	32.43	87.50	27.11
Pashmina Fabric							
Without Mordant		53.25	2.40	30.56	30.65	85.50	31.10
Pre mordanting		58.85	2.06	32.89	32.95	86.40	27.58
Simultaneous mordanting		52.11	3.52	34.16	34.34	84.10	33.93
Post mordanting		52.69	3.57	30.84	31.05	83.40	31.79

Table-18 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. leaves dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		64.12	2.68	33.50	33.61	85.40	30.93
Pre mordanting		63.81	3.38	34.25	34.42	84.40	31.72
Simultaneous mordanting		61.00	3.89	30.61	30.86	82.70	31.65
Post mordanting		57.77	3.34	32.51	32.68	84.10	35.32
Cotton Fabric							
Without Mordant		71.66	3.15	22.29	22.51	81.90	26.53
Pre mordanting		80.22	2.29	19.23	19.37	83.20	17.93
Simultaneous mordanting		77.25	1.92	28.20	28.27	86.10	26.59
Post mordanting		76.95	2.72	23.27	23.43	83.30	23.28
Silk Fabric							
Without Mordant		64.15	2.85	33.26	33.38	85.10	33.60
Pre mordanting		63.86	3.40	32.62	32.80	84.10	33.39
Simultaneous mordanting		65.62	3.07	30.46	30.61	84.20	30.61
Post mordanting		58.21	3.14	34.08	34.23	84.70	39.45
Pashmina Fabric							
Without Mordant		53.25	2.40	30.56	30.65	85.50	31.10
Pre mordanting		53.96	3.35	33.79	33.96	84.30	32.16
Simultaneous mordanting		57.69	3.34	30.04	30.23	83.70	27.02
Post mordanting		51.30	3.14	34.08	34.23	84.70	34.55

30.46, 33.50 and 30.04, C* 30.61, 33.61 and 30.23, h° 84.20, 85.40 and 83.70 and ΔE 30.61, 30.93 and 27.02 respectively (Table-18). Lowest L* (51.30) was recorded by pashmina fabric dyed post mordanting with a*, b*, C*, h° and ΔE values of 3.14, 34.08, 34.23, 84.70 and 34.55 respectively followed by wool, silk and cotton with L* to the tune of 57.77, 58.21 and 71.66 respectively, a* 3.34, 3.14 and 3.15, b* 32.51, 34.09 and 22.29, C* 32.68, 34.24 and 22.51, h° 84.10, 84.70 and 81.90, ΔE 35.32, 39.45 and 26.53 following post mordanting, post mordanting and without mordanting (Table-18).

4.5.7 Colour coordinates of fabrics dyed with *Juglans regia* L. leaves using *Populus deltoides* Bartram ex Marsh. wood ash as mordant

Highest L* (79.05) was recorded in cotton fabric using pre mordanting method. Values to the tune of 2.60, 22.21, 22.37, 83.30 and 20.84 were recorded for a*, b*, C*, h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L* values recorded are 64.15, 64.12 and 53.25 respectively in dyeing without mordanting with a* values to the tune of 2.85, 2.68 and 2.40 respectively, b* 33.26, 33.50 and 30.56, C* 33.38, 33.61 and 30.65, h° 85.10, 85.40 and 85.50 and ΔE 33.60, 30.93 and 31.10. Lowest L* (45.41) was recorded by pashmina fabric dyed pre mordanting with a*, b*, C*, h° and ΔE values of 3.35, 29.98, 30.17, 83.60 and 38.05 respectively followed by silk, wool and cotton with L* to the tune of 51.34, 54.11 and 71.66 respectively, a* 4.77, 3.90 and 3.15, b* 30.59, 30.61 and 22.29, C* 30.97, 30.86 and 22.51, h° 81.10, 82.70 and 81.90, ΔE 42.29, 31.76 and 26.53 following simultaneous mordanting, simultaneous mordanting and without mordanting (Table-19).

4.5.8 Colour coordinates of fabrics dyed with *Juglans regia* L. leaves using *Punica granatum* L. peel as mordant

Highest L* (72.07) was recorded in cotton fabric adopting pre mordanting method. Values to the tune of 2.94, 26.29, 26.45, 83.60 and 22.18 were recorded for a*, b*, C*, h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L* values recorded are 64.15, 64.12 and 58.75 respectively in dyeing without mordanting, without mordanting and pre mordanting with a*

Table-19 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. leaves dye using *Populus deltoides* Bartram ex Marsh wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		64.12	2.68	33.5	33.61	85.4	30.93
Pre mordanting		57.32	4.04	31.09	31.35	82.6	34.98
Simultaneous mordanting		54.11	3.9	30.61	30.86	82.7	31.76
Post mordanting		57.9	4.68	27.39	27.79	80.3	27.28
Cotton Fabric							
Without Mordant		71.66	3.15	22.29	22.51	81.9	26.53
Pre mordanting		79.05	2.6	22.21	22.37	83.3	20.84
Simultaneous mordanting		75.90	3.26	18.14	18.44	79.8	20.29
Post mordanting		85.64	2.69	18.14	18.34	81.6	13.38
Silk Fabric							
Without Mordant		64.15	2.85	33.26	33.38	85.1	33.60
Pre mordanting		61.80	3.56	32.70	32.90	83.8	34.96
Simultaneous mordanting		51.34	4.77	30.59	30.97	81.1	42.29
Post mordanting		57.98	5.70	26.79	27.39	78	34.83
Pashmina Fabric							
Without Mordant		53.25	2.40	30.56	30.65	85.5	31.1
Pre mordanting		45.41	3.35	29.98	30.17	83.6	38.05
Simultaneous mordanting		49.54	4.95	34.55	34.91	81.8	36.44
Post mordanting		49.53	5.03	31.79	32.19	81	35.16

Table-20 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. leaves dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		64.12	2.68	33.5	33.61	85.40	30.93
Pre mordanting		60.04	5.35	31.90	32.35	80.50	27.14
Simultaneous mordanting		53.46	6.99	36.26	36.93	79.10	34.83
Post mordanting		55.06	5.24	35.35	35.74	81.60	33.05
Cotton Fabric							
Without Mordant		71.66	3.15	22.29	22.51	81.90	26.53
Pre mordanting		72.07	2.94	26.29	26.45	83.60	22.18
Simultaneous mordanting		70.15	1.71	32.69	32.73	87.00	34.32
Post mordanting		80.87	1.37	21.60	21.64	86.40	18.95
Silk Fabric							
Without Mordant		64.15	2.85	33.26	33.38	85.10	33.60
Pre mordanting		59.25	4.69	28.45	28.84	80.60	34.29
Simultaneous mordanting		58.62	3.65	30.94	31.16	83.30	35.95
Post mordanting		55.46	5.59	32.75	33.22	80.30	39.77
Pashmina Fabric							
Without Mordant		53.25	2.40	30.56	30.65	85.50	31.10
Pre mordanting		58.75	4.46	35.11	35.40	82.80	29.22
Simultaneous mordanting		48.40	6.64	37.14	37.73	79.90	38.96
Post mordanting		48.23	5.59	17.75	18.61	72.50	32.93

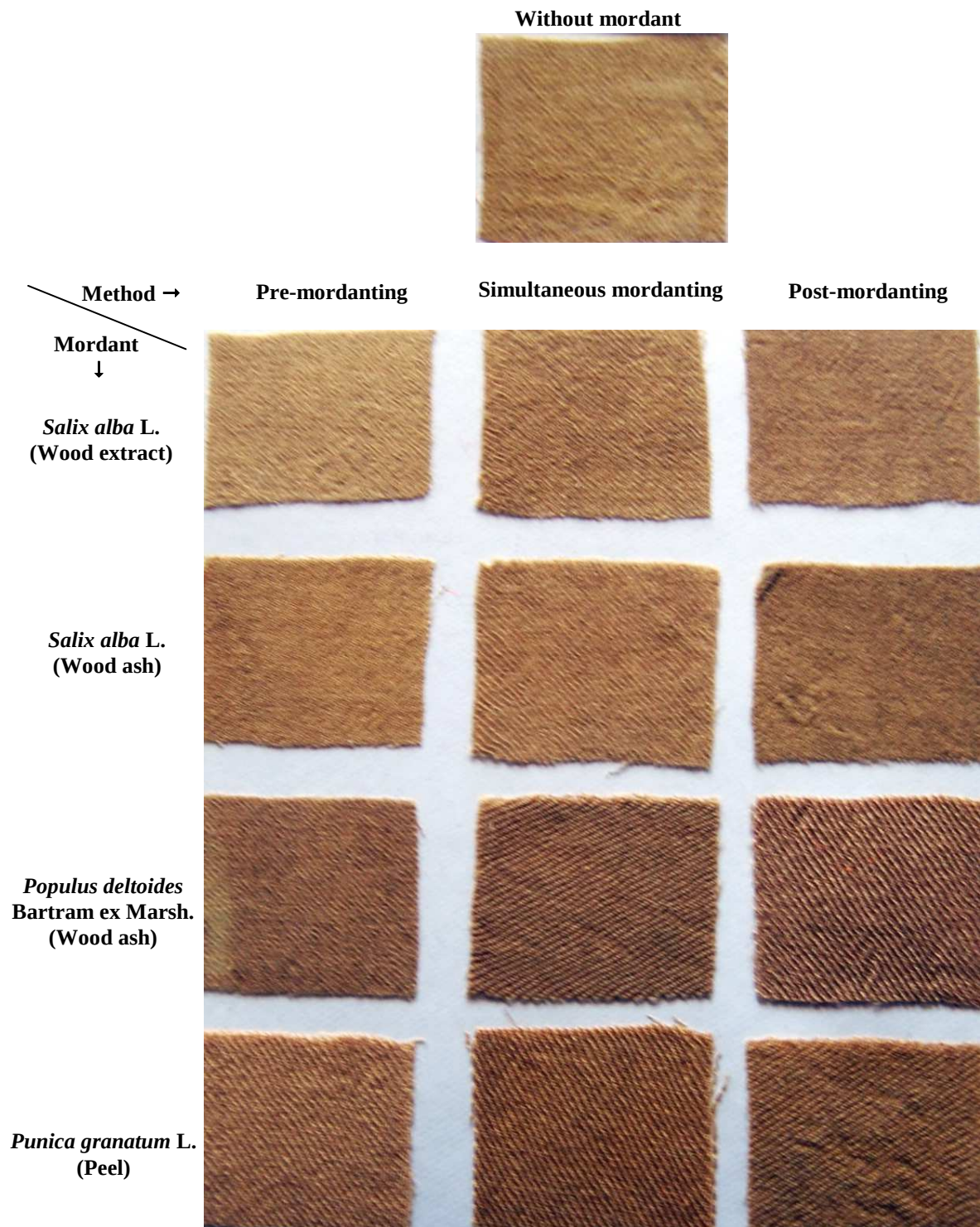


Plate-12 : Wool samples dyed with *Juglans regia* L. (leaves) in combination with different mordants

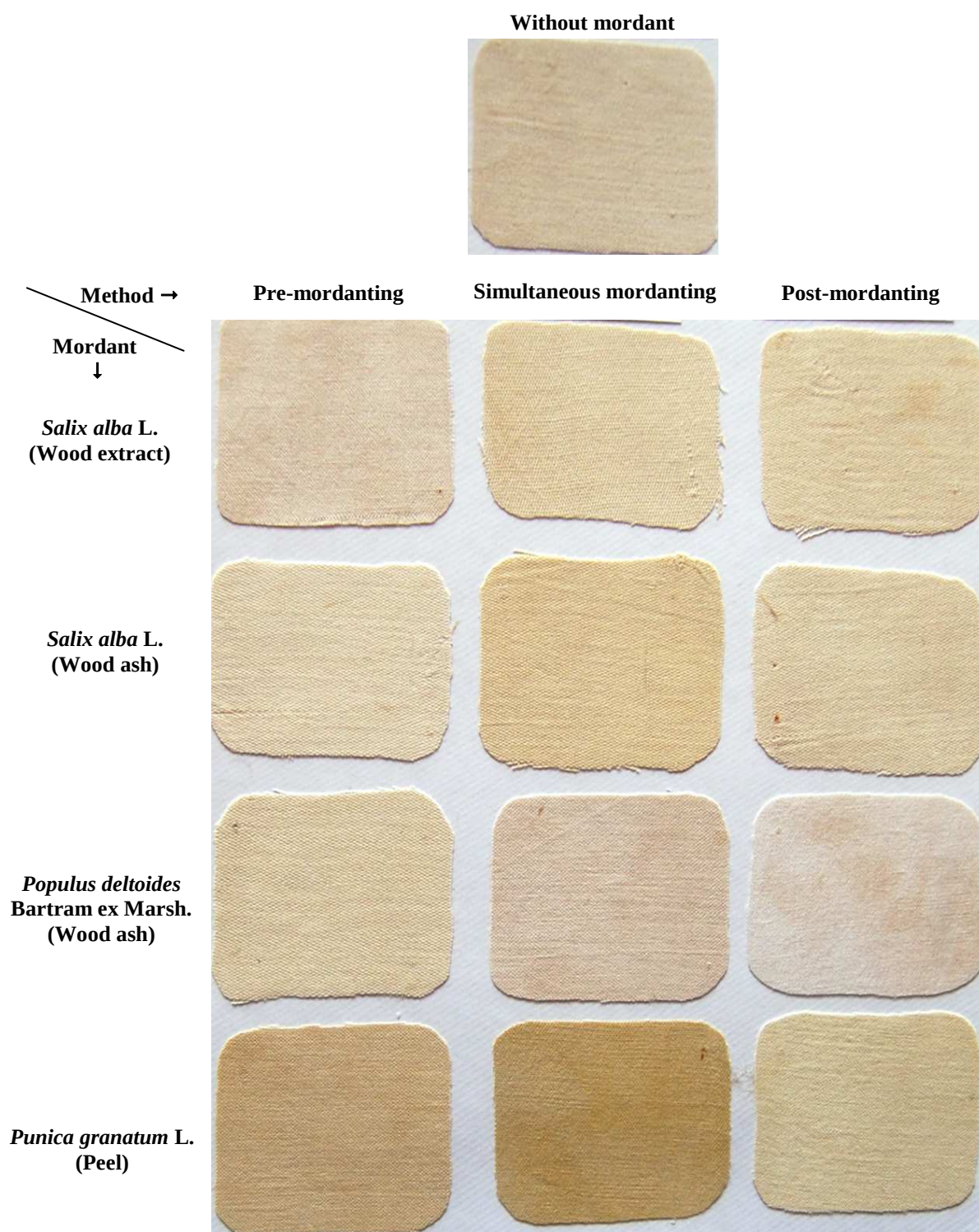


Plate-13 : Cotton samples dyed with *Juglans regia* L. (leaves) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-14 : Silk samples dyed with *Juglans regia* L. (leaves) in combination with different mordants

		Without mordant		
				
Method →		Pre-mordanting	Simultaneous mordanting	Post-mordanting
Mordant ↓				
<i>Salix alba</i> L. (Wood extract)				
<i>Salix alba</i> L. (Wood ash)				
<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)				
<i>Punica granatum</i> L. (Peel)				

Plate-15 : Pashmina samples dyed with *Juglans regia* L. (leaves) in combination with different mordants

values to the tune of 2.85, 2.68 and 4.46, b^* 33.26, 33.50 and 35.11, C^* 33.38, 33.61 and 35.40, h^0 85.10, 85.40 and 82.80 and ΔE 33.60, 30.93 and 29.22 (Table-20). Lowest L^* (48.23) was recorded by pashmina fabric dyed post mordanting with a^* , b^* , C^* , h^0 and ΔE values of 5.59, 17.75, 18.61, 72.50 and 32.93 respectively followed by wool, silk and cotton with L^* to the tune of 53.46, 55.46 and 70.15 respectively, a^* 6.99, 5.59 and 1.71, b^* 36.21, 32.75 and 32.69, C^* 36.93, 33.22 and 32.73, h^0 79.10, 80.30 and 87.00, ΔE 34.83, 39.77 and 34.32 following simultaneous mordanting, post mordanting and simultaneous mordanting (Table-20).

4.5.9 Colour coordinates of fabrics dyed with *Juglans regia* L. fruit hull using *Salix alba* L. wood extract as mordant

Highest L^* (83.78) was recorded in cotton fabric following pre mordanting method. Values to the tune of 1.46, 15.71, 15.78, 84.70 and 12.62 were recorded for a^* , b^* , C^* , h^0 and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 67.29, 59.92 and 53.07 respectively in dyeing post mordanting, pre mordanting and simultaneous mordanting with a^* values to the tune of 2.84, 4.46 and 3.01, b^* 24.71, 31.72 and 29.95, C^* 24.87, 32.04 and 30.11, h^0 83.40, 82.00 and 84.30 and ΔE 25.30, 27.00 and 31.01. Lowest L^* (43.70) was recorded by pashmina fabric dyed post mordanting with a^* , b^* , C^* , h^0 and ΔE values of 3.38, 29.29, 29.49, 83.40 and 39.44 respectively followed by wool, silk and cotton with L^* to the tune of 52.10, 55.01 and 79.28 respectively, a^* 5.23, 4.15 and 1.63, b^* 32.44, 29.07 and 17.14, C^* 32.86, 29.37 and 17.22, h^0 80.80, 81.90 and 84.60, ΔE 34.45, 38.28 and 16.95 adopting post mordanting, pre mordanting and simultaneous mordanting (Table-21).

4.5.10 Colour coordinates of fabrics dyed with *Juglans regia* L. fruit hull using *Salix alba* L. wood ash as mordant

Highest L^* (86.91) was recorded in cotton fabric following post mordanting method. Values to the tune of 2.15, 13.33, 13.51, 80.80 and 8.71 were recorded for a^* , b^* , C^* , h^0 and ΔE respectively. However, in silk, wool and

Table-21 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. fruit hull dye using *Salix alba* L. wood extract as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		54.26	5.74	29.01	29.57	78.80	34.35
Pre mordanting		59.92	4.46	31.72	32.04	82.00	27.00
Simultaneous mordanting		53.43	4.81	33.34	33.69	81.80	33.53
Post mordanting		52.10	5.23	32.44	32.86	80.80	34.45
Cotton Fabric							
Without Mordant		81.19	2.38	14.17	14.37	80.40	13.67
Pre mordanting		83.78	1.46	15.71	15.78	84.70	12.62
Simultaneous mordanting		79.28	1.63	17.14	17.22	84.60	16.95
Post mordanting		82.09	1.62	16.15	16.23	84.30	14.15
Silk Fabric							
Without Mordant		55.90	4.34	29.78	30.10	81.70	37.82
Pre mordanting		55.01	4.15	29.07	29.37	81.90	38.28
Simultaneous mordanting		60.78	3.19	26.16	26.36	83.00	31.68
Post mordanting		67.29	2.84	24.71	24.87	83.40	25.30
Pashmina Fabric							
Without Mordant		50.06	4.21	33.10	33.37	82.70	35.21
Pre mordanting		53.07	3.01	29.95	30.11	84.30	31.01
Simultaneous mordanting		43.94	2.72	26.35	26.50	84.10	38.28
Post mordanting		43.70	3.38	29.29	29.49	83.40	39.44

Table-22 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. fruit hull dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		54.26	5.74	29.01	29.57	78.80	34.35
Pre mordanting		54.20	5.17	31.77	32.19	80.70	32.27
Simultaneous mordanting		51.71	5.94	28.74	29.35	78.30	33.72
Post mordanting		48.46	4.78	27.67	28.08	80.20	36.40
Cotton Fabric							
Without Mordant		81.19	2.38	14.17	14.37	80.40	13.67
Pre mordanting		82.74	2.20	15.36	15.52	81.80	13.12
Simultaneous mordanting		82.02	2.29	16.73	16.89	82.20	14.57
Post mordanting		86.91	2.15	13.33	13.51	80.80	8.71
Silk Fabric							
Without Mordant		55.90	4.34	29.78	30.10	81.70	37.82
Pre mordanting		63.49	3.37	26.14	26.36	82.70	29.35
Simultaneous mordanting		65.65	3.06	26.65	26.83	83.50	27.69
Post mordanting		62.70	3.80	21.30	21.64	79.90	28.24
Pashmina Fabric							
Without Mordant		50.06	4.21	33.10	33.37	82.70	35.21
Pre mordanting		42.43	2.83	29.77	29.91	84.60	40.74
Simultaneous mordanting		44.75	4.22	26.92	27.25	81.10	37.75
Post mordanting		46.00	4.16	27.41	27.73	81.40	36.69

pashmina fabrics highest L^* values recorded are 65.65, 54.26 and 50.06 respectively adopting simultaneous mordanting, pre mordanting and without mordanting with a^* values to the tune of 3.06, 5.74 and 4.21, b^* 26.65, 29.01 and 33.10, C^* 26.83, 29.57 and 33.37, h° 83.50, 78.80 and 82.70 and ΔE 27.69, 34.35 and 35.21 respectively (Table-22). Lowest L^* (42.43) was recorded by pashmina fabric dyed post mordanting with a^* , b^* , C^* , h° and ΔE values of 2.83, 29.77, 29.91, 84.60 and 40.74 respectively followed by wool, silk and cotton with L^* to the tune of 48.46, 55.90 and 81.19 respectively, a^* 4.78, 4.34 and 2.38, b^* 27.67, 29.78 and 14.17, C^* 28.08, 30.10 and 14.37, h° 80.20, 81.70 and 80.40, ΔE 36.40, 37.82 and 13.67 following post mordanting, without mordanting and without mordanting (Table-22).

4.5.11 Colour coordinates of fabrics dyed with *Juglans regia* L. fruit hull using *Populus deltoides* Bartram ex Marsh. wood ash as mordant

Highest L^* (89.93) was recorded in cotton fabric using post mordanting method. Values to the tune of 2.78, 8.51, 8.96, 71.90 and 3.29 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 64.02, 54.79 and 50.06 respectively in dyeing post mordanting, simultaneous mordanting and without mordanting with a^* values to the tune of 3.51, 3.16 and 4.21, b^* 22.39, 23.69 and 33.10, C^* 22.67, 23.90 and 33.37, h° 81.10, 82.40 and 82.70 and ΔE 27.34, 29.30 and 35.21. Lowest L^* (40.99) was recorded by pashmina fabric dyed pre mordanting with a^* , b^* , C^* , h° and ΔE values of 3.21, 26.78, 26.97, 83.20 and 41.26 respectively followed by wool, silk and cotton with L^* to the tune of 43.10, 55.90 and 81.91 respectively, a^* 3.76, 4.34 and 2.38, b^* 24.08, 29.78 and 14.17, C^* 24.37, 30.10 and 14.37, h° 81.10, 81.70 and 80.40, ΔE 44.09, 37.82 and 13.67 following pre mordanting, without mordanting and without mordanting (Table-23).

4.5.12 Colour coordinates of dyed fabrics with *Juglans regia* L. fruit hull dye and *Punica granatum* L. peel mordant

Highest L^* (81.19) was recorded in cotton fabric following pre mordanting method. Values to the tune of 2.38, 14.17, 14.37, 80.40 and 13.67

Table-23 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. fruit hull dye using *Populus deltoides* Bartram ex Marsh. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		54.26	5.74	29.01	29.57	78.80	34.35
Pre mordanting		43.10	3.76	24.08	24.37	81.10	44.09
Simultaneous mordanting		54.79	3.16	23.69	23.90	82.40	29.30
Post mordanting		51.05	3.09	21.02	21.25	81.60	32.76
Cotton Fabric							
Without Mordant		81.19	2.38	14.17	14.37	80.40	13.67
Pre mordanting		82.12	2.63	15.04	15.27	80.10	13.41
Simultaneous mordanting		83.46	2.52	12.31	12.57	78.40	10.77
Post mordanting		89.93	2.78	8.51	8.96	71.90	3.29
Silk Fabric							
Without Mordant		55.90	4.34	29.78	30.10	81.70	37.82
Pre mordanting		58.52	3.59	26.00	26.25	82.10	33.78
Simultaneous mordanting		57.94	3.10	23.61	23.82	82.50	33.41
Post mordanting		64.02	3.51	22.39	22.67	81.10	27.34
Pashmina Fabric							
Without Mordant		50.06	4.21	33.10	33.37	82.70	35.21
Pre mordanting		40.99	3.21	26.78	26.97	83.20	41.26
Simultaneous mordanting		47.26	2.88	25.63	25.80	83.60	34.90
Post mordanting		48.41	2.90	25.55	25.71	83.50	33.77

Table-24 : Average colour coordinate values of different fabrics treated with *Juglans regia* L. fruit hull dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		54.26	5.74	29.01	29.57	78.80	34.35
Pre mordanting		64.54	5.83	30.57	31.13	79.20	22.76
Simultaneous mordanting		51.95	6.06	32.55	33.11	79.50	34.76
Post mordanting		48.99	4.80	26.27	26.71	79.60	35.60
Cotton Fabric							
Without Mordant		81.19	2.38	14.17	14.37	80.40	13.67
Pre mordanting		76.66	0.28	24.18	24.19	90.70	23.77
Simultaneous mordanting		71.71	0.70	27.99	28.00	88.60	29.85
Post mordanting		77.16	0.78	26.90	26.92	88.30	25.41
Silk Fabric							
Without Mordant		55.90	4.34	29.78	30.10	81.70	37.82
Pre mordanting		76.32	1.43	23.88	23.92	86.60	17.29
Simultaneous mordanting		54.89	2.78	26.39	26.54	84.00	37.21
Post mordanting		51.63	3.24	30.13	30.31	83.90	41.71
Pashmina Fabric							
Without Mordant		50.06	4.21	33.10	33.37	82.70	35.21
Pre mordanting		32.55	4.73	38.84	39.13	83.10	53.42
Simultaneous mordanting		42.94	5.13	32.34	32.74	81.00	41.35
Post mordanting		47.76	4.73	33.60	33.94	82.00	37.51

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-16 : Wool samples dyed with *Juglans regia* L. (fruit hull) in combination with different mordants

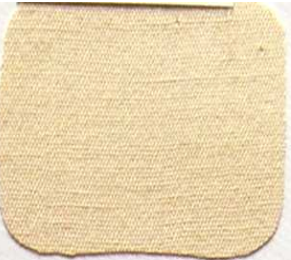
		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-17 : Cotton samples dyed with *Juglans regia* L. (fruit hull) in combination with different mordants

Without mordant



Method → Mordant ↓	Pre-mordanting	Simultaneous mordanting	Post-mordanting
<i>Salix alba</i> L. (Wood extract)			
<i>Salix alba</i> L. (Wood ash)			
<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
<i>Punica granatum</i> L. (Peel)			

Plate-18 : Silk samples dyed with *Juglans regia* L. (fruit hull) in combination with different mordants

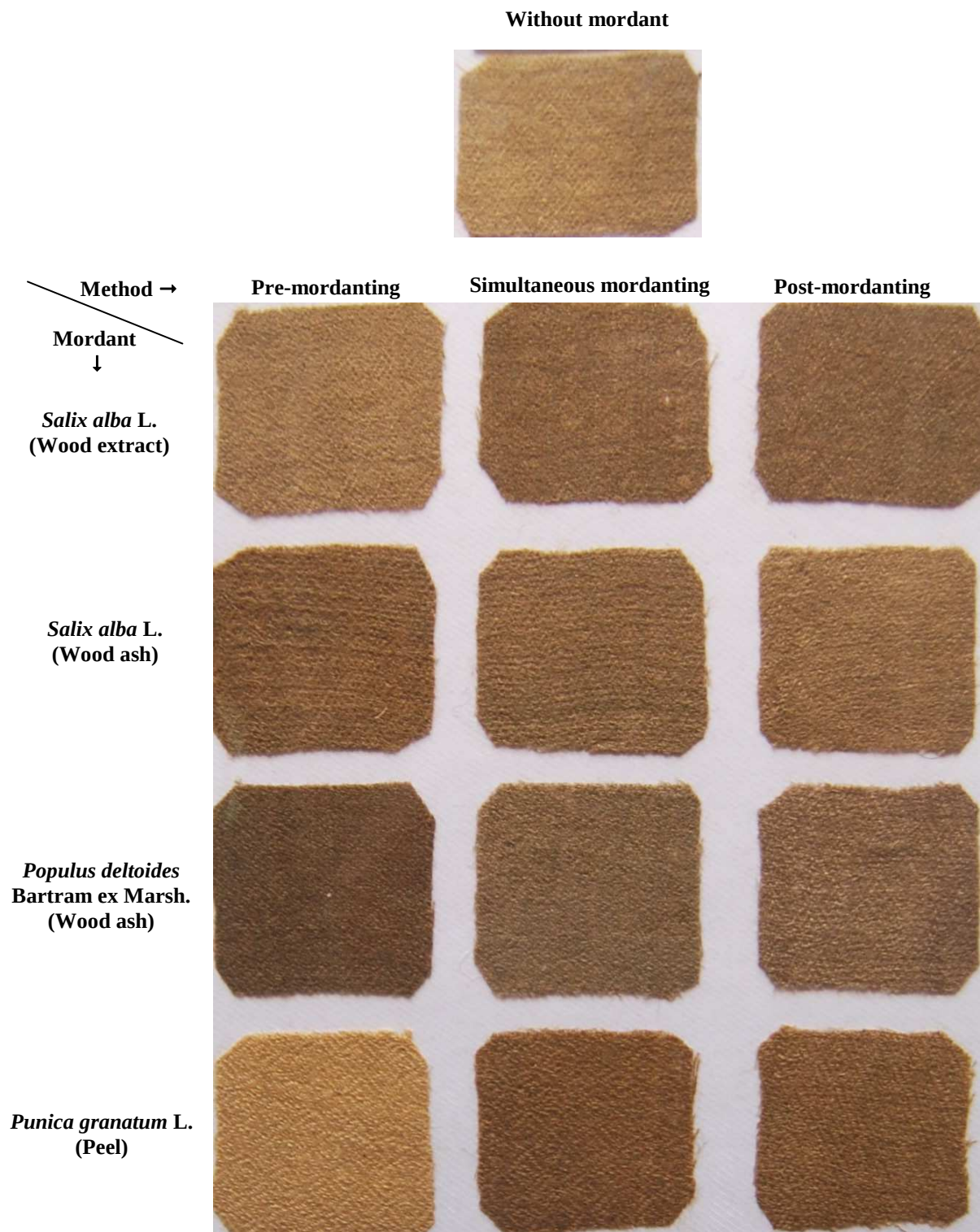


Plate-19 : Pashmina samples dyed with *Juglans regia* L. (fruit hull) in combination with different mordants

were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 76.32, 64.54 and 50.06 respectively adopting pre mordanting, pre mordanting and without mordanting with a^* values to the tune of 1.43, 5.83 and 4.21, b^* 23.88, 30.57 and 33.10, C^* 23.92, 31.13 and 33.37, h° 86.60, 79.20 and 82.70 and ΔE 17.29, 22.76 and 35.21 respectively (Table-24). Lowest L^* (32.55) was recorded by pashmina fabric adopting pre mordanting with a^* , b^* , C^* , h° and ΔE values of 4.73, 38.84, 39.13, 83.10 and 53.42 respectively followed by wool, silk and cotton with L^* to the tune of 48.99, 51.63 and 77.16 respectively, a^* 4.80, 3.24 and 0.78, b^* 26.27, 30.13 and 26.90, C^* 26.71, 30.31 and 26.92, h° 79.60, 83.90 and 88.30, ΔE 35.60, 41.71 and 25.41 following post mordanting method (Table-24).

4.5.13 Colour coordinates of fabrics dyed with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves using *Salix alba* L. wood extract as mordant

Highest L^* (84.82) was recorded in cotton fabric adopting simultaneous mordanting method. Values to the tune of 0.91, 17.79, 17.81, 87.10 and 13.57 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in silk, wool and pashmina fabrics highest L^* values recorded are 67.36, 63.09 and 59.69 respectively following simultaneous mordanting, pre mordanting and pre mordanting with a^* values to the tune of 6.39, 6.49 and 5.41, b^* 22.35, 31.69 and 30.54, C^* 23.25, 32.35 and 31.02, h° 74.00, 78.40 and 80.00 and ΔE 24.75, 24.69 and 25.87. Lowest L^* (53.26) was recorded by pashmina fabric following post mordanting method with a^* , b^* , C^* , h° and ΔE values of 5.75, 27.00, 27.61, 78.00 and 31.77 respectively followed by pashmina, silk and cotton with L^* to the tune of 55.42, 61.97 and 76.14 respectively, a^* 5.90, 6.17 and 1.52, b^* 29.67, 27.31 and 23.28, C^* 30.26, 28.00 and 23.33, h° 78.80, 77.30 and 86.30, ΔE 29.11, 31.59 and 23.70 adopting post mordanting, pre mordanting and without mordanting (Table-25).

4.5.14 Colour coordinates of fabrics dyed with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves using *Salix alba* L. wood ash as mordant

Highest L^* (83.60) was recorded in cotton fabric following pre mordanting

Table-25 : Average colour coordinate values of different fabrics treated with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves dye using *Salix alba* L. wood extract as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		62.37	6.08	31.40	31.99	79.00	31.32
Pre mordanting		63.09	6.49	31.69	32.35	78.40	24.69
Simultaneous mordanting		57.15	6.29	29.85	30.51	78.10	29.07
Post mordanting		53.26	5.75	27.00	27.61	78.00	31.77
Cotton Fabric							
Without Mordant		76.14	1.52	23.28	23.33	86.30	23.70
Pre mordanting		83.53	1.57	18.99	19.06	85.30	15.25
Simultaneous mordanting		84.82	0.91	17.79	17.81	87.10	13.57
Post mordanting		84.49	0.70	18.24	18.26	87.80	14.15
Silk Fabric							
Without Mordant		62.16	6.40	26.04	26.82	76.20	30.96
Pre mordanting		61.97	6.17	27.31	28.00	77.30	31.59
Simultaneous mordanting		67.36	6.39	22.35	23.25	74.00	24.75
Post mordanting		67.00	5.81	24.20	24.89	76.50	25.88
Pashmina Fabric							
Without Mordant		59.00	4.65	28.64	29.02	80.80	25.34
Pre mordanting		59.69	5.41	30.54	31.02	80.00	25.87
Simultaneous mordanting		56.33	5.71	30.59	31.12	79.40	28.75
Post mordanting		55.42	5.90	29.67	30.26	78.80	29.11

Table-26 : Average colour coordinate values of different fabrics treated with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		62.37	6.08	31.40	31.99	79.00	31.32
Pre mordanting		65.86	5.22	23.96	24.53	77.70	24.27
Simultaneous mordanting		59.45	4.40	30.21	30.53	81.70	32.76
Post mordanting		53.78	5.15	29.20	29.66	80.00	31.77
Cotton Fabric							
Without Mordant		76.14	1.52	23.28	23.33	86.30	23.70
Pre mordanting		83.60	1.92	15.94	16.06	83.10	13.23
Simultaneous mordanting		77.71	2.70	21.47	21.64	82.80	21.28
Post mordanting		79.85	2.50	20.31	20.45	83.50	18.43
Silk Fabric							
Without Mordant		62.16	6.40	26.04	26.82	76.20	30.96
Pre mordanting		65.95	5.22	23.96	24.53	77.70	26.52
Simultaneous mordanting		63.60	6.60	25.09	25.95	75.30	29.29
Post mordanting		66.36	3.63	22.24	22.54	80.70	25.10
Pashmina Fabric							
Without Mordant		59.00	4.65	28.64	29.02	80.80	25.34
Pre mordanting		54.07	3.90	32.33	32.57	83.10	31.34
Simultaneous mordanting		53.95	3.39	31.37	31.56	83.80	30.92
Post mordanting		48.04	4.53	31.11	31.44	81.70	36.15

method. Values to the tune of 1.92, 15.94, 16.06, 83.10 and 13.23 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in silk, wool and pashmina fabrics highest L^* values recorded are 66.36, 65.86 and 59.00 respectively adopting post mordanting, pre mordanting and without mordant with a^* values to the tune of 3.63, 5.22 and 4.65, b^* 22.24, 23.98 and 28.64, C^* 22.54, 24.53 and 29.02, h° 80.70, 81.70 and 80.80 and ΔE 25.10, 77.70 and 25.34 (Table-26). Lowest L^* (48.04) was recorded by pashmina fabric following post mordanting with a^* , b^* , C^* , h° and ΔE values of 4.53, 31.11, 31.44, 81.70 and 36.15 respectively followed by wool, silk and cotton with L^* 53.78, 63.60 and 76.14 respectively, a^* 5.15, 6.60 and 1.52 respectively, b^* 29.20, 25.09 and 23.28, C^* 29.66, 25.95 and 23.33, h° 80.00, 75.30 and 86.30, ΔE 31.77, 29.29 and 23.70 following post mordanting, simultaneous mordanting and pre mordanting (Table-26).

4.5.15 Colour coordinates of fabrics dyed with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves using *Populus deltoides* Bartram ex Marsh. wood ash

Highest L^* (91.07) was recorded in cotton fabric adopting simultaneous mordanting method. Values to the tune of 2.57, 8.16, 8.56, 72.50 and 2.14 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in silk, wool and pashmina fabrics highest L^* values recorded are 66.51, 64.83 and 59.00 respectively following simultaneous mordanting, pre mordanting and without mordanting with values to the tune of a^* 3.46, 4.49 and 4.65, b^* 3.77, 28.20 and 28.64, C^* 24.02, 28.54 and 29.02, h° 81.70, 81.20 and 80.80 and ΔE 25.61, 21.13 and 25.34. Lowest L^* (41.72) was recorded by pashmina fabric adopting post mordanting with a^* , b^* , C^* , h° and ΔE values of 3.58, 27.79, 28.02, 82.60 and 40.85 respectively followed by wool, silk and cotton with values to the tune of L^* 49.13, 54.29 and 76.14 respectively, a^* 2.50, 4.85 and 1.52, b^* 27.33, 22.72 and 23.28, C^* 27.44, 23.24 and 23.33, h° 84.80, 77.90 and 86.30, ΔE 35.46, 36.76 and 23.70 following post mordanting, post mordanting and without mordanting (Table-27).

Table-27 : Average colour coordinate values of different fabrics treated with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves dye using *Populus deltoides* Bartram ex Marsh. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		62.37	6.08	31.40	31.99	79.00	31.32
Pre mordanting		64.83	4.39	28.20	28.54	81.20	21.13
Simultaneous mordanting		59.85	2.34	26.79	26.90	85.00	24.97
Post mordanting		49.13	2.50	27.33	27.44	84.80	35.46
Cotton Fabric							
Without Mordant		76.14	1.52	23.28	23.33	86.30	23.70
Pre mordanting		83.22	2.14	16.06	16.21	82.40	13.26
Simultaneous mordanting		91.07	2.57	8.16	8.56	72.50	2.14
Post mordanting		89.14	3.06	9.48	9.97	72.10	4.52
Silk Fabric							
Without Mordant		62.16	6.40	26.04	26.82	76.20	30.96
Pre mordanting		61.10	7.01	25.99	26.92	74.90	31.92
Simultaneous mordanting		66.51	3.46	23.77	24.02	81.70	25.61
Post mordanting		54.29	4.85	22.72	23.24	77.90	36.76
Pashmina Fabric							
Without Mordant		59.00	4.65	28.64	29.02	80.80	25.34
Pre mordanting		53.48	4.37	30.46	30.77	81.80	30.99
Simultaneous mordanting		50.00	3.26	28.11	28.30	83.40	33.12
Post mordanting		41.72	3.58	27.79	28.02	82.60	40.85

Table-28 : Average colour coordinate values of different fabrics treated with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		62.37	6.08	31.40	31.99	79.00	31.32
Pre mordanting		57.17	4.14	27.66	27.97	81.50	27.97
Simultaneous mordanting		52.75	4.05	29.06	29.35	82.10	32.56
Post mordanting		44.90	4.72	23.67	24.14	78.70	39.22
Cotton Fabric							
Without Mordant		76.14	1.52	23.28	23.33	86.30	23.70
Pre mordanting		71.44	0.85	20.55	20.57	87.60	25.36
Simultaneous mordanting		75.08	0.85	23.81	23.83	88.00	24.52
Post mordanting		82.83	1.35	21.00	21.05	86.30	17.30
Silk Fabric							
Without Mordant		62.16	6.40	26.04	26.82	76.20	30.96
Pre mordanting		48.29	6.14	21.54	22.40	74.10	42.41
Simultaneous mordanting		48.58	4.50	22.17	22.63	78.50	42.09
Post mordanting		52.87	6.41	28.38	29.09	77.30	37.90
Pashmina Fabric							
Without Mordant		59.00	4.65	28.64	29.02	80.80	25.34
Pre mordanting		45.86	3.78	25.90	26.18	81.70	36.37
Simultaneous mordanting		39.05	3.15	27.19	27.38	83.40	43.23
Post mordanting		40.95	5.62	28.66	29.21	78.90	41.95

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-21 : Cotton samples dyed with *Prunus cerasifera* var. *atropurpurea* (leaves) in combination with different mordants

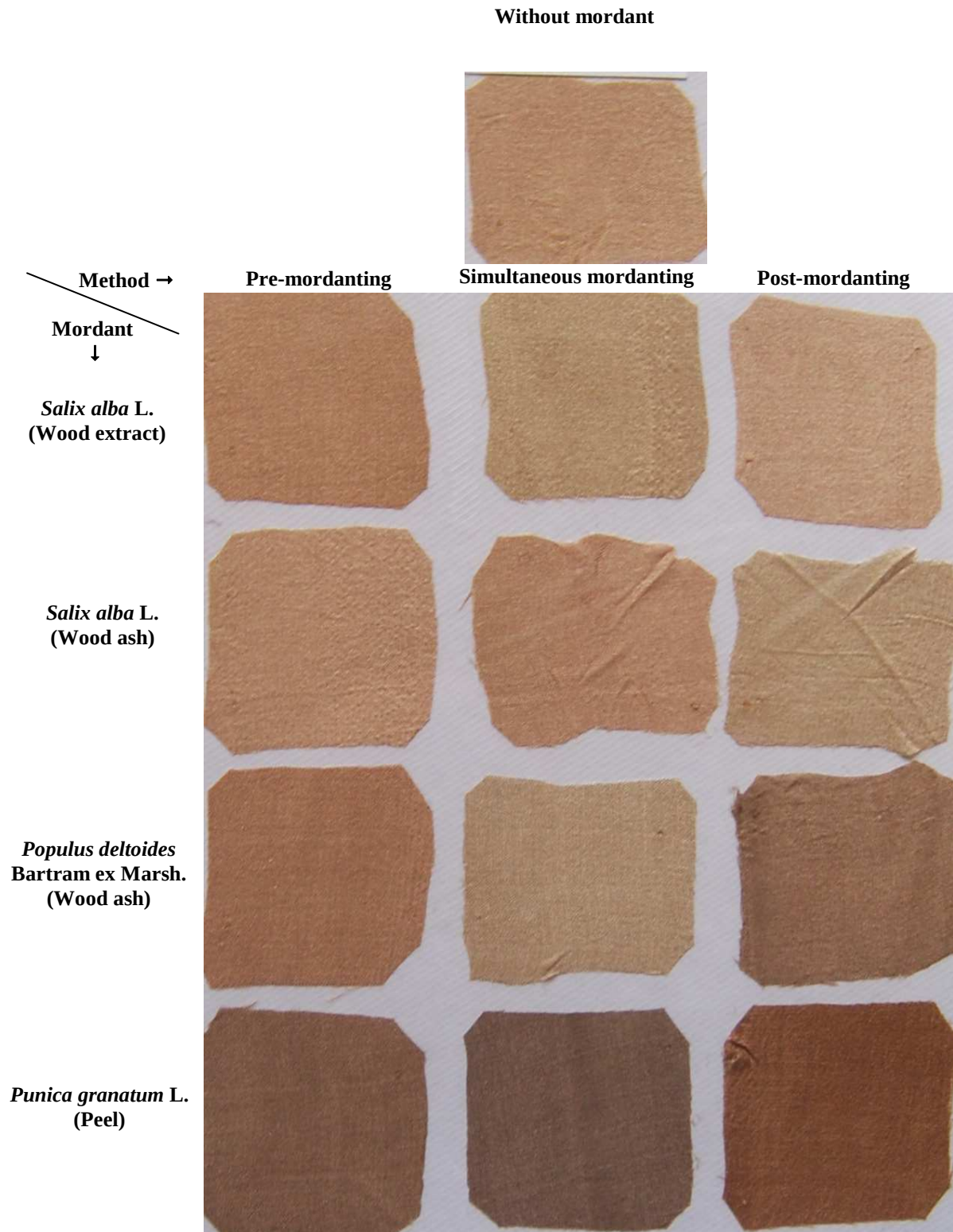


Plate-22 : Silk samples dyed with *Prunus cerasifera* var. *atropurpurea* (leaves) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-23 : Pashmina samples dyed with *Prunus cerasifera* var. *atropurpurea* (leaves) in combination with different mordants

4.5.16 Colour coordinates of fabrics dyed with *Prunus cerasifera* Ehrh. var. *atropurpurea* leaves using *Punica granatum* L. peel mordant

Highest L^* (82.83) was recorded in cotton fabric adopting post mordanting method. Values to the tune of 1.35, 21.00, 21.05, 86.30 and 17.30 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in wool, silk and pashmina fabrics highest L^* values recorded are 62.37, 62.16 and 59.00 respectively in dyeing without mordanting with a^* values to the tune of 6.08, 6.40 and 4.65, b^* 31.40, 26.04 and 28.64, C^* 31.99, 26.82 and 29.02, h° 79.00, 76.20 and 80.80 and ΔE 31.32, 30.96 and 25.34 (Table-28). Lowest L^* (39.05) was recorded in pashmina fabric following simultaneous mordanting with a^* , b^* , C^* , h° and ΔE values of 3.15, 27.19, 27.38, 83.40 and 43.23 respectively followed by wool, silk and cotton with L^* to the tune of 44.90, 48.29 and 71.44 respectively, a^* 4.72, 6.14 and 0.86, b^* 23.67, 21.54 and 20.55, C^* 24.14, 22.40 and 20.57, h° 78.70, 74.10 and 87.60, ΔE 39.22, 42.41 and 25.36 following post mordanting, pre mordanting and pre mordanting (Table-28).

4.5.17 Colour coordinates of fabrics dyed with *Nasturtium officinale* R.Br. leaves using *Salix alba* L. wood extract as mordant

Highest L^* (88.76) was recorded in cotton fabric following post mordanting method. Values to the tune of 0.25, 16.31, 16.32, 89.10 and 10.64 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in silk, wool and pashmina fabrics highest L^* values recorded are 77.58, 75.26 and 71.40 respectively adopting post mordanting, without mordanting and without mordanting with values to the tune of a^* 2.01, 1.58 and 1.57, b^* 31.91, 30.61 and 30.77, C^* 31.98, 30.65 and 30.82, h° 86.40, 87.00 and 87.10 and ΔE 24.65, 21.22 and 17.33. Lowest L^* (65.72) was recorded in pashmina fabric following simultaneous mordanting with a^* , b^* , C^* , h° and ΔE values of 1.91, 36.38, 36.43, 87.00 and 25.18 respectively followed by silk, wool and cotton with values to the tune of L^* 69.64, 71.80 and 85.31 respectively, a^* 1.33, 1.65 and 0.52, b^* 29.80, 34.00 and 17.68, C^* 29.83, 34.04 and 17.69, h° 87.40, 87.20 and 88.30, ΔE 27.43, 26.17 and 13.52 following simultaneous mordanting, simultaneous mordanting and without mordanting (Table-29).

Table-29 : Average colour coordinate values of different fabrics treated with *Nasturtium officinale* R.Br. leaves dye using *Salix alba* L. wood extract as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		75.26	1.58	30.61	30.65	87.00	21.22
Pre mordanting		71.81	2.47	32.97	32.87	85.70	25.36
Simultaneous mordanting		71.80	1.65	34.00	34.04	87.20	26.17
Post mordanting		74.17	1.22	33.66	33.68	87.90	24.59
Cotton Fabric							
Without Mordant		85.31	0.52	17.68	17.69	88.30	13.52
Pre mordanting		87.53	0.59	16.80	16.82	88.00	11.67
Simultaneous mordanting		87.94	0.73	14.85	14.87	87.20	9.72
Post mordanting		88.76	0.25	16.31	16.32	89.10	10.64
Silk Fabric							
Without Mordant		75.88	1.82	26.83	26.89	86.10	21.07
Pre mordanting		73.81	1.68	33.10	33.15	87.10	27.46
Simultaneous mordanting		69.64	1.33	29.80	29.83	87.40	27.43
Post mordanting		77.58	2.01	31.91	31.98	86.40	24.65
Pashmina Fabric							
Without Mordant		71.40	1.57	30.77	30.82	87.10	17.33
Pre mordanting		71.19	2.13	35.72	35.78	86.60	21.63
Simultaneous mordanting		65.72	1.91	36.38	36.43	87.00	25.18
Post mordanting		68.84	1.62	31.91	31.96	87.10	19.73

Table-30 : Average colour coordinate values of different fabrics treated with *Nasturtium officinale* R.Br. leaves dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		75.26	1.58	30.61	30.65	87.00	21.22
Pre mordanting		75.94	0.88	32.06	32.07	88.40	22.31
Simultaneous mordanting		72.91	1.67	34.48	34.53	87.20	25.96
Post mordanting		69.36	1.68	32.71	32.76	87.10	26.66
Cotton Fabric							
Without Mordant		85.31	0.52	17.68	17.69	88.30	13.52
Pre mordanting		88.18	0.83	18.29	18.31	87.40	12.52
Simultaneous mordanting		84.59	0.27	21.29	21.30	89.30	16.91
Post mordanting		91.67	0.76	13.43	13.45	86.70	6.90
Silk Fabric							
Without Mordant		75.88	1.82	26.83	26.89	86.10	21.07
Pre mordanting		76.80	0.81	30.72	30.73	88.50	23.94
Simultaneous mordanting		79.00	0.34	26.45	26.46	89.30	19.16
Post mordanting		78.13	0.77	26.77	26.78	88.40	19.84
Pashmina Fabric							
Without Mordant		71.40	1.57	30.77	30.82	87.10	17.33
Pre mordanting		70.91	1.49	32.38	32.42	87.40	18.94
Simultaneous mordanting		71.42	1.28	34.42	34.45	87.90	20.47
Post mordanting		65.63	1.24	32.83	32.86	87.80	22.50

4.5.18 Colour coordinates of fabrics dyed with *Nasturtium officinale* R.Br. leaves using *Salix alba* L. wood ash as mordant

Highest L^* (91.67) was recorded in cotton fabric adopting post mordanting method. Values to the tune of 0.76, 13.43, 13.45, 86.70 and 6.90 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 79.00, 75.94 and 71.42 respectively following simultaneous mordanting, pre mordanting and simultaneous mordanting with a^* values to the tune of 0.34, 0.88 and 1.28 respectively, b^* 26.45, 32.06 and 34.42, C^* 26.46, 32.07 and 34.45, h° 89.30, 88.40 and 87.90 and ΔE 19.16, 22.31 and 20.47 (Table-30). Lowest L^* (65.63) was recorded in pashmina fabric following post mordanting with a^* , b^* , C^* , h° and ΔE values of 1.24, 32.83, 32.86, 87.80 and 22.50 respectively followed by silk, wool and cotton with L^* to the tune of 69.36, 75.88 and 84.59 respectively, a^* 1.68, 1.82 and 0.27, b^* 32.71, 26.83 and 21.29, C^* 32.76, 26.89 and 21.30, h° 87.10, 86.10 and 89.30, ΔE 26.66, 21.07 and 16.91 following post mordanting, without mordanting and simultaneous mordanting (Table-30).

4.5.19 Colour coordinates of fabrics dyed with *Nasturtium officinale* R.Br. leaves using *Populus deltoides* Bartram ex Marsh. wood ash as mordant

Highest L^* (92.24) was recorded in cotton fabric adopting post mordanting method. Values to the tune of 1.36, 11.76, 11.84, 83.40 and 5.02 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However in wool, silk and pashmina fabrics highest L^* values recorded are 76.09, 75.88 and 71.40 respectively following pre mordanting, without mordanting and without mordanting with a^* values to the tune of 1.27, 1.82 and 1.57 respectively, b^* 33.72, 26.83 and 30.77, C^* 33.75, 26.89 and 30.82, h° 87.80, 86.10 and 87.10 and ΔE 16.10, 21.07 and 17.33. Lowest L^* (60.48) was recorded in pashmina fabric following post mordanting with a^* , b^* , C^* , h° and ΔE values of 2.03, 33.32, 33.38, 86.50 and 26.59 respectively followed by wool, silk and cotton with L^* to the tune of 64.82, 71.27 and 83.42, a^* 3.17, 0.63 and -2.44, b^* 34.24, 35.26 and

Table-31 : Average colour coordinate values of different fabrics treated with *Nasturtium officinale* R.Br. leaves dye using *Populus deltoides* Bartram ex Marsh. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		75.26	1.58	30.61	30.65	87.00	21.22
Pre mordanting		76.09	1.27	33.72	33.75	87.80	16.10
Simultaneous mordanting		69.09	2.82	35.60	35.72	85.50	21.83
Post mordanting		64.82	3.17	34.24	34.39	84.70	24.07
Cotton Fabric							
Without Mordant		85.31	0.52	17.68	17.69	88.30	13.52
Pre mordanting		88.70	-1.52	18.04	18.10	94.80	12.49
Simultaneous mordanting		83.42	-2.44	29.07	29.17	94.80	24.55
Post mordanting		92.24	1.36	11.76	11.84	83.40	5.02
Silk Fabric							
Without Mordant		75.88	1.82	26.83	26.89	86.10	21.07
Pre mordanting		74.92	1.09	31.30	31.32	88.00	23.67
Simultaneous mordanting		71.27	0.63	35.26	35.27	89.00	29.03
Post mordanting		76.29	0.90	25.43	25.45	88.00	18.35
Pashmina Fabric							
Without Mordant		71.40	1.57	30.77	30.82	87.10	17.33
Pre mordanting		68.40	1.86	18.18	18.28	84.10	12.59
Simultaneous mordanting		62.83	3.17	34.24	34.39	84.70	25.53
Post mordanting		60.48	2.03	33.32	33.38	86.50	26.59

Table-32 : Average colour coordinate values of different fabrics treated with *Nasturtium officinale* R.Br. leaves dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		75.26	1.58	30.61	30.65	87.00	21.22
Pre mordanting		61.40	3.62	33.29	33.49	83.80	26.37
Simultaneous mordanting		79.22	3.82	38.05	38.05	84.30	19.37
Post mordanting		57.70	5.12	34.82	35.20	81.60	30.51
Cotton Fabric							
Without Mordant		85.31	0.52	17.68	17.69	88.30	13.52
Pre mordanting		80.36	-1.38	30.02	30.06	92.60	26.52
Simultaneous mordanting		77.05	-2.96	47.15	47.25	93.60	43.56
Post mordanting		83.14	-0.63	35.26	35.27	91.00	30.13
Silk Fabric							
Without Mordant		75.88	1.82	26.83	26.89	86.10	21.07
Pre mordanting		62.83	1.40	31.3	31.33	87.40	32.50
Simultaneous mordanting		64.65	2.59	33.48	33.58	85.60	32.44
Post mordanting		65.90	1.56	35.26	35.30	87.50	32.66
Pashmina Fabric							
Without Mordant		71.40	1.57	30.77	30.82	87.10	17.33
Pre mordanting		62.96	3.20	38.16	38.30	85.00	28.35
Simultaneous mordanting		60.24	3.87	38.90	39.09	84.30	30.73
Post mordanting		55.68	5.47	36.27	36.69	81.40	32.43

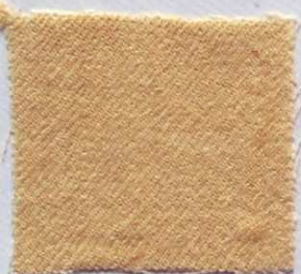
		Without mordant		
				
Method → Mordant ↓	<i>Salix alba</i> L. (Wood extract)	Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			
				

Plate-24 : Wool samples dyed with *Nasturtium officinale* R.Br. (leaves) in combination with different mordants

		Without mordant		
				
Method →	Mordant ↓	Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-25 : Cotton samples dyed with *Nasturtium officinale* R.Br. (leaves) in combination with different mordants

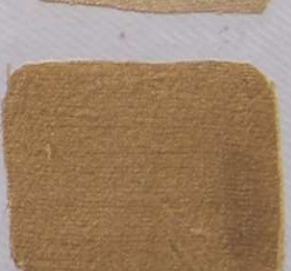
		Without mordant		
				
Method →		Pre-mordanting	Simultaneous mordanting	Post-mordanting
Mordant ↓				
<i>Salix alba</i> L. (Wood extract)				
<i>Salix alba</i> L. (Wood ash)				
<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)				
<i>Punica granatum</i> L. (Peel)				

Plate-26 : Silk samples dyed with *Nasturtium officinale* R.Br. (leaves) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-27 : Pashmina samples combination with different dyed with *Nasturtium officinale* R.Br. (leaves) in mordants

29.07, C* 34.39, 35.27 and 29.17, h° 84.70, 89.00 and 94.80, ΔE 24.07, 29.03 and 24.55 following post mordanting, simultaneous mordanting and simultaneous mordanting (Table-31).

4.5.20 Colour coordinates of fabrics dyed with *Nasturtium officinale* R.Br. leaves using *Punica granatum* L. peel as mordant

Highest L* (85.31) was recorded in cotton fabric using without mordanting method. Values to the tune of 0.52, 17.68, 17.69, 88.30 and 13.52 were recorded for a*, b*, C*, h° and ΔE respectively. However, in wool, silk and pashmina fabrics highest L* values recorded are 79.22, 75.88 and 71.40 respectively following simultaneous mordanting, without mordanting and without mordanting with a* values to the tune of 3.82, 1.82 and 71.40 respectively, b* 38.05, 26.83 and 30.77, C* 38.05, 26.89 and 30.82, h° 84.30, 86.10 and 87.10 and ΔE 19.37, 21.07 and 17.33 (Table-32). Lowest L* (55.68) was recorded in pashmina fabric following post mordanting with a*, b*, C*, h° and ΔE values of 5.47, 36.27, 36.69, 81.40 and 32.43 respectively followed by wool, silk and cotton with L* to the tune of 57.70, 62.83 and 77.05 respectively, a* 5.12, 1.40 and -2.96, b* 34.82, 31.30 and 47.15, C* 35.20, 31.33 and 47.25, h° 81.60, 87.40 and 93.60, ΔE 30.51, 32.50 and 43.56 following post mordanting, pre mordanting and simultaneous mordanting (Table-32).

4.5.21 Colour coordinates of fabrics dyed with *Tagetes patula* L. petals using *Salix alba* L. wood extract as mordant

Highest L* (83.18) was recorded in cotton fabric adopting pre mordanting method. Values to the tune of 0.41, 21.86, 21.87, 88.90 and 18.12 were recorded for a*, b*, C*, h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L* values recorded are 76.50, 69.11 and 62.93 respectively following post mordanting, without mordanting and pre mordanting with a* values to the tune of 2.37, 3.03 and 2.64 respectively, b* 22.10, 28.78 and 29.20, C* 22.23, 28.94 and 29.32, h° 83.90, 84.00 and 84.80 and ΔE 16.99, 24.11 and 22.14. Lowest L* (48.67) was recorded by pashmina fabric following simultaneous mordanting with a*, b*, C*, h° and ΔE values of 6.42, 32.91, 33.54,

Table-33 : Average colour coordinate values of different fabrics treated with *Tagetes patula* L. petals dye using *Salix alba* L. wood extract as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		69.11	3.03	28.78	28.94	84.00	24.11
Pre mordanting		66.99	3.37	29.64	29.83	83.50	26.29
Simultaneous mordanting		52.54	3.83	31.86	32.09	83.10	39.45
Post mordanting		62.01	2.40	28.62	28.72	85.20	29.58
Cotton Fabric							
Without Mordant		81.67	1.15	19.35	19.38	86.60	17.05
Pre mordanting		83.18	0.41	21.86	21.87	88.90	18.12
Simultaneous mordanting		81.91	1.56	17.03	17.11	84.80	15.25
Post mordanting		79.89	-0.69	25.22	25.23	91.60	22.89
Silk Fabric							
Without Mordant		67.39	4.59	24.17	24.60	79.20	25.38
Pre mordanting		66.65	3.36	25.89	26.11	82.60	26.88
Simultaneous mordanting		62.76	5.80	27.92	28.52	78.30	31.44
Post mordanting		76.50	2.37	22.10	22.23	83.90	16.99
Pashmina Fabric							
Without Mordant		60.97	3.24	27.66	27.85	83.30	23.00
Pre mordanting		62.93	2.64	29.20	29.32	84.80	22.14
Simultaneous mordanting		48.67	6.42	32.91	33.54	79.00	36.60
Post mordanting		54.69	2.42	26.07	26.18	84.70	27.95

Table-34 : Average colour coordinate values of different fabrics treated with *Tagetes patula* L. petals dye using *Salix alba* L. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		69.11	3.03	28.78	28.94	84.00	24.11
Pre mordanting		66.30	2.15	33.84	33.91	86.40	29.58
Simultaneous mordanting		68.99	0.61	34.32	34.33	89.00	28.11
Post mordanting		50.55	0.78	24.17	24.18	88.10	38.07
Cotton Fabric							
Without Mordant		81.67	1.15	19.35	19.38	86.60	17.05
Pre mordanting		82.17	1.13	20.41	20.44	86.80	17.51
Simultaneous mordanting		75.44	-0.61	28.28	28.29	91.20	27.99
Post mordanting		74.26	-0.60	20.39	20.40	91.70	23.57
Silk Fabric							
Without Mordant		67.39	4.59	24.17	24.60	79.20	25.38
Pre mordanting		71.72	2.13	24.88	24.98	85.10	22.31
Simultaneous mordanting		77.82	1.82	23.83	23.90	85.60	17.50
Post mordanting		73.31	0.30	18.91	18.91	89.10	17.39
Pashmina Fabric							
Without Mordant		60.97	3.24	27.66	27.85	83.30	23.00
Pre mordanting		61.46	1.91	32.90	32.96	86.70	25.55
Simultaneous mordanting		60.25	2.02	29.57	29.64	86.10	24.53
Post mordanting		49.72	2.49	26.27	26.39	84.60	32.71

79.00 and 36.60 respectively followed by wool, silk and cotton with L^* to the tune of 52.54, 62.76 and 79.89 respectively, a^* 3.83, 5.80 and -0.69, b^* 31.86, 27.92 and 25.22, C^* 32.09, 28.52 and 25.23, h° 83.10, 78.30 and 91.60, ΔE 39.45, 31.44 and 22.89 following simultaneous mordanting, simultaneous mordanting and post mordanting (Table-33).

4.5.22 Colour coordinates of fabrics dyed with *Tagetes patula* L. petals using *Salix alba* L. wood ash as mordant

Highest L^* (82.17) was recorded in cotton fabric adopting pre mordanting method. Values to the tune of 1.13, 20.41, 20.44, 86.80 and 17.51 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 77.82, 69.11 and 61.46 respectively following simultaneous mordanting, without mordanting and pre mordanting with values to the tune of a^* 1.82, 3.03 and 1.91, b^* 23.83, 28.78 and 32.90, C^* 23.90, 28.94 and 32.96, h° 85.60, 84.00 and 86.70 and ΔE 17.50, 24.11 and 25.55 (Table-34). Lowest L^* (49.72) was recorded in pashmina fabric adopting post mordanting with a^* , b^* , C^* , h° and ΔE values of 2.49, 26.27, 26.39, 84.60 and 32.71 respectively followed by wool, silk and cotton with L^* to the tune of 50.55, 67.39 and 74.26 respectively, a^* 0.78, 4.59 and -0.60, b^* 24.17, 24.17 and 20.39, C^* 24.18, 24.60 and 20.40, h° 88.10, 79.20 and 91.70, ΔE 38.07, 25.38 and 23.57 following post mordanting, without mordanting and post mordanting (Table-34).

4.5.23 Colour coordinates of fabrics dyed with *Tagetes patula* L. petals using *Populus deltoides* Bartram ex Marsh. wood ash as mordant

Highest L^* (91.88) was recorded in cotton fabric adopting post mordanting method. Values to the tune of 1.84, 10.92, 11.08, 80.40 and 4.18 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 69.46, 69.11 and 60.99 respectively following simultaneous mordanting, without mordanting and pre mordanting with a^* values to the tune of 2.96, 3.03 and 3.50, b^* 33.16, 28.78 and 30.25, C^* 33.30, 28.94 and 30.45, h° 84.90, 84.00 and 83.40 and ΔE 28.74, 24.11 and 24.39. Lowest L^* (42.99) was recorded in pashmina fabric adopting

Table-35 : Average colour coordinate values of different fabrics treated with *Tagetes patula* L. petals dye using *Populus deltoides* Bartram ex Marsh. wood ash as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		69.11	3.03	28.78	28.94	84.00	24.11
Pre mordanting		65.40	1.22	27.69	27.72	87.50	20.00
Simultaneous mordanting		47.88	14.27	48.17	50.25	73.50	47.92
Post mordanting		60.00	3.26	33.67	33.83	84.50	27.71
Cotton Fabric							
Without Mordant		81.67	1.15	19.35	19.38	86.60	17.05
Pre mordanting		82.95	0.39	21.79	21.79	89.00	17.96
Simultaneous mordanting		84.33	-0.65	22.97	22.98	68.10	18.41
Post mordanting		91.88	1.84	10.92	11.08	80.40	4.18
Silk Fabric							
Without Mordant		67.39	4.59	24.17	24.60	79.20	25.38
Pre mordanting		67.92	2.79	22.99	23.16	83.10	23.95
Simultaneous mordanting		69.46	2.96	33.16	33.30	84.90	28.74
Post mordanting		71.67	2.70	20.23	20.41	82.40	19.40
Pashmina Fabric							
Without Mordant		60.97	3.24	27.66	27.85	83.30	23.00
Pre mordanting		60.99	3.50	30.25	30.45	83.40	24.39
Simultaneous mordanting		42.99	1.57	48.20	49.35	77.60	50.41
Post mordanting		53.78	2.01	31.16	31.23	86.30	30.90

Table-36 : Average colour coordinate values of different fabrics treated with *Tagetes patula* L. petals dye using *Punica granatum* L. peel as mordant dyed by different mordanting methods

Methods	Colour coordinates	L*	a*	b*	C*	h°	Δ E
Wool Fabric							
Without Mordant		69.11	3.03	28.78	28.94	84.00	24.11
Pre mordanting		54.99	2.01	31.16	31.23	86.30	30.97
Simultaneous mordanting		59.78	4.19	35.75	36.00	83.30	29.19
Post mordanting		59.08	4.69	32.64	32.98	81.80	28.20
Cotton Fabric							
Without Mordant		81.67	1.15	19.35	19.38	86.60	17.05
Pre mordanting		78.66	-0.29	25.31	25.23	90.70	23.35
Simultaneous mordanting		76.56	-0.59	34.75	34.76	91.00	32.38
Post mordanting		78.61	0.31	22.51	22.52	89.20	21.17
Silk Fabric							
Without Mordant		67.39	4.59	24.17	24.60	79.20	25.38
Pre mordanting		65.44	2.26	28.91	29.00	85.50	29.03
Simultaneous mordanting		62.74	1.67	27.26	27.31	86.50	30.44
Post mordanting		67.77	1.44	29.69	29.73	87.20	27.58
Pashmina Fabric							
Without Mordant		60.97	3.24	27.66	27.85	83.30	23.00
Pre mordanting		58.88	4.50	35.25	35.54	82.70	29.22
Simultaneous mordanting		55.53	4.72	37.17	37.47	82.80	33.02
Post mordanting		57.39	4.58	39.02	39.29	83.30	32.86

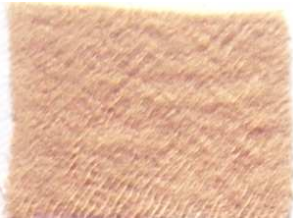
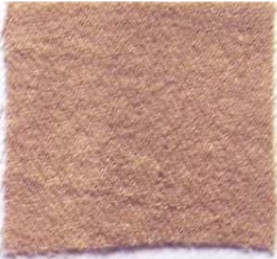
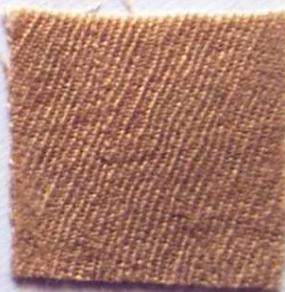
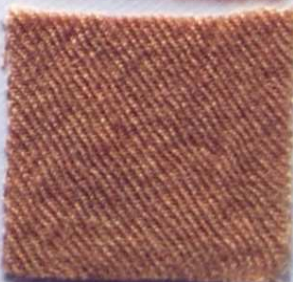
		Without mordant		
				
Method →	Mordant ↓	Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-28 : Wool samples dyed with *Tagetes patula* L. (petals) in combination with different mordants

		Without mordant		
				
Method → Mordant ↓		Pre-mordanting	Simultaneous mordanting	Post-mordanting
	<i>Salix alba</i> L. (Wood extract)			
	<i>Salix alba</i> L. (Wood ash)			
	<i>Populus deltoides</i> Bartram ex Marsh. (Wood ash)			
	<i>Punica granatum</i> L. (Peel)			

Plate-29 : Cotton samples dyed with *Tagetes patula* L. (petals) in combination with different mordants

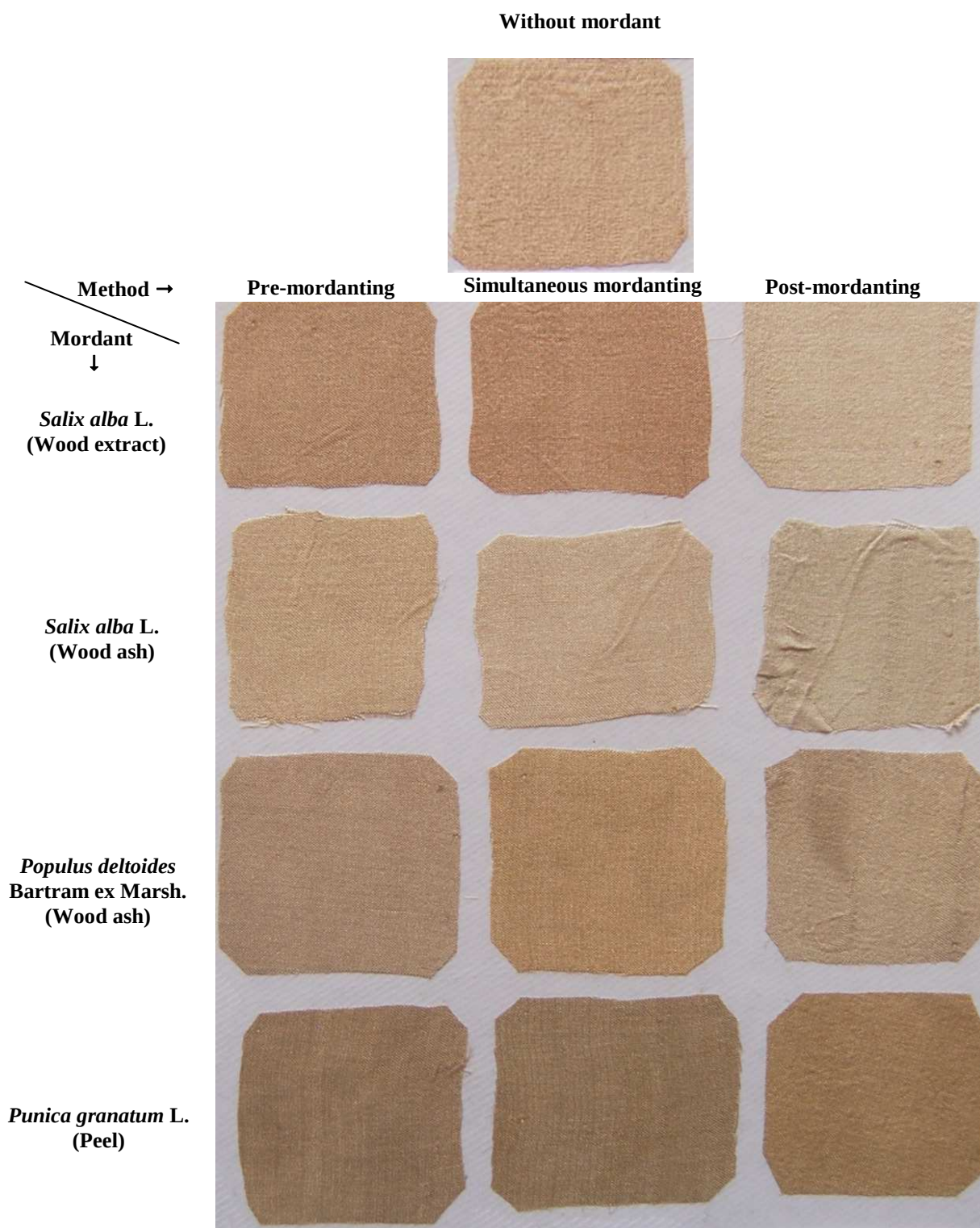


Plate-30 : Silk samples dyed with *Tagetes patula* L. (petals) in combination with different mordants

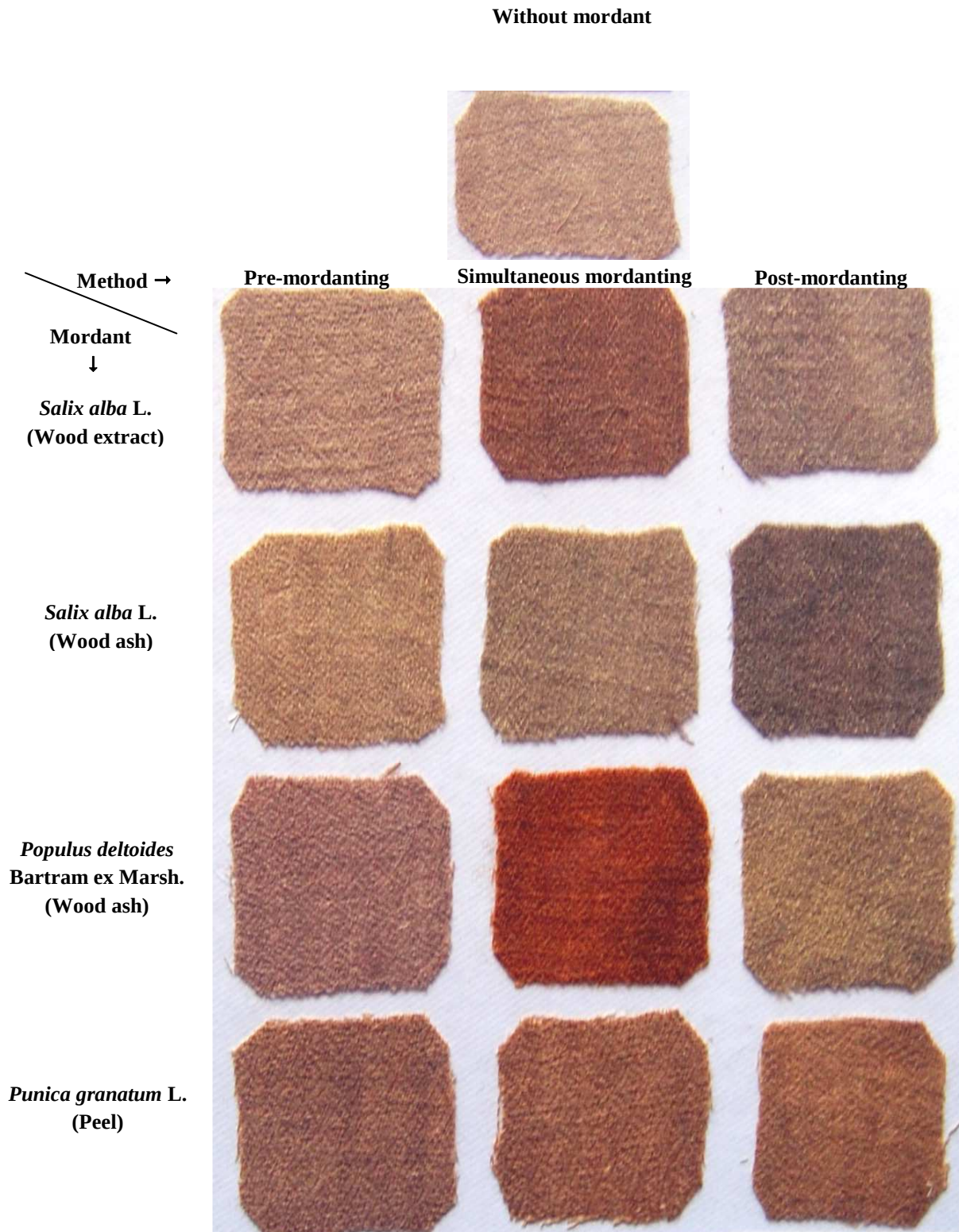


Plate-31 : Pashmina samples dyed with *Tagetes patula* L. (petals) in combination with different mordants

simultaneous mordanting with a^* , b^* , C^* , h° and ΔE values of 1.57, 48.20, 49.35, 77.60 and 50.41 respectively followed by wool, silk and cotton with L^* to the tune of 47.88, 67.39 and 81.67, a^* 14.27, 4.59 and 1.15, b^* 48.17, 24.17 and 19.35, C^* 50.25, 24.60 and 19.38, h° 73.50, 79.20 and 86.60, ΔE 47.92, 25.38 and 17.05 following simultaneous mordanting, without mordanting and without mordanting (Table-35).

4.5.24 Colour coordinates of fabrics dyed with *Tagetes patula* L. petals using *Punica granatum* L. peel as mordant

Highest L^* (81.67) was recorded in cotton fabric using without mordanting method. Values to the tune of 1.15, 19.35, 19.38, 86.60 and 17.05 were recorded for a^* , b^* , C^* , h° and ΔE respectively. However, in silk, wool and pashmina fabrics highest L^* values recorded are 69.11, 67.39 and 60.97 respectively in dyeing without mordanting with a^* values to the tune of 3.03, 4.59 and 3.24 respectively, b^* 28.78, 24.17 and 27.66, C^* 28.94, 24.60 and 27.85, h° 84.00, 79.20 and 83.30 and ΔE 24.11, 25.38 and 23.00 (Table-36). Lowest L^* (54.99) was recorded in wool fabric following pre mordanting with a^* , b^* , C^* , h° and ΔE values of 2.01, 31.16, 31.23, 86.30 and 30.97 respectively followed by pashmina, silk and cotton with L^* to the tune of 55.53, 62.74 and 76.56 respectively, a^* 4.72, 1.67 and -0.59, b^* 37.17, 27.26 and 34.75, C^* 37.47, 27.31 and 34.76, h° 82.80, 86.50 and 91.00, ΔE 33.02, 30.44 and 32.38 adopting simultaneous mordanting (Table-36).

4.6 Colour strength and Relative colour strength (K/S) of dyed fabrics

In present study significant effect of mordants and methods of mordanting on colour strength and relative colour strength (K/S) of the dyed fabrics was recorded. The dyes, mordants, methods, interaction of dye×mordant, dye×method, mordant×method and dye×mordant×method showed a significant effect on colour strength of the dyed fabrics. Among the selected fabrics maximum colour strength (K/S) 0.930 with relative colour strength of 2.34 was recorded in wool using *Juglans regia* L. (leaves) dye with *Punica granatum* L. (peel) mordant adopting

Table-37 : Colour strength (K/S) and effect of different mordants on dye properties of wool fabric

Mordants →	Salix alba L. (wood extract)					Salix alba L. (wood ash)					Populus deltoides Bartram ex Marsh. (wood ash)					Punica granatum L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	0.621	0.552	0.574	0.637	0.596	0.621	0.589	0.621	0.689	0.63	0.621	0.653	0.602	0.630	0.626	0.621	0.754	0.367	0.721	0.615	0.616	0.646
<i>Juglans regia</i> L. (leaves)	0.737	0.682	0.761	0.732	0.728	0.737	0.711	0.721	0.757	0.731	0.737	0.725	0.772	0.852	0.771	0.737	0.772	0.841	0.930	0.820	0.762	0.696
<i>Juglans regia</i> L. (fruit hull)	0.69	0.63	0.772	0.718	0.702	0.69	0.725	0.675	0.744	0.708	0.69	0.73	0.686	0.679	0.696	0.69	0.69	0.780	0.737	0.724	0.707	0.674
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	0.777	0.702	0.759	0.668	0.726	0.777	0.732	0.73	0.749	0.747	0.777	0.786	0.695	0.732	0.747	0.777	0.846	0.783	0.800	0.801	0.755	0.711
<i>Nasturtium officinale</i> R.Br. (leaves)	0.601	0.605	0.616	0.58	0.600	0.601	0.605	0.411	0.584	0.550	0.601	0.573	0.421	0.431	0.506	0.601	0.625	0.735	0.710	0.667	0.580	
<i>Tagetes patula</i> L. (petals)	0.452	0.684	0.61	0.649	0.598	0.452	0.79	0.749	0.746	0.684	0.452	0.675	0.787	0.814	0.682	0.452	0.888	0.719	0.792	0.712	0.669	
Mean	0.646	0.642	0.682	0.664	0.658	0.646	0.692	0.651	0.711	0.675	0.646	0.690	0.660	0.689	0.671	0.646	0.762	0.704	0.781	0.723		

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.000805
Mordants (M)	:	0.000657
Methods (Me)	:	0.000657
Dye x Mordant	:	0.00161
Dye x Method	:	0.00161
Mordant x Method	:	0.00131
Dye x Mordant x Method	:	0.0322

Table-38 : Effect of different natural dyes and mordants on relative colour strength (K/S) of wool fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	1.54	1.36	1.42	1.58	1.47	1.54	1.46	1.54	1.78	1.56	1.54	1.70	1.64	1.72	1.67	1.54	2.06	1.00	1.97	1.64	1.58	1.62
<i>Juglans regia</i> L. (leaves)	1.82	1.69	1.88	1.81	1.80	1.82	1.76	1.78	1.87	1.81	1.82	1.79	2.11	2.26	2.00	1.82	2.11	2.30	2.54	2.19	1.95	1.79
<i>Juglans regia</i> L. (fruit hull)	1.71	1.56	2.00	1.78	1.74	1.71	1.79	1.67	1.91	1.75	1.89	1.90	1.87	1.83	1.89	1.89	1.89	2.13	2.01	1.98	1.84	1.76
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	1.92	1.74	1.88	1.65	1.80	1.92	1.81	1.81	1.85	1.85	1.92	1.95	1.90	2.00	1.94	1.92	2.31	2.14	2.19	2.14	1.93	1.85
<i>Nasturtium officinale</i> R.Br. (leaves)	1.49	1.50	1.52	1.43	1.48	1.49	1.50	1.01	1.46	1.36	1.49	1.56	1.15	1.18	1.38	1.49	1.71	2.01	1.94	1.79	1.50	
<i>Tagetes patula</i> L. (petals)	1.12	1.69	1.51	1.61	1.48	1.12	1.96	1.85	1.85	1.69	1.12	1.67	2.15	2.23	1.79	1.12	2.43	1.96	2.16	1.92	1.72	
Mean	1.60	1.59	1.69	1.64	1.63	1.60	1.71	1.61	1.76	1.67	1.65	1.79	1.80	1.87	1.78	1.63	2.08	1.92	2.14	1.94	1.75	

post mordanting followed by 0.886 and 0.774 with relative colour strength 1.98 and 2.43 was recorded using *Salix alba* L. (wood extract) and *Punica granatum* L. (peel) mordant adopting simultaneous and post mordanting methods in pashmina and silk fabric respectively, whereas minimum colour strength (0.159) with relative colour strength of 0.33 was recorded in cotton fabric using *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant following simultaneous mordanting (Table-37).

4.6.1 Colour strength (K/S) and Relative colour strength of wool fabric

Highest colour strength (K/S) value (0.754) in wool fabric was recorded in samples dyed with *Quercus robura* L. (fruit cups) dyed with *Punica granatum* L. (peel) mordant adopting pre mordanting method. Values to the tune of 0.689, 0.653 and 0.637 were recorded using *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Salix alba* (wood extract) mordants respectively adopting post, pre and post mordanting methods. The relative colour strength (K/S) values also followed the same trend with highest value of 2.06 and corresponding values of 1.78, 1.70 and 1.58 respectively (Table-38).

Highest colour strength 0.93 and relative colour strength 2.54 in wool samples dyed with *Juglans regia* L. (leaves) was recorded with *Punica granatum* (peel) adopting post mordanting method followed by *Populus deltoides* (wood ash) 0.852 and 2.26, *Salix alba* (wood extract) 0.761 and 1.88 and *Salix alba* (wood ash) 0.757 and 1.87 respectively adopting post, simultaneous and post mordanting methods.

The highest colour strength 0.780 of *Juglans regia* L. (fruit hull) dye was recorded with *Punica granatum* L. (peel) mordant followed by *Salix alba* L. (wood extract), *Salix alba* L. (wood ash) and *Populus deltoides* Bartram ex Marsh (wood ash) and with the values of 0.772, 0.744 and 0.730 respectively adopting simultaneous, post and pre mordanting methods. Relative colour strength of the *Juglans regia* L. (fruit hull) dyed fabrics followed the same trend with highest

value of 2.13 with *Punica granatum* L. (peel) mordant followed by 2.00, 1.91 and 1.90 respectively.

Prunus cerasifera Ehrh. var. *atropurpurea*. (leaves) dye with *Punica granatum* L. (peel) mordant recorded highest colour strength 0.846 and relative colour strength 2.31 adopting pre mordanting whereas *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood ash) and *Salix alba* L. (wood extract) recorded the corresponding values of 0.786 and 1.95, 0.777 and 1.92 and 0.777 and 1.92 respectively adopting pre mordanting, without mordanting and without mordanting methods.

In *Nasturtium officinale* R.Br. (leaves) dye colour strength and Relative colour strength (K/S) followed the same trend with highest colour strength and relative colour strength (0.735, 2.01) using *Punica granatum* L. (peel) mordant by adopting simultaneous mordanting. Values to the tune of 0.616 and 1.52, 0.605 and 1.50 and 0.601 and 1.49 respectively recorded for colour strength and relative colour strength using *Salix alba* L. (wood extract), *Salix alba* L. (wood ash) and *Populus deltoides* Bartram ex Marsh (wood ash) mordant adopting simultaneous, pre and without mordanting methods.

Tagetes patula L. (petals) dye recorded highest (0.888, 2.43) colour strength and relative colour strength (K/S) with *Punica granatum* L. (peel) mordant following pre mordanting method. *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood ash) and *Salix alba* L. (wood extract) recorded (0.814, 2.23), (0.79, 1.96) and (0.684, 1.69) respectively by adopting post, pre and without mordanting methods (Table-38).

4.6.2 Colour strength (K/S) and Relative colour strength of cotton fabric

Cotton fabric recorded highest colour strength and relative colour strength (K/S) (0.576 and 1.22) dyed with *Quercus robura* (fruit cups) and *Punica granatum* (peel) mordant adopting simultaneous mordanting. Without mordanting dyed fabric recorded highest colour strength and relative colour strength (K/S) of

Table-39 : Colour strength (K/S) and effect of different mordants on dye properties of cotton fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	0.521	0.425	0.352	0.357	0.413	0.521	0.356	0.458	0.413	0.437	0.521	0.301	0.493	0.426	0.435	0.521	0.570	0.576	0.459	0.531	0.454	0.547
<i>Juglans regia</i> L. (leaves)	0.599	0.503	0.37	0.435	0.476	0.599	0.399	0.514	0.371	0.470	0.599	0.395	0.531	0.591	0.529	0.599	0.549	0.715	0.533	0.599	0.510	0.442
<i>Juglans regia</i> L. (fruit hull)	0.484	0.481	0.355	0.336	0.414	0.484	0.327	0.331	0.281	0.355	0.484	0.328	0.517	0.424	0.438	0.484	0.538	0.643	0.649	0.578	0.446	0.472
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	0.592	0.482	0.357	0.392	0.455	0.592	0.387	0.362	0.365	0.426	0.592	0.355	0.159	0.357	0.365	0.592	0.551	0.603	0.470	0.554	0.450	0.434
<i>Nasturtium officinale</i> R.Br. (leaves)	0.550	0.434	0.278	0.383	0.411	0.550	0.362	0.353	0.303	0.392	0.550	0.344	0.745	0.537	0.544	0.550	0.526	0.720	0.495	0.572	0.479	
<i>Tagetes patula</i> L. (petals)	0.539	0.494	0.250	0.41	0.423	0.539	0.416	0.458	0.466	0.469	0.539	0.39	0.538	0.407	0.468	0.539	0.706	0.655	0.566	0.616	0.494	
Mean	0.547	0.469	0.327	0.385	0.432	0.547	0.374	0.412	0.366	0.425	0.547	0.352	0.497	0.457	0.463	0.547	0.573	0.652	0.528	0.575		

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.000795
Mordants (M)	:	0.000649
Methods (Me)	:	0.000649
Dye x Mordant	:	0.00159
Dye x Method	:	0.00159
Mordant x Method	:	0.00129
Dye x Mordant x Method	:	0.00318

Table-40 : Effect of different natural dyes and mordants on relative colour strength (K/S) of cotton fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	1.10	0.90	0.74	0.75	0.87	1.10	0.75	0.97	0.87	0.92	1.10	0.63	1.04	0.90	0.92	1.10	1.21	1.22	0.97	1.12	0.96	1.16
<i>Juglans regia</i> L. (leaves)	1.27	1.06	0.78	0.92	1.01	1.27	0.84	1.09	0.78	0.99	1.27	0.83	1.12	1.25	1.12	1.27	1.16	1.51	1.13	1.27	1.10	0.96
<i>Juglans regia</i> L. (fruit hull)	1.02	1.02	0.75	0.71	0.87	1.02	0.69	0.70	0.59	0.75	1.02	0.69	1.09	0.90	0.93	1.02	1.14	1.14	1.37	1.17	0.93	0.99
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	1.25	1.02	0.75	0.83	0.96	1.25	1.25	0.82	0.77	1.02	1.25	0.75	0.33	0.75	0.77	1.25	1.25	1.28	0.99	1.19	0.94	0.92
<i>Nasturtium officinale</i> R.Br. (leaves)	1.16	0.92	0.59	0.81	0.87	1.16	0.76	0.74	0.64	0.83	1.16	0.73	1.58	1.14	1.15	1.16	1.11	1.52	1.21	1.25	1.02	
<i>Tagetes patula</i> L. (petals)	1.14	1.04	0.53	0.87	0.89	1.14	0.88	0.97	0.98	0.99	1.14	0.82	1.14	0.86	0.99	1.14	1.49	1.39	1.20	1.30	1.04	
Mean	1.16	0.99	0.69	0.81	0.91	1.16	0.86	0.88	0.77	0.92	1.16	0.74	1.05	0.96	0.98	1.16	1.23	1.34	1.14	1.22		

0.521 and 1.10 with all the mordant combinations of *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) (Tables-39 to 40).

Juglans regia (leaves) dye recorded highest colour strength (0.715) and relative colour strength (1.51) with mordant *Punica granatum* (peel) adopting simultaneous mordanting. Using *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) as mordants highest value of colour strength and relative colour strength recorded (0.599 and 1.27) in without mordanting dyed samples.

Juglans regia (fruit hull) dye recorded the highest colour strength and relative colour strength (K/S) (0.649 and 1.37) with *Punica granatum* (peel) adopting post mordanting followed by *Populus deltoides* (wood ash), *Salix alba* (wood extract) and *Salix alba* (wood ash) with the values of 0.517 and 1.09, 0.484 and 1.02 and 0.484 and 1.02 respectively adopting simultaneous, without mordanting and without mordanting respectively.

Highest colour strength and relative colour strength (K/S) 0.603 and 1.28 of the dyed fabric with *Prunus cerasifera* (leaves) was recorded with *Punica granatum* (peel) adopting simultaneous mordanting. However *Salix alba* (wood ash), *Salix alba* (wood extract) and *Populus deltoides* (wood ash) recorded highest colour strength and relative colour strength (K/S) 0.529 and 1.25 by adopting without mordanting method.

Nasturtium officinale (leaves) recorded highest colour strength and relative colour strength of 0.74 and 1.58 respectively using *Populus deltoides* (wood ash) as mordant adopting simultaneous mordanting followed by *Punica granatum* (peel), *Salix alba* (wood extract) and *Salix alba* (wood ash) with corresponding values of 0.72 and 1.52, 0.55 and 1.16 and 0.55 and 1.16 respectively adopting simultaneous, without mordanting and without mordanting method respectively.

The highest value of colour strength (0.706) and relative colour strength (1.49) of fabric dyed with *Tagetes patula* (leaves) was recorded with *Punica*

Table-41 : Colour strength (K/S) and effect of different mordants on dye properties of silk fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	0.615	0.58	0.601	0.48	0.569	0.615	0.555	0.599	0.555	0.581	0.615	0.57	0.596	0.695	0.619	0.615	0.534	0.733	0.701	0.645	0.603	0.622
<i>Juglans regia</i> L. (leaves)	0.714	0.695	0.718	0.56	0.671	0.714	0.679	0.657	0.713	0.690	0.714	0.658	0.757	0.746	0.718	0.714	0.688	0.753	0.774	0.732	0.703	0.615
<i>Juglans regia</i> L. (fruit hull)	0.675	0.642	0.604	0.522	0.610	0.675	0.592	0.565	0.561	0.598	0.675	0.636	0.605	0.556	0.618	0.675	0.534	0.689	0.717	0.653	0.620	0.638
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	0.593	0.639	0.651	0.595	0.619	0.593	0.592	0.615	0.585	0.596	0.593	0.628	0.586	0.710	0.629	0.593	0.721	0.721	0.732	0.691	0.633	0.602
<i>Nasturtium officinale</i> R.Br. (leaves)	0.506	0.609	0.556	0.463	0.533	0.506	0.526	0.500	0.502	0.508	0.506	0.560	0.609	0.470	0.536	0.506	0.624	0.664	0.652	0.611	0.547	
<i>Tagetes patula</i> L. (petals)	0.631	0.635	0.652	0.474	0.598	0.631	0.581	0.541	0.474	0.556	0.631	0.593	0.656	0.507	0.596	0.631	0.698	0.698	0.707	0.683	0.608	
Mean	0.622	0.633	0.630	0.515	0.600	0.622	0.587	0.579	0.565	0.588	0.622	0.607	0.634	0.614	0.619	0.622	0.633	0.709	0.713	0.669		

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.00000128
Mordants (M)	:	0.00000104
Methods (Me)	:	0.00000104
Dye x Mordant	:	0.00000256
Dye x Method	:	0.00000256
Mordant x Method	:	0.00000209
Dye x Mordant x Method	:	0.00000512

Table-42 : Effect of different natural dyes and mordants on relative colour strength (K/S) of silk fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	1.94	1.83	1.90	1.51	1.80	1.94	1.75	1.89	1.75	1.83	1.94	1.80	1.87	2.18	1.95	1.94	1.67	2.30	2.20	2.03	1.90	1.96
<i>Juglans regia</i> L. (leaves)	2.25	2.19	2.27	1.77	2.12	2.25	2.14	2.07	2.25	2.18	2.25	2.06	2.38	2.34	2.26	2.25	2.16	2.36	2.43	2.30	2.21	1.95
<i>Juglans regia</i> L. (fruit hull)	2.13	2.03	1.91	1.65	1.93	2.13	1.87	1.78	1.77	1.89	2.13	2.00	1.90	1.74	1.94	2.13	1.67	2.16	2.25	2.05	1.95	2.01
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	1.87	2.02	2.06	1.88	1.96	1.87	1.87	1.94	1.85	1.88	1.87	1.98	1.84	2.23	1.98	1.87	2.26	2.26	2.30	2.17	2.00	1.89
<i>Nasturtium officinale</i> R.Br. (leaves)	1.60	1.92	1.75	1.46	1.68	1.60	1.66	1.58	1.58	1.60	1.60	1.76	1.92	1.47	1.68	1.60	1.96	2.08	1.92	1.89	1.71	
<i>Tagetes patula</i> L. (petals)	1.99	2.00	2.06	1.50	1.89	1.99	1.83	1.71	1.50	1.76	1.99	1.86	2.06	1.59	1.87	1.99	2.19	2.19	2.22	2.15	1.92	
Mean	1.96	2.00	1.99	1.63	1.89	1.96	1.90	1.84	1.78	1.87	1.96	1.91	1.99	1.93	1.95	1.96	1.99	2.23	2.22	2.10		

granatum (peel) mordant adopting pre mordanting method, whereas without mordanted dyed samples recorded highest values (0.539 and 1.14) in *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordants respectively (Tables-39 to 40).

4.6.3 Colour strength (K/S) and Relative colour strength of silk fabric

Colour strength and relative colour strength of *Quercus robura* (fruit cups) dyed fabric recorded highest (0.733 and 2.30) using *Punica granatum* (peel) mordant adopting simultaneous mordanting. Values to the tune of 0.695 and 2.18, 0.615 and 1.94 and 0.615 and 1.94 recorded highest in *Populus deltoides* (wood ash), *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant following post, without mordanting and without mordanting method respectively (Table-41 to 42).

The highest value of colour strength and relative colour strength (0.774 and 2.43) of *Juglans regia* (leaves) dyed fabric was recorded with *Punica granatum* (peel) mordant adopting post mordanting method followed by *Populus deltoides* (wood ash), *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant with the corresponding values of 0.757 and 2.38 by simultaneous mordanting 0.718 and 2.27 adopting simultaneous mordanting and 0.714 and 2.25 following without mordanting method respectively.

Highest colour strength and relative colour strength (0.717 and 2.25) of *Juglans regia* (fruit hull) dyed fabric was recorded with *Punica granatum* (peel) mordant adopting post mordanting method. Without mordanted samples recorded highest colour strength and relative colour strength values to the tune of 0.675 and 2.13, 0.675 and 2.13 and 0.675 and 2.13 respectively using *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant.

Prunus cerasifera (leaves) dyed fabric recorded highest colour strength and relative colour strength (0.732 and 2.30) with *Punica granatum* (peel) mordant adopting post mordanting method followed by *Populus deltoides* (wood ash) 0.71 and 2.23, *Salix alba* (wood extract) 0.651 and 2.06 and *Salix alba* (wood

ash) 0.615 and 1.94 adopting post, simultaneous mordanting and simultaneous mordanting methods respectively.

The highest value of colour strength and relative colour strength (0.664 and 2.08) of *Nasturtium officinale* (leaves) dyed fabric was recorded using *Punica granatum* (peel) mordant. Values to the tune of 0.609 and 1.92, 0.609 and 1.92 and 0.526 and 1.66 were recorded using *Salix alba* (wood extract) adopting pre mordanting, *Populus deltoides* (wood ash) adopting simultaneous mordanting and *Salix alba* (wood ash) adopting pre mordanting method respectively.

Fabrics dyed using *Tagetes patula* (petals) dye recorded highest colour strength and relative colour strength (0.707 and 2.22) with *Punica granatum* (peel) mordant adopting post mordanting. Using *Populus deltoides* (wood ash), *Salix alba* (wood extract) and *Salix alba* (wood ash) as mordants, values of 0.656 and 2.06, 0.652 and 2.06 and 0.631 and 1.99 were recorded adopting simultaneous, simultaneous and without mordanting method respectively (Tables-41 to 42).

4.6.4 Colour strength (K/S) and relative colour strength of Pashmina fabric

Quercus robura (fruit cups) dye recorded highest colour strength and relative colour strength (0.848 and 2.18) with *Punica granatum* (peel) mordant adopting post mordanting method followed by *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Salix alba* (wood extract) with the values of 0.739 and 1.65, 0.736 and 1.89 and 0.711 and 1.59 adopting post mordanting, post mordanting and simultaneous mordanting respectively (Tables-43 to 44).

Highest colour strength and relative colour strength (0.886 and 1.98) was recorded in samples dyed with *Juglans regia* (leaves) and *Salix alba* (wood extract) adopting simultaneous mordanting. Values to the tune of 0.824 and 1.84, 0.807 and 2.07 and 0.807 and 2.07 were recorded using *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively following simultaneous, simultaneous and pre mordanting methods.

Table-43 : Colour strength (K/S) and effect of different mordants on dye properties of pashmina fabric

Mordants →	Salix alba L. (wood extract)				Mean	Salix alba L. (wood ash)				Mean	Populus deltoides Bartram ex Marsh. (wood ash)				Mean	Punica granatum L. (peel)				Mean	Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		M ₁	M ₂	M ₃	M ₄		Dye	Method
Quercus robura L. (fruit cups)	0.667	0.637	0.711	0.671	0.671	0.667	0.710	0.662	0.739	0.694	0.667	0.707	0.678	0.736	0.697	0.667	0.741	0.833	0.848	0.772	0.708	0.700
Juglans regia L. (leaves)	0.789	0.728	0.886	0.756	0.789	0.789	0.820	0.824	0.764	0.799	0.789	0.754	0.807	0.780	0.782	0.789	0.807	0.782	0.780	0.789	0.790	0.736
Juglans regia L. (fruit hull)	0.746	0.753	0.765	0.763	0.756	0.746	0.772	0.767	0.726	0.752	0.746	0.818	0.727	0.727	0.754	0.746	0.735	0.787	0.820	0.772	0.759	0.760
Prunus cerasifera Ehrh. var. atropurpurea. (leaves)	0.734	0.708	0.773	0.721	0.734	0.734	0.759	0.718	0.780	0.747	0.734	0.747	0.710	0.763	0.738	0.734	0.798	0.806	0.784	0.780	0.750	0.741
Nasturtium officinale R.Br. (leaves)	0.582	0.615	0.657	0.595	0.612	0.582	0.695	0.596	0.689	0.640	0.582	0.707	0.862	0.712	0.715	0.582	0.754	0.747	0.785	0.717	0.671	
Tagetes patula L. (petals)	0.682	0.685	0.752	0.728	0.711	0.682	0.734	0.754	0.704	0.718	0.682	0.736	0.853	0.678	0.737	0.682	0.765	0.793	0.749	0.747	0.728	
Mean	0.700	0.687	0.757	0.705	0.712	0.700	0.748	0.720	0.733	0.725	0.700	0.744	0.772	0.732	0.737	0.700	0.766	0.791	0.794	0.762		

M₁ = Without mordant; M₂ = Pre-mordanting; M₃ = Simultaneous mordanting; M₄ = Post mordanting

C.D (p ≤ 0.05)

Dyes (D)	:	0.000796
Mordants (M)	:	0.000650
Methods (Me)	:	0.000650
Dye x Mordant	:	0.00159
Dye x Method	:	0.00159
Mordant x Method	:	0.00130
Dye x Mordant x Method	:	0.00318

Table-44 : Effect of different natural dyes and mordants on relative colour strength (K/S) of pashmina fabric

Mordants →	<i>Salix alba</i> L. (wood extract)					<i>Salix alba</i> L. (wood ash)					<i>Populus deltoides</i> Bartram ex Marsh. (wood ash)					<i>Punica granatum</i> L. (peel)					Factor mean	
Dye Source ↓	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	M ₁	M ₂	M ₃	M ₄	Mean	Dye	Method
<i>Quercus robura</i> L. (fruit cups)	1.49	1.42	1.59	1.50	1.50	1.49	1.58	1.48	1.65	1.55	1.49	1.58	1.51	1.89	1.61	1.49	1.9	2.14	2.18	1.92	1.64	1.58
<i>Juglans regia</i> L. (leaves)	1.76	1.62	1.98	1.69	1.76	1.76	1.83	1.84	1.7	1.78	1.76	1.68	2.07	2.01	1.88	1.76	2.07	2.01	2.01	1.96	1.84	1.71
<i>Juglans regia</i> L. (fruit hull)	1.66	1.68	1.71	1.7	1.68	1.66	1.72	1.71	1.62	1.67	1.66	1.82	1.62	1.62	1.68	1.9	1.88	2.02	2.11	1.97	1.75	1.78
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	1.64	1.58	1.72	1.61	1.63	1.64	1.69	1.6	1.74	1.66	1.88	1.90	1.82	1.96	1.89	1.64	2.05	2.07	2.02	1.94	1.78	1.72
<i>Nasturtium officinale</i> R.Br. (leaves)	1.30	1.37	1.46	1.33	1.36	1.30	1.55	1.33	1.54	1.43	1.30	1.82	2.22	1.83	1.59	1.3	1.94	1.92	2.02	1.79	1.54	
<i>Tagetes patula</i> L. (petals)	1.52	1.53	1.68	1.62	1.58	1.52	1.64	1.68	1.57	1.60	1.52	1.89	2.19	1.77	1.64	1.52	1.97	2.04	1.92	1.86	1.67	
Mean	1.56	1.53	1.69	1.57	1.59	1.56	1.66	1.60	1.63	1.61	1.60	1.70	1.80	1.76	1.71	1.60	1.96	2.03	2.04	1.91	1.70	

Juglans regia (fruit hull) dye recorded highest colour strength 0.820 and relative colour strength 2.11 with *Punica granatum* (peel) mordant adopting post mordanting. Whereas, *Populus deltoides* (wood ash), *Salix alba* (wood ash) and *Salix alba* (wood extract) recorded corresponding values of 0.818 and 1.82, 0.772 and 1.72 and 0.746 and 1.66 respectively adopting pre mordanting, pre mordanting and simultaneous mordanting methods.

Highest colour strength 0.806 of *Prunus cerasifera* (leaves) dyed fabric was recorded with *Punica granatum* (peel) mordant adopting simultaneous mordanting followed by *Salix alba* (wood ash), *Salix alba* (wood extract) and *Populus deltoides* (wood ash) with the tune of values 0.780, 0.773 and 0.710 respectively adopting post, simultaneous and simultaneous mordanting methods. Relative colour strength of dyed fabrics also followed the same trend with highest value of 2.07 followed by 1.96, 1.74 and 1.70 respectively.

Highest value of colour strength and relative colour strength (0.862 and 2.22) of *Nasturtium officinale* (leaves) dyed fabric was recorded with *Populus deltoides* (wood ash) mordant adopting simultaneous mordanting. Values to the tune of 0.780 and 2.02, 0.695 and 1.55 and 0.657 and 1.46 were recorded using *Punica granatum* (peel), *Salix alba* (wood ash) and *Salix alba* (wood extract) mordants respectively adopting post, pre and simultaneous mordanting methods respectively.

Tagetes patula (petals) dyed fabric recorded highest colour strength and relative colour strength (0.853 and 2.198) using *Populus deltoides* (wood ash) mordant adopting simultaneous mordanting. Values to the tune of 0.793 and 2.040, 0.754 and 1.680 and 0.752 and 1.68 respectively were recorded using *Punica granatum* (peel), *Salix alba* (wood ash) and *Salix alba* (wood extract) mordant adopting simultaneous mordanting method (Tables-43 to 44).

4.7 Colour fastness properties of fabrics dyed with combinations of dyes and mordants

Dyed fabrics were evaluated on the basis of washing fastness, light fastness and rubbing fastness tests as per the ISO standard test methods. For washing fastness, colour change and colour staining were recorded. For light fastness colour change was recorded and for rubbing fastness, staining and fading with dry and wet rubbing were recorded (Tables-45 to 56).

4.7.1 Colour fastness properties of wool fabric adopting pre mordanting method

4.7.1.1 Washing fastness

Excellent (5) grade for colour change was recorded due to *Nasturtium officinale* (leaves) dye without mordanting. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) colour change grade was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Quercus robura* dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) and *Prunus cerasifera* (leaves) dye without mordant respectively. The lowest grade Fair (3) for colour change was

Table-45 : Fastness grades of wool fabric dyed with different natural dyes and mordants by pre mordanting method

Dye source	Mordants	Washing		Light	Rubbing Fastness				
		Fastness			Fastness	Staining		Fading	
		CC	CS			CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4	4/5	4/5	4/5	4/5	5	4/5	
	M ₂	4/5	5	4/5	5	5	5	4/5	
	M ₃	4/5	5	4/5	5	5	5	5	
	M ₄	4	5	5	5	5	5	5	
	M ₅	3/4	5	4	5	5	4/5	4	
<i>Juglans regia</i> L. (leaves)	M ₁	4	4/5	5	4/5	4	5	4/5	
	M ₂	4	5	5	5	4/5	5	5	
	M ₃	3/4	5	5	5	4/5	5	5	
	M ₄	4/5	5	5	5	4/5	5	5	
	M ₅	4	5	4/5	5	4/5	5	5	
<i>Juglans regia</i> L. (fruit hull)	M ₁	3	5	5	4/5	4/5	5	5	
	M ₂	4	5	5	5	4/5	5	5	
	M ₃	3/4	5	5	5	4/5	5	5	
	M ₄	4	5	5	4/5	4/5	5	5	
	M ₅	3/4	5	5	5	5	5	5	
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3/4	5	4/5	4/5	4/5	5	4/5	
	M ₂	3	5	4/5	4/5	4/5	5	4/5	
	M ₃	3	5	4/5	4/5	4/5	5	4/5	
	M ₄	3	5	4/5	5	4/5	5	5	
	M ₅	4/5	5	4/5	5	4/5	5	5	
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	5	5	4	5	4/5	5	5	
	M ₂	4/5	5	4/5	4/5	4/5	5	5	
	M ₃	4	5	4/5	5	5	5	5	
	M ₄	4/5	5	4/5	4/5	5	5	5	
	M ₅	4/5	5	5	4/5	4/5	5	5	
<i>Tagetes patula</i> L. (petals)	M ₁	3	5	5	5	5	5	5	
	M ₂	4	5	5	5	5	5	5	
	M ₃	4	5	4/5	5	5	5	5	
	M ₄	4/5	5	5	4/5	4	5	5	
	M ₅	4/5	5	5	4	4	4/5	5	

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash), M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).
CC: Colour change, CS : Colour staining.

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

recorded due to *Juglans regia* (fruit hull) dye without mordanting, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordanting respectively. The washing fastness for colour staining recorded Excellent (5) grade due to all dye and mordant combinations except without mordant *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dyed samples which recorded Good to Excellent (4/5) colour staining grade (Table-45).

4.7.1.2 Light fastness

Excellent (5) grade for colour change in light fastness was recorded due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with all the mordants, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant, *Tagetes patula* (petals) dye with all the mordants except with *Salix alba* (wood ash) mordant. Good to Excellent (4/5) grade for colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively, *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with all the mordants, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) mordant respectively and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant respectively. The lowest grade (4) Good for colour change was recorded due to *Quercus robura* (fruit cups) dye and *Nasturtium officinale* (leaves) dye without mordant and with *Punica granatum* (peel) mordant respectively (Table-45).

4.7.1.3 Rubbing fastness

Rubbing fastness for dry staining recorded Excellent (5) due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye with all the mordants except in

without mordanting, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant, with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye without mordant, with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) without mordant, with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant respectively. Good (4) grade was recorded due to *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant.

Wet staining recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with all the mordants except without mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) grade for wet staining were recorded due to *Prunus cerasifera* (leaves) dye without mordant and with all the mordants, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye without mordant and with all mordant combinations and *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Good

(4) grade for wet staining were recorded due to *Juglans regia* (leaves) dye without mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively.

Dry fading recorded Excellent (5) grade with all the dye and mordant combinations except due to *Quercus robura* (fruit cups) and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant combination. Excellent grade (5) for wet fading was recorded due to all dye and mordant combinations except due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) mordant, *Juglans regia* (leaves) dye without mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively (Table-45).

4.7.2 Colour fastness properties of wool fabric adopting simultaneous mordanting method

4.7.2.1 Washing fastness

Washing fastness of dyed wool fabric recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Nasturtium officinale* (leaves) dye without mordanting and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant respectively. Good (4) grade for colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with

Table-46 : Colour fastness properties of wool fabric dyed with different natural dyes and mordants by simultaneous mordanting method

Dye source	Mordants	Washing		Light	Rubbing Fastness			
		Fastness	Fastness		Staining		Fading	
					CC	CS	Dry	Wet
<i>Quercus robura</i> L. (fruit cups)	M ₁	4	4/5	4/5	4/5	4/5	5	4/5
	M ₂	5	5	5	4/5	4	5	4/5
	M ₃	4	5	4/5	5	4/5	5	4/5
	M ₄	3	5	5	5	5	5	5
	M ₅	4/5	5	4/5	5	5	4/5	4
<i>Juglans regia</i> L. (leaves)	M ₁	4	4/5	5	4/5	4	5	4/5
	M ₂	4	5	5	5	5	5	5
	M ₃	4/5	5	5	5	4/5	5	5
	M ₄	3/4	5	5	5	4/5	5	5
	M ₅	4/5	5	4/5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3	5	5	4/5	4/5	5	5
	M ₂	3/4	5	5	5	5	5	5
	M ₃	3/4	5	5	4/5	4/5	5	5
	M ₄	4	5	5	4/5	4/5	5	5
	M ₅	4	5	5	4/5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3/4	5	4/5	4/5	4/5	5	4/5
	M ₂	3/4	5	4/5	5	4/5	5	5
	M ₃	3	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	5	5	5	4/5
	M ₅	4/5	5	4/5	5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	5	5	4	5	4/5	5	5
	M ₂	4/5	5	4/5	5	5	5	5
	M ₃	4	5	4/5	5	5	5	5
	M ₄	4/5	5	4/5	4/5	4/5	5	5
	M ₅	4	5	5	4/5	4/5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	3	5	5	5	5	5	5
	M ₂	4	5	4	5	4/5	5	4/5
	M ₃	4	5	5	5	5	5	4/5
	M ₄	4/5	5	3	5	5	5	5
	M ₅	5	5	4/5	5	5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃ : *Salix alba* L. (wood ash), M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).
CC: Colour change, CS: Colour staining.

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

Salix alba (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Fair to good (3/4) colour change grade recorded due to *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye without and with *Salix alba* (wood extract) mordant. Lowest grade Fair (3) for colour change was recorded due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash), *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Tagetes patula* (petals) dye without mordanting respectively. Washing fastness for colour staining recorded Excellent (5) grade with all dye and mordant combinations except *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye without mordant samples recorded Good to Excellent (4/5) colour staining grade (Table-46).

4.7.2.2 Light fastness

Light fastness of dyed wool fabric for colour change recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with all mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves)

dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye recorded with *Punica granatum* (peel) mordant respectively. Good (4) grade for colour change was recorded due to without mordant *Nasturtium officinale* (leaves) dye and *Tagetes patula* (petals) dye with *Salix alba* (wood extract). Lowest grade Fair (3) of light fastness for colour change was recorded due to *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant respectively (Table-46).

4.7.2.3 Rubbing fastness

Dry staining rubbing fastness of dyed samples recorded Excellent (5) grade due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (Peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) whereas *Tagetes patula* (petals) dye recorded Excellent (5) grade with all the mordants. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) without mordant and with *Salix alba* (wood extract), *Juglans regia* (leaves) without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) without mordant and with *Salix alba* (wood ash) mordant and *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively.

Excellent (5) grade of dyed fabrics for wet staining was recorded due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye and *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with

Salix alba (wood extract) and *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade for wet staining were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash), *Juglans regia* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash), *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively. Lowest grade of wet staining Good (4) was recorded due to *Quercus robura* (fruit cups) dye and *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant respectively.

Dry fading recorded Excellent (5) grade with all the dye and mordant combinations except due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, recorded Good to Excellent (4/5) grade. Wet fading recorded Excellent grade (5) due to *Quercus robura* (fruit cups) dye and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (Peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with all mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with all mordants and *Tagetes patula* (petals) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash), *Juglans regia* (leaves) dye without mordant,

Prunus cerasifera (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Lowest dry fading grade Good (4) was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant (Table-46).

4.7.3 Colour fastness properties of wool fabric adopting post mordanting method

4.7.3.1 Washing fastness

Excellent (5) grade of colour change adopting post mordanting method was recorded due to *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Colour change grade Good to Excellent (4/5) were recorded due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye with *Salix alba* (wood extract) mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Good (4) grade of colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Prunus cerasifera* (leaves) dye without mordant. The lowest recorded grade Fair (3) of colour change was due to *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) mordant, *Prunus cerasifera*

Table-47 : Colour fastness properties of wool fabric dyed with different natural dyes and mordants by post mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
					Staining		Fading	
		CC	CS		CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4	4/5	4/5	4/5	4/5	5	4/5
	M ₂	4/5	4/5	4/5	5	4/5	5	5
	M ₃	4	5	4/5	5	5	5	5
	M ₄	4	5	4/5	5	5	5	5
	M ₅	4	5	5	4/5	4	5	5
<i>Juglans regia</i> L. (leaves)	M ₁	4	4/5	5	4/5	4	5	4/5
	M ₂	4/5	5	5	5	4/5	5	5
	M ₃	4	5	5	4/5	4/5	5	5
	M ₄	4	5	5	5	5	5	5
	M ₅	4	5	5	5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3	5	5	4/5	4/5	5	5
	M ₂	3	5	4/5	5	4/5	5	5
	M ₃	4	5	5	5	4/5	5	5
	M ₄	5	5	5	5	5	5	5
	M ₅	4/5	5	5	5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3/4	5	4/5	4/5	4/5	5	4/5
	M ₂	3	5	4/5	5	5	5	4/5
	M ₃	5	5	5	5	5	5	5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	4/5	5	4/5	5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	5	5	4	5	4/5	5	5
	M ₂	4/5	5	4/5	5	5	5	5
	M ₃	5	5	4/5	5	5	5	5
	M ₄	5	5	5	5	5	5	5
	M ₅	4/5	5	5	5	5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	3	5	5	5	5	5	5
	M ₂	4/5	5	5	5	5	5	5
	M ₃	5	5	5	5	5	5	5
	M ₄	4/5	5	4/5	5	5	5	5
	M ₅	5	5	4/5	5	5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining.

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

(leaves) dye with *Salix alba* (wood extract) and *Tagetes patula* (petals) dye without mordant respectively.

Colour staining by washing recorded Excellent (5) grade due to all dye and mordant combinations except in *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) mordant and *Juglans regia* (leaves) dye without mordanting recorded Good to Excellent (4/5) colour staining grade (Table-47).

4.7.3.2 Light fastness

Light fastness recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with all mordant combinations, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) colour change grade recorded lowest in light fastness due to without mordant *Nasturtium officinale* (leaves) dye (Table-47).

4.7.3.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) and *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye recorded Excellent (5) grade with all mordant combinations. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Juglans regia* (fruit hull) and *Prunus cerasifera* (leaves) dye without mordant respectively.

Wet rubbing recorded Excellent (5) staining grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) and *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye recorded Excellent grade (5) with all the mordant combinations. Good to Excellent (4/5) grade for wet staining were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) dye

without mordant. Wet staining recorded lowest Good (4) grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant and *Juglans regia* (leaves) dye without mordant respectively.

Dry fading recorded Excellent (5) grade with all dye and mordant combinations. Wet fading recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with all mordants, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with all mordant combinations. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups), *Juglans regia* (leaves) without mordant and *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant respectively (Table-47).

4.7.4 Colour fastness properties of cotton fabric adopting pre mordanting method

4.7.4.1 Washing fastness

Excellent (5) grade for colour change was recorded due to *Quercus robura* (fruit cups) dye, *Juglans regia* (fruit hull) dye, *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant respectively. Colour change grade Good (4) was

Table-48 : Colour fastness properties of cotton fabric dyed with different natural dyes and mordants by pre mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
					Staining		Fading	
		CC	CS		CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	4/5	4	5	5	5	4/5
	M ₂	4/5	5	4	5	5	5	4/5
	M ₃	4/5	5	4/5	5	5	5	5
	M ₄	3/4	5	4/5	5	5	5	5
	M ₅	5	5	4	5	4/5	5	4/5
<i>Juglans regia</i> L. (leaves)	M ₁	4/5	5	5	5	4/5	5	4/5
	M ₂	4	5	4/5	5	5	5	5
	M ₃	3/4	5	4/5	5	5	5	5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	4/5	5	4	5	5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	4	5	5	5	5	5	5
	M ₂	4/5	5	5	5	4/5	5	5
	M ₃	4	5	5	5	5	5	5
	M ₄	4	5	5	5	5	5	5
	M ₅	5	5	5	5	5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	5
	M ₂	3	5	5	5	5	5	5
	M ₃	4	5	5	5	5	5	4/5
	M ₄	3	5	5	5	4/5	5	5
	M ₅	4/5	5	5	5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4	5	5	5	4/5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	4	5	5	5	5	5	4/5
	M ₄	3/4	5	5	5	5	5	4/5
	M ₅	5	5	5	4/5	4/5	5	4/5
<i>Tagetes patula</i> L. (petals)	M ₁	4/5	5	5	5	5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	4	5	5	5	4/5	5	5
	M ₄	4	5	5	5	4/5	5	5
	M ₅	5	5	5	5	4/5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

recorded due to *Juglans regia* (leaves) dye with *Salix alba* (wood extract) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash), *Nasturtium officinale* (leaves) without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant and *Nasturtium officinale* (leaves) with *Populus deltoides* (wood ash) mordant respectively. The lowest grade Fair (3) recorded for colour change due to *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively.

Colour staining in washing fastness recorded Excellent (5) grade due to all dye and mordant combinations except due to *Quercus robura* (fruit cups) dye without mordant which recorded Good to Excellent (4/5) grade (Table-48).

4.7.4.2 Light fastness

Light fastness recorded Excellent (5) grade due to *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with all mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively and *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with all mordant combination. Good to Excellent (4/5) grade of colour change was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant and *Prunus cerasifera* (leaves) dye without mordant respectively (Table-48).

4.7.4.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) grade due to all dye and mordant combinations except due to *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant, recorded Good to Excellent (4/5) grade. Excellent (5) grade of wet staining was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract). Lowest grade Good to Excellent (4/5) of wet staining were recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively.

Dry fading rubbing fastness recorded Excellent (5) grade with all the dye and mordant combinations. Wet fading rubbing fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye recorded Excellent (5)

grade with all mordant combinations, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant and *Tagetes patula* (petals) dye with all dye and mordant combinations respectively. Lowest grade Good to Excellent (4/5) for wet fading was recorded due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively (Table-48).

4.7.5 Colour fastness properties of cotton fabric adopting simultaneous mordanting method

4.7.5.1 Washing fastness

Washing fastness colour change recorded Excellent (5) grade due to *Quercus robura* dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Good (4) colour change grade was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba*

Table-49 : Colour fastness properties of cotton fabric dyed with different natural dyes and mordants by simultaneous mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
					Staining		Fading	
		CC	CS		CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	4/5	4	4/5	4/5	5	4/5
	M ₂	4/5	5	4/5	5	5	5	4/5
	M ₃	4	5	4	5	5	5	4/5
	M ₄	4	5	4	5	5	5	5
	M ₅	5	5	5	5	4/5	5	5
<i>Juglans regia</i> L. (leaves)	M ₁	4/5	5	5	5	4/5	5	4/5
	M ₂	5	5	4/5	5	5	5	5
	M ₃	3	5	4/5	5	4/5	5	5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	5	5	5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	4	5	5	5	5	5	5
	M ₂	3/4	5	5	5	5	5	5
	M ₃	4	5	5	5	5	5	5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	5	5	5	4/5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	5
	M ₂	3	5	5	5	5	5	5
	M ₃	3	5	5	5	4/5	5	5
	M ₄	4	5	5	5	5	5	5
	M ₅	4/5	5	5	5	4/5	5	4/5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4	5	5	5	4/5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	3/4	5	5	5	5	5	5
	M ₄	4	5	5	5	4/5	5	5
	M ₅	5	5	5	4/5	4	5	4/5
<i>Tagetes patula</i> L. (petals)	M ₁	4/5	5	5	5	5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	4/5	5	5	4/5	4/5	4/5	4/5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	5	5	5	5	4/5	5	4/5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),
M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).
CC: Colour change, CS: Colour staining.

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

(wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (fruit hull) dye and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant respectively. Lowest grade Fair (3) for colour change was recorded due to *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant and *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively.

Colour staining in washing fastness recorded Excellent (5) grade due to all dye and mordant combinations except due to *Quercus robura* (fruit cups) dye without mordant which recorded Good to Excellent (4/5) colour staining grade (Table-49).

4.7.5.2 Light fastness

Light fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with all the mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, whereas *Nasturtium officinale* (leaves) dye and *Tagetes patula* (petals) dye recorded Excellent (5) colour change grade with all the mordant combinations. Colour change grade Good to Excellent (4/5) of light fastness for colour change was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant and *Prunus cerasifera* (leaves) dye without mordant respectively. Lowest grade Good (4) of colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix*

alba (wood ash) and *Populus deltoides* (wood ash) mordant respectively (Table-49).

4.7.5.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with all the mordants, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with all mordant combinations respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and *Juglans regia* (leaves), *Juglans regia* (fruit hull) and *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant respectively.

Wet staining recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) mordant respectively. Good to Excellent (4/5) grade of wet staining were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without

mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively.

Fading due to dry rubbing recorded Excellent (5) grade without mordant and with all the dye and mordant combinations.

Wet fading recorded Excellent grade (5) due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with all dye and mordant combinations, *Prunus cerasifera* (leaves) and *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Good to Excellent (4/5) grade of wet fading were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant, *Prunus cerasifera* (leaves) dye and *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively (Table-49).

4.7.6 Colour fastness properties of cotton fabric adopting post mordanting method

4.7.6.1 Washing fastness

Colour change grade of dyed cotton fabric adopting post mordanting method recorded Excellent (5) due to *Juglans regia* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) mordant respectively.

Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Populus deltoides* (wood ash) mordant respectively. Good (4) grade for colour change was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant respectively. The lowest grade of colour change recorded Fair (3) due to *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant respectively.

Colour staining in washing recorded Excellent (5) grade due to all dye and mordant combinations except in *Quercus robura* (fruit cups) dye without mordant, recorded Good to Excellent (4/5) colour staining grade (Table-50).

4.7.6.2 Light fastness

Light fastness of dyed cotton fabrics adopting post mordanting recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with all mordant combinations, *Prunus cerasifera* (leaves)

Table-50 : Colour fastness properties of cotton fabric dyed with different natural dyes and mordants by post mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
					Staining		Fading	
		CC	CS		CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	4/5	4	5	5	5	4/5
	M ₂	4	5	4/5	5	5	5	4/5
	M ₃	4	5	4/5	5	5	5	5
	M ₄	4/5	5	4	5	5	5	5
	M ₅	4	5	5	4	4	5	4/5
<i>Juglans regia</i> L. (leaves)	M ₁	4/5	5	5	5	4/5	5	4/5
	M ₂	4/5	5	4	5	5	5	5
	M ₃	4/5	5	4/5	5	5	5	4/5
	M ₄	5	5	5	5	5	5	5
	M ₅	4/5	5	5	5	5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	4	5	5	5	5	5	5
	M ₂	3/4	5	5	5	5	5	5
	M ₃	4/5	5	5	5	5	5	5
	M ₄	5	5	5	5	5	5	5
	M ₅	5	5	5	5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	5
	M ₂	3	5	4/5	5	5	5	5
	M ₃	4	5	5	4/5	5	5	5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	4/5	5	5	5	5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4	5	5	5	4/5	5	5
	M ₂	4	5	4/5	4/5	5	5	5
	M ₃	4	5	5	5	5	5	4/5
	M ₄	5	5	5	5	5	5	5
	M ₅	4/5	5	5	5	5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	4/5	5	5	5	5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	3/4	5	5	5	4/5	5	4/5
	M ₄	4/5	5	5	5	5	5	5
	M ₅	4	5	5	5	4/5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye recorded Excellent (5) colour change grade with all mordant combinations. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) mordant respectively. Lowest grade of colour change in light fastness recorded Good (4) due to without mordant *Quercus robura* (fruit cups) dye and with *Populus deltoides* (wood ash) and *Juglans regia* (leaves) dye with *Salix alba* (wood extract) mordant respectively (Table-50).

4.7.6.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) grade due to majority of dye and mordant combinations except due to *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) mordant and *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant recorded Good to Excellent (4/5) dry staining grade.

Wet staining recorded Excellent (5) staining grade due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and

Populus deltoides (wood ash) mordant respectively. Good to Excellent (4/5) wet staining grade was recorded due to *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye and *Nasturtium officinale* (leaves) dye without mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Wet staining recorded lowest Good (4) grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant respectively.

Dry fading recorded Excellent (5) grade with all the dye and mordant combinations. Wet fading recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye and *Prunus cerasifera* (leaves) dye with all mordant combinations, *Nasturtium officinale* (leaves) dye and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Lowest grade Good to Excellent (4/5) of wet fading grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant respectively (Table-50).

4.7.7 Colour fastness properties of silk fabric adopting pre mordanting method

4.7.7.1 Washing fastness

Colour change grade of washing fastness recorded Excellent (5) due to *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant. Good to Excellent (4/5) grade was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash)

mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good (4) grade of colour change was recorded due to *Quercus robura* (fruit cups) dye and *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Quercus robura* (fruit cups) and *Juglans regia* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively. Lowest grade Fair (3) of colour change was recorded due to *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant respectively.

Washing fastness for colour staining recorded Excellent (5) grade due to all dye and mordant combinations except without mordant *Quercus robura* (fruit cups) dye and *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant and *Prunus cerasifera* (leaves) dye with *Punica granatum* (peel) mordant recorded Good to Excellent (4/5) for colour staining grade (Table-51).

4.7.7.2 Light fastness

Light fastness of silk fabric recorded Excellent (5) grade of colour change due to *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood

Table-51 : Colour fastness properties of silk fabric dyed with different natural dyes and mordants by pre mordanting method

Dye source	Mordants	Washing		Light	Rubbing Fastness				
		Fastness			Fastness	Staining		Fading	
		CC	CS			CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	4/5	4/5	5	5	5	5	
	M ₂	4/5	5	4/5	5	4/5	5	5	
	M ₃	4/5	5	4/5	5	5	5	4/5	
	M ₄	3/4	5	4/5	5	5	5	5	
	M ₅	4	5	4	5	5	4/5	4/5	
<i>Juglans regia</i> L. (leaves)	M ₁	4/5	5	5	5	5	5	5	
	M ₂	4/5	5	5	5	4/5	5	4/5	
	M ₃	4/5	4/5	5	5	5	5	4/5	
	M ₄	4/5	5	5	5	4/5	5	4/5	
	M ₅	4	5	4/5	5	4/5	5	5	
<i>Juglans regia</i> L. (fruit hull)	M ₁	3	5	5	4/5	4/5	5	5	
	M ₂	4	5	5	5	4/5	5	5	
	M ₃	3/4	5	5	5	5	5	5	
	M ₄	4	5	5	4/5	5	5	4/5	
	M ₅	5	5	5	5	5	5	4/5	
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	4/5	
	M ₂	3	5	4/5	5	4/5	5	4/5	
	M ₃	4	5	4/5	5	4/5	5	4/5	
	M ₄	3	5	5	5	4/5	5	5	
	M ₅	4/5	4/5	5	5	4/5	5	4/5	
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4/5	5	4	5	4/5	5	4/5	
	M ₂	4	5	5	5	4/5	5	4/5	
	M ₃	4/5	5	4/5	5	4/5	5	4/5	
	M ₄	4	5	4/5	5	4/5	5	4/5	
	M ₅	4/5	5	5	5	4/5	5	4/5	
<i>Tagetes patula</i> L. (petals)	M ₁	3	5	5	5	4/5	5	4/5	
	M ₂	3/4	5	5	5	4/5	5	5	
	M ₃	4	5	5	4/5	4/5	4/5	4/5	
	M ₄	4	5	5	5	4/5	5	5	
	M ₅	4/5	5	5	5	4/5	5	4/5	

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with all the mordant combinations, *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with all the mordant combinations. Good to Excellent (4/5) light fastness grade of colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Lowest grade Good (4) of colour change was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) dye without mordant respectively (Table-51).

4.7.7.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) due to all dye and mordant combinations except due to *Juglans regia* (fruit hull) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant recorded Good to Excellent (4/5) grade of dry staining.

Wet staining recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Prunus cerasifera* (leaves) dye without mordant respectively. Good to Excellent (4/5) wet staining grade was recorded due to *Quercus robura* (fruit cups) dye and *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves), *Nasturtium officinale* (leaves)

and *Tagetes patula* (petals) dye recorded Good to Excellent (4/5) wet staining grade without mordant and with all the dye and mordant combinations respectively.

Dry fading recorded Excellent (5) grade without mordant and with all the dye and mordant combinations except due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant recorded Good to Excellent (4/5) grade dry fading grade.

Wet fading recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Lowest grade of wet fading Good to Excellent (4/5) grade was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with all mordant combinations, and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively (Table-51).

4.7.8 Colour fastness properties of silk fabric adopting simultaneous mordanting method

4.7.8.1 Washing fastness

Washing fastness of silk fabric adopting simultaneous mordanting method recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with

Populus deltoides (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) respectively. Colour change grade, Good to Excellent (4/5) were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good (4) colour change grade was recorded due to *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (fruit hull) dye and *Tagetes patula* (petals) dye without mordant respectively. Lowest Fair (3) grade was recorded due to *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant and *Prunus cerasifera* (leaves) dye without mordant respectively.

Colour staining due to washing recorded Excellent (5) grade due to all dye and mordant combinations including without mordanted samples (Table-52).

4.7.8.2 Light fastness

Light fastness recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia*

Table-52 : Colour fastness properties of silk fabric dyed with different natural dyes and mordants by simultaneous mordanting method

Dye source	Mordants	Washing		Light	Rubbing Fastness			
		Fastness			Fastness	Staining		Fading
		CC	CS			Dry	Wet	
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	5	4/5	5	5	5	5
	M ₂	4/5	5	4/5	5	5	5	4/5
	M ₃	5	5	4/5	5	5	5	4/5
	M ₄	4/5	5	4	5	5	5	5
	M ₅	4/5	5	5	5	4/5	5	4/5
<i>Juglans regia</i> L. (leaves)	M ₁	4	5	5	5	5	5	5
	M ₂	4	5	5	5	5	5	5
	M ₃	4/5	5	5	5	4/5	5	4/5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	4	5	5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3/4	5	5	4/5	4/5	5	5
	M ₂	3	5	5	5	5	5	5
	M ₃	4	5	5	5	4/5	5	5
	M ₄	5	5	5	4/5	4/5	5	4/5
	M ₅	4/5	5	5	5	4/5	5	4/5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	4/5
	M ₂	4/5	5	5	5	4/5	5	4/5
	M ₃	5	5	4/5	5	5	5	5
	M ₄	4/5	5	5	5	5	5	4/5
	M ₅	4/5	5	5	5	4/5	5	4/5
<i>Nasturtium officinale</i> R.Br (leaves)	M ₁	4/5	5	4	5	4/5	5	4/5
	M ₂	5	5	5	5	4/5	5	4/5
	M ₃	5	5	4/5	5	5	5	5
	M ₄	5	5	4/5	5	4/5	5	4/5
	M ₅	5	5	5	5	4/5	5	4/5
<i>Tagetes patula</i> L. (petals)	M ₁	3/4	5	5	5	4/5	5	4/5
	M ₂	4	5	4/5	5	4/5	5	5
	M ₃	5	5	5	5	4/5	5	4/5
	M ₄	5	5	4/5	5	4/5	5	4/5
	M ₅	4/5	5	5	5	4/5	5	5

M₁: Without mordant; **M₂**: *Salix alba* L. (wood extract), **M₃**: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), **M₅**: *Punica granatum* L. (peel).

CC: Colour change, **CS**: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

(leaves) dye and *Juglans regia* (fruit hull) dye without mordant and with all mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Good (4) light fastness colour change grade was recorded due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant and *Nasturtium officinale* (leaves) dye without mordant (Table-52).

4.7.8.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye without mordant and with all mordant combinations, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant and *Prunus cerasifera* (leaves), *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye without mordant and with all mordant combinations.

Wet rubbing recorded Excellent (5) grade of staining due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant,

Prunus cerasifera (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant respectively. Lowest grade, Good to Excellent (4/5) of wet staining were recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with all mordant combinations.

Dry fading recorded Excellent (5) grade of rubbing fastness due to all dyes without mordant and with all mordant combinations.

Wet fading recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade were recorded due to *Quercus robura* (fruit cups) with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye and *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without

mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively (Table-52).

4.7.9 Colour fastness properties of silk fabric adopting post mordanting method

4.7.9.1 Washing fastness

Washing fastness recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cup) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Good (4) washing fastness colour change grade was recorded due to *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant and *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant respectively. Lowest grade Fair (3) of colour change was recorded due to *Juglans regia* (fruit hull) dye, *Prunus cerasifera* (leaves) dye and *Tagetes patula* (petals) dye without mordant respectively.

Table-53 : Colour fastness properties of silk fabric dyed with different natural dyes and mordants by post mordanting method

Dye source	Mordants	Washing		Light	Rubbing Fastness				
		Fastness			Fastness	Staining		Fading	
		CC	CS			CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	5	4/5	5	5	5	5	
	M ₂	5	5	4/5	5	5	5	4/5	
	M ₃	5	5	4/5	5	5	5	5	
	M ₄	5	5	4/5	5	5	5	5	
	M ₅	4/5	5	5	5	5	5	5	
<i>Juglans regia</i> L. (leaves)	M ₁	4/5	5	5	5	5	5	5	
	M ₂	4/5	5	4	5	5	5	4/5	
	M ₃	3/4	5	5	4/5	4/5	5	5	
	M ₄	4/5	5	5	5	5	5	4/5	
	M ₅	4	5	5	5	4/5	5	5	
<i>Juglans regia</i> L. (fruit hull)	M ₁	3	5	5	4/5	4/5	5	5	
	M ₂	3/4	5	5	5	5	5	5	
	M ₃	4/5	5	5	5	5	5	5	
	M ₄	5	5	5	5	5	5	4/5	
	M ₅	4/5	5	5	5	4/5	5	4/5	
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	5	4/5	5	4/5	
	M ₂	4	5	4/5	5	5	5	4/5	
	M ₃	4	5	5	5	5	5	5	
	M ₄	4/5	5	5	5	5	5	4/5	
	M ₅	4/5	5	4/5	5	4/5	5	5	
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4/5	5	4	5	4/5	5	4/5	
	M ₂	4	5	4/5	5	5	5	4/5	
	M ₃	4	5	4/5	5	5	5	4/5	
	M ₄	4/5	5	5	5	5	5	5	
	M ₅	4	5	5	5	4/5	5	4/5	
<i>Tagetes patula</i> L. (petals)	M ₁	3	5	5	5	4/5	5	4/5	
	M ₂	4/5	5	5	5	5	5	4/5	
	M ₃	5	5	5	5	5	5	4/5	
	M ₄	5	5	5	5	5	5	4/5	
	M ₅	4/5	5	5	5	4	5	5	

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

Colour staining for washing fastness recorded Excellent (5) grade due to all dyes without mordant and with all mordant combinations (Table-53).

4.7.9.2 Light fastness

Excellent (5) grade for Light fastness colour change was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with all the mordant combinations, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye recorded Excellent (5) colour change grade without mordant and with all the mordant combinations. Good to Excellent (4/5) colour change grade for light fastness was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Lowest grade recorded Good (4) due to *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Nasturtium officinale* (leaves) dye without mordant respectively (Table-53).

4.7.9.3 Rubbing fastness

Dry staining recorded Excellent (5) grade due to without mordant *Quercus robura* (fruit cups) dye and with all mordant combinations, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye, *Nasturtium*

officinale (leaves) dye and *Tagetes patula* (petals) dye without mordant and with all mordant combinations respectively. Good to Excellent (4/5) grade were recorded due to *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant and *Juglans regia* (fruit hull) dye without mordant respectively.

Wet staining recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye without mordant and with all mordant combinations, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash), *Juglans regia* (fruit hull), *Prunus cerasifera* (leaves), *Nasturtium officinale* (leaves) and *Tagetes patula* (petals) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade for wet staining were recorded due to *Juglans regia* (leaves) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull), *Prunus cerasifera* (leaves) and *Nasturtium officinale* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant respectively. Lowest grade for wet staining recorded Good (4) due to *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively.

Dry fading recorded Excellent (5) grade in all dyes without mordant and with all mordant combinations respectively.

Wet fading recorded Excellent grade (5) due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade of wet fading was recorded due to *Quercus robura* (fruit

cups) dye with *Salix alba* (wood extract), *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively (Table-53).

4.7.10 Colour fastness properties of pashmina fabric adopting pre mordanting method

4.7.10.1 Washing fastness

Washing fastness of pashmina fabric recorded Excellent (5) colour change grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) colour change grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good (4) grade colour change was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (leaves) dye with *Salix alba*

Table-54 : Colour fastness properties of pashmina fabric dyed with different natural dyes and mordants by pre mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
		CC	CS		Staining		Fading	
				CC	Dry	Wet	Dry	Wet
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	5	4/5	4/5	4	5	5
	M ₂	5	5	4/5	5	4/5	5	4/5
	M ₃	5	5	4/5	4/5	4	5	5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	4	5	4	4/5	4/5	5	5
<i>Juglans regia</i> L. (leaves)	M ₁	4	5	4/5	4/5	4	5	5
	M ₂	3/4	5	5	5	4/5	5	5
	M ₃	3/4	5	5	5	5	5	5
	M ₄	4/5	5	5	4/5	4	5	5
	M ₅	4/5	5	4/5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3/4	5	4/5	4/5	4/5	5	5
	M ₂	4	5	5	5	4/5	5	5
	M ₃	4	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	4	4	5	5
	M ₅	4	5	5	4/5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	4/5	4/5	5	5
	M ₂	4	5	4	4/5	4/5	5	4/5
	M ₃	4	5	4/5	4/5	4/5	5	5
	M ₄	3/4	5	4/5	4/5	4/5	5	5
	M ₅	4/5	5	5	4/5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4/5	5	4	5	4/5	5	5
	M ₂	4/5	5	4/5	4/5	4/5	5	5
	M ₃	4	5	4/5	5	5	5	5
	M ₄	5	5	4/5	5	5	5	5
	M ₅	5	5	5	5	5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	3/4	5	5	4/5	5	5	5
	M ₂	3/4	5	5	5	5	5	5
	M ₃	4	5	4/5	4/5	4/5	5	5
	M ₄	4	5	5	5	4/5	5	5
	M ₅	4/5	5	5	4/5	4/5	5	5

M₁: Without mordant; **M₂**: *Salix alba* L. (wood extract), **M₃**: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), **M₅**: *Punica granatum* L. (peel).

CC: Colour change, **CS**: Colour staining

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Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

(wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) mordant respectively. The lowest grade Fair (3) of colour change was recorded due to *Prunus cerasifera* (leaves) dye without mordant respectively.

Colour staining for washing fastness recorded Excellent (5) grade without mordant and due to all dye and mordant combinations (Table-54).

4.7.10.2 Light fastness

Light fastness colour change recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye and *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade of colour change was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant respectively. Lowest grade Good (4) was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) mordant and *Nasturtium officinale* (leaves) dye without mordant respectively (Table-54).

4.7.10.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively. Good to Excellent (4/5) grade was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with all mordant combinations, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively. Lowest grade Good (4) was recorded due to *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant respectively.

Wet staining recorded Excellent (5) grade due to *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) respectively. Good to Excellent (4/5) grade for wet staining were recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel)

mordant, *Prunus cerasifera* (leaves) dye without mordant and with all mordant combinations, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Lowest grade Good (4) for wet staining was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant and with *Populus deltoides* (wood ash) mordant and *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant respectively.

Dry fading rubbing fastness recorded Excellent (5) grade for all dyes without mordant and with all mordant combinations. Wet fading rubbing fastness recorded Excellent (5) due to all without mordant dyes and with all mordant combinations, except due to *Quercus robura* (fruit cups) and *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) mordant respectively recorded Good to Excellent (4/5) grade for wet fading respectively (Table-54).

4.7.11 Colour fastness properties of pashmina fabric adopting simultaneous mordanting method

4.7.11.1 Washing fastness

Washing fastness recorded Excellent (5) colour change grade due to *Quercus robura* dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant and *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade was recorded due to *Quercus robura* dye without mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye without mordant and with

Populus deltoides (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) grade of colour change was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye without mordant, *Juglans regia* (fruit hull) dye and *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract) and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Fair to good (3/4) colour change grade for washing fastness were recorded due to *Juglans regia* (fruit hull) dye and *Tagetes patula* (petals) dye without mordant respectively. Lowest grade Fair (3) was recorded due to *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant respectively.

Colour staining by washing fastness recorded Excellent (5) grade due to all dyes without mordant and with all mordant combinations except due to *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively, recorded Good to Excellent (4/5) colour staining grade (Table-55).

4.7.11.2 Light fastness

Light fastness of pashmina fabric recorded Excellent (5) colour change grade due to *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood ash) mordant respectively. Good to Excellent (4/5) light fastness grade were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Juglans*

Table-55 : Colour fastness properties of pashmina fabric dyed with different natural dyes and mordants by simultaneous mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
					Staining		Fading	
		CC	CS		CC	Dry	Wet	Dry
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	5	4/5	4/5	4	5	5
	M ₂	5	5	4/5	5	4/5	5	5
	M ₃	4	5	4	5	5	5	4/5
	M ₄	4	5	4	5	4/5	4/5	4
	M ₅	5	5	4/5	4/5	4/5	5	5
<i>Juglans regia</i> L. (leaves)	M ₁	4	5	4/5	4	4	5	5
	M ₂	4/5	4/5	5	5	5	5	5
	M ₃	4/5	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	4/5	4	5	5
	M ₅	5	4/5	4/5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3/4	5	4/5	4/5	4/5	5	5
	M ₂	4	5	5	4/5	4/5	5	5
	M ₃	4/5	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	4/5	4	5	5
	M ₅	4/5	5	5	4/5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	4/5	4/5	5	5
	M ₂	4	5	5	4/5	4/5	5	5
	M ₃	3	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	4/5	5	4/5	4/5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4/5	5	4	5	4/5	5	5
	M ₂	5	5	4/5	5	4/5	5	5
	M ₃	4/5	5	4	4/5	4/5	5	5
	M ₄	4/5	5	4/5	5	5	5	5
	M ₅	5	5	5	5	4/5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	3/4	5	5	4/5	5	5	5
	M ₂	4	5	4/5	4/5	4/5	4/5	4/5
	M ₃	4	5	5	4/5	4/5	5	5
	M ₄	4/5	5	4	4/5	4/5	5	5
	M ₅	4/5	5	4/5	5	4/5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

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Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

regia (leaves) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract) and with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant respectively. Grade Good (4) was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant respectively (Table-55).

4.7.11.3 Rubbing fastness

Rubbing fastness recorded Excellent (5) dry staining grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade for dry staining was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with all mordant combinations, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively.

Wet staining rubbing fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash), *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye without mordant respectively. Good to Excellent (4/5) wet staining grade was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with all mordant combinations, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) grade was recorded due to *Quercus robura* (fruit cups) dye without mordant, *Juglans regia* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant respectively.

Dry fading recorded Excellent (5) grade due to all dyes without mordant and with all mordant combinations except due to *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively recorded Good to Excellent (4/5) dry fading grade.

Wet fading recorded Excellent grade (5) due to all dyes without mordant and with all mordant combinations except due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) mordant respectively recorded Good to Excellent (4/5) wet fading grade (Table-55).

4.7.12 Colour fastness properties of pashmina fabric adopting post mordanting method

4.7.12.1 Washing fastness

In pashmina fabric post mordanting method recorded Excellent (5) grade due to *Juglans regia* (fruit hull) dye with *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Good to Excellent (4/5) grade was recorded due to *Quercus robura* (fruit cups) dye without mordant and with all mordant combinations, *Juglans regia* (leaves) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant. Good (4) colour change grade was recorded due to *Juglans regia* (leaves) dye without mordant and with *Salix alba* (wood extract), *Juglans regia* (fruit hull) dye with *Salix alba* (wood ash) and *Tagetes patula* (petals) dye with *Salix alba* (wood extract). Fair to good (3/4) colour change grade was recorded due to *Juglans regia* (fruit hull) dye and *Tagetes patula* (petals) dye without mordant respectively. Lowest grade Fair (3) of colour change was recorded due to *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant and *Prunus cerasifera* (leaves) dye without mordant respectively.

Washing fastness for colour staining recorded Excellent (5) grade due to all dyes without mordant and with all mordant combinations (Table-56).

4.7.12.2 Light fastness

Light fastness of pashmina fabric adopting post mordanting method recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant, *Juglans regia* (leaves) and *Juglans regia* (fruit hull) dye

Table-56 : Colour fastness properties of pashmina fabric dyed with different natural dyes and mordants by post mordanting method

Dye source	Mordants	Washing Fastness		Light Fastness	Rubbing Fastness			
		CC	CS		Staining		Fading	
				CC	Dry	Wet	Dry	Wet
<i>Quercus robura</i> L. (fruit cups)	M ₁	4/5	5	4/5	4/5	4	5	5
	M ₂	4/5	5	4/5	4/5	4/5	5	5
	M ₃	4/5	5	4/5	5	5	5	5
	M ₄	4/5	5	4/5	5	4/5	5	5
	M ₅	4/5	5	5	4	4/5	5	5
<i>Juglans regia</i> L. (leaves)	M ₁	4	5	4/5	4/5	4	5	5
	M ₂	4	5	5	5	4/5	5	5
	M ₃	4/5	5	5	4	4/5	5	5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	4/5	5	5	4/5	4/5	5	5
<i>Juglans regia</i> L. (fruit hull)	M ₁	3/4	5	4/5	4/5	4/5	5	5
	M ₂	3	5	5	4/5	4	5	5
	M ₃	4	5	5	4/5	4/5	5	5
	M ₄	5	5	5	4/5	4/5	5	5
	M ₅	4/5	5	5	4/5	4/5	5	5
<i>Prunus cerasifera</i> Ehrh. var. <i>atropurpurea</i> . (leaves)	M ₁	3	5	4/5	4/5	4/5	5	5
	M ₂	4/5	5	4/5	4/5	4/5	5	5
	M ₃	5	5	5	4/5	4/5	5	5
	M ₄	4/5	5	5	5	4/5	5	5
	M ₅	4/5	5	4/5	4/5	4/5	5	5
<i>Nasturtium officinale</i> R.Br. (leaves)	M ₁	4/5	5	4	5	4/5	5	5
	M ₂	5	5	4/5	5	5	5	5
	M ₃	5	5	4	5	5	5	4/5
	M ₄	5	5	4/5	5	5	5	5
	M ₅	5	5	4/5	4/5	4/5	5	5
<i>Tagetes patula</i> L. (petals)	M ₁	3/4	5	5	4/5	5	5	5
	M ₂	4	5	5	4/5	5	4/5	4/5
	M ₃	5	5	4/5	4/5	4/5	5	5
	M ₄	5	5	4/5	4/5	4/5	4/5	4/5
	M ₅	4/5	5	4/5	5	4/5	5	5

M₁: Without mordant; M₂: *Salix alba* L. (wood extract), M₃: *Salix alba* L. (wood ash),

M₄: *Populus deltoides* Bartram ex Marsh. (wood ash), M₅: *Punica granatum* L. (peel).

CC: Colour change, CS: Colour staining

Index	
Grade	Rating
5	Excellent
4	Good
3	Fair
2	Poor
1	Very poor

with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) mordant respectively. Good to Excellent (4/5) grade for light fastness colour change were recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye and *Juglans regia* (fruit hull) dye without mordant, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) grade of colour change recorded lowest due to *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood ash) mordant respectively (Table-56).

4.7.12.3 Rubbing fastness

Dry staining rubbing fastness recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) mordant and *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Punica granatum* (peel) mordant respectively. Good to Excellent (4/5) grade for dry staining was recorded due to *Quercus robura* (fruit cups) dye without mordant and with *Salix alba* (wood extract) mordant, *Juglans regia* (leaves) dye without mordant and with *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with all mordant combinations, *Prunus cerasifera* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Punica granatum* (peel) mordant, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye without mordant

and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant respectively. Lowest grade Good (4) was recorded due to *Quercus robura* (fruit cups) dye with *Punica granatum* (peel) mordant and *Juglans regia* (leaves) dye with *Salix alba* (wood ash) mordant respectively.

Wet staining recorded Excellent (5) grade due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood ash) mordant, *Nasturtium officinale* (leaves) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash) and *Populus deltoides* (wood ash) mordant, *Tagetes patula* (petals) dye without mordant and with *Salix alba* (wood extract) mordant respectively. Good to Excellent (4/5) wet staining grade was recorded due to *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (leaves) dye with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant, *Juglans regia* (fruit hull) dye without mordant and with *Salix alba* (wood ash), *Populus deltoides* (wood ash) mordant and *Punica granatum* (peel) mordant, *Prunus cerasifera* (leaves) dye without mordant and with all mordant combinations, *Nasturtium officinale* (leaves) dye without mordant and with *Punica granatum* (peel) mordant and *Tagetes patula* (petals) dye recorded Good to Excellent (4/5) wet staining grade with *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. Good (4) grade was recorded lowest due to *Quercus robura* (fruit cups) dye and *Juglans regia* (leaves) dye without mordant and *Juglans regia* (fruit hull) dye with *Salix alba* (wood extract) mordant respectively.

Dry fading recorded Excellent (5) grade with all dyes without mordant and with all the mordant combinations except due to *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant respectively, recorded Good to Excellent (4/5) dry fading grade.

Wet fading recorded Excellent grade (5) due to all dyes without mordant and with all mordant combinations except due to *Nasturtium officinale* (leaves) dye with *Salix alba* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Populus deltoides* (wood ash) mordant, recorded Good to Excellent (4/5) wet fading grade (Table-56).

Chapter – 5

DISCUSSION

The present investigation entitled “Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley” was carried out during 2012-13 at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar, Srinagar (J&K). The results obtained during the present investigation are discussed below:

5.1 Quantification and colour quality of pigments

The data presented in Table-7 revealed that photosynthetic pigments (anthocyanins, carotenoids and chlorophyll) in all the test species varied significantly. Anthocyanins are water-soluble vacuolar pigments of higher plants abundant in juvenile and senescing plants. Anthocyanins are glycosides of anthocyanidins (also called aglycones) and sugars and span quite a range of colour hues and give rise to the blue, purple, red, orange colour to flowers and fruits of many plants. The absorption spectra of Anthocyanins of plant tissues indicate a strong overlapping of anthocyanins, chlorophyll and carotenoids (Lee and Graham, 1986). Anthocyanin synthesis in vegetative organs is induced by different environmental factors (Chalker, 1999) and anthocyanins concentration increases during senescence (Chang *et al.*, 1989). In the present study total anthocyanin content ranged between 71.30 to 215.50 mg/100 g among all the selected plant species. Value of anthocyanin content during 2011 and 2012 recorded highest (215.50 mg/100 g) in *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) followed by *Juglans regia* L. (fruit hull) (179.70 mg/100 g), *Tagetes patula* L. (petals) (122.24 mg/100 g), *Juglans regia* L. (leaves) (121.11 mg/100 g), *Quercus robura* L. (fruit cups) (120.13 mg/100 g) and lowest value of anthocyanin content (71.30 mg/100 g) was recorded in *Nasturtium officinale* R.Br. (leaves) respectively.

Carotenoids are lipid soluble, yellow, orange and red pigments found in all higher plants. The distinctive yellow colour of light-harvesting carotenoids become more apparent in leaves during autumn when chlorophyll degrades revealing their strong colours. Carotenoids are required for the correct assembly of photosystems (Pogson *et al.*, 2005; Li and Guthrie, 2009). Highest carotenoids content to the tune of (0.18 mg g⁻¹ fw) was recorded highest in *Juglans regia* L. (leaves), whileas *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves), *Juglans regia* L. (fruit hull), *Tagetes patula* L. (petals), *Nasturtium officinale* R.Br. (leaves) and *Quercus robura* L. (fruit cups) recorded the corresponding values of 0.12 mg g⁻¹ fw, 0.08 mg g⁻¹ fw, 0.07 mg g⁻¹ fw, 0.06 mg g⁻¹ fw and 0.05 mg g⁻¹ fw respectively (Table-7).

Chlorophyll is the green pigment utilized by all higher plants for photosynthesis in response to available sunlight. Chlorophyll is a fat soluble tetrapyrrole pigment, occurring in chloroplasts of green plants, photosynthetic bacteria and algae (Priestley, 1979). It plays a fundamental role in the photosynthesis, being capable of converting sunlight into chemical energy (Luh and Woodroof, 1988). The most important forms of chlorophyll are chlorophyll a and chlorophyll b, occurring in an approximate ratio of 3:1 (Weemaes *et al.*, 1999). Chlorophyll content of selected test material of different plant species recorded highest value (0.58 mg g⁻¹ fw) in *Juglans regia* L. (leaves) followed by *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves), *Nasturtium officinale* R.Br. (leaves), *Juglans regia* L. (fruit hull), *Tagetes patula* L. (petals) and *Quercus robura* L. (fruit cups) with the values tune of 0.45 mg g⁻¹ fw, 0.39 mg g⁻¹ fw, 0.36 mg g⁻¹ fw, 0.34 mg g⁻¹ fw and 0.12 mg g⁻¹ fw respectively (Table-7).

Anatoly *et al.*, (2001) reported variation in anthocyanins, carotenoids and chlorophyll content of the leaves of *Acer platanoides*, *Cornus alba*, *Coton easter alaunica* and *Pelargonium zonale* plant species. Anthocyanins content was reported ranging between 1.5-48.2, 1.94-50.4, 0.03-97.2 and 0.03-10.88 respectively. Carotenoids ranged between 3.2- 18.2, 0.73-16.4, 5.1-13.0 and 0

nmol/cm² respectively while as total chlorophyll content was reported ranged between 0.16-36.7, 0.1-53.7, 0.4-62.8 and 23.8-35.6 nmol/cm² respectively. Kyparissis *et al.*, (2007) reported total carotenoids and chlorophyll ranging between 0.851 ± 0.073 mg g⁻¹ and 4.610 ± 0.288 mg g⁻¹ in red leaves of *Prunus cerasifera* respectively. The difference in the pigment contents can be determined by an integration of genetic and environmental factors which affect the photochemistry, biochemistry, physical diffusion of CO₂ into chloroplasts and activities of non-photosynthetic plant tissues (Zelitch, 1971). Photosynthetic efficiency is affected by diverse plant and site factors e.g. properties of leaves, plant architecture, duration of photosynthesis, photosynthesis by organs other than leaves, soil factors such as soil moisture, nutrient availability, and CO₂ released in soil respiration and ambient climatic factors such as air temperature, wind speed, CO₂ concentration, relative humidity, angle of sun, and nature of radiation and thus makes an difference in the composition of the pigments.

5.2 Yield of natural colourant

Dye yield is the quantity of dye powder obtained after evaporation of water from the extracted dye solution (Table-8). The percent yield of dye powder of the selected plant materials varied ranging between 2.026 to 5.114 with highest value in *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) and lowest in *Tagetes patula* (petals). The variation in the yield of the dye powder may be attributed to the difference in source of dye. The percent yield of dye powder of *Juglans regia* L. (leaves), *Quercus robura* (fruit cups), *Juglans regia* L. (fruit hull) and *Nasturtium officinale* R.Br. (leaves) recorded is 3.666, 2.406, 2.162 and 2.108 respectively. Muangthai (2010) reported percentage dye powder yield of 31.75, 32.96 and 32.14 in *Livistona speciosa* bark purified with marly limestone, silica gel and bentonite clay adsorbents. Gumel and Ali (2012) reported percentage dye powder yield of 6.40 in *Sorgham bicolour* using distilled water as solvent, while as Abera *et al.* (2013) reported crude dye powder yield of 17.64, 23.87, 26.33 and 14.14 % in bark of *Bamiba*, *Dokima*, *Warica* and *Wonbela* and dye powder yield

of 17.86, 17.06 and 24.38 % in the leaves of *Abalo*, *Zana* and *Gesho* and 15.43 and 20.76 % yield in flowers of *Gimea* and *Fesson* respectively.

5.3 Percent absorption of different dyes by selected fabrics

The dyeing process consists of three principal stages, any of which may control or influence the rate at which dye molecules are transferred. These stages are the diffusion of dye to the surface of the fibre, the adsorption of dye molecules at the surface of the fibre and the diffusion of the dye from the surface of the fibre into its interior. The absorption of the dye by the fabrics is due to electro-potential forces, temperature and agitation which drive dye molecules towards the fibre surface (Trotman, 1990). When a fibre is placed in the dye bath, water penetrates the pores very rapidly, whereas, for the large dye molecules, penetration takes much longer time. Within a short time, however, the dye solution is in contact with the internal surface and an interface is formed between the polymer and the solution (Giles, 1995) causing absorption of the dye by the fabrics.

To work out percent dye absorption, three mordanting methods namely, pre mordanting, simultaneous mordanting and post-mordanting were adopted which gave different colour tones with different mordants. It is evident from (Table-9 to 12) that all the dyes, mordant, method and their interactions showed significant differences. Pashmina fabric recorded highest percent absorption followed by wool, silk and cotton. Mordanted samples showed better percent dye absorption than the unmordanted samples thus confirming the best absorption results of the natural dyes when used in combination with natural mordants.

In pashmina and wool fabric, the pre mordanting method of dyeing showed the best absorption results 28.66 and 27.07 followed by simultaneous mordanting, 28.17 and 26.97, post mordanting 26.77 and 26.13 and without mordant 26.77 and 25.63. While as in silk fabric simultaneous mordanting method recorded the best absorption results 26.92 followed by pre mordanting 26.66, post mordanting 25.97 and without mordant 25.87 respectively. The cotton fabric

recorded highest absorption adopting simultaneous mordanting 15.29 followed by pre mordanting, without mordant and post mordanting with the values to the tune of 15.18, 14.92 and 14.74 respectively, (Table-9 to 12). The best results obtained may be attributed to the increase in binding of dye molecules to the fabric by forming chemical bridge between dye and fibre through mordants, which get fixed on the fibre and help in fixation of natural dyes thus preventing bleeding and fading of colours (Prabhu and Bhute, 2012).

Mordanted samples showed better percent dye absorption than the unmordanted samples thus confirming the best absorption results of the natural dyes when used in combination with different natural mordants. All the dyes and mordants showed significant effect on percent absorption and the interaction of dye, mordant and method varied significantly where the highest percent absorption (29.28) was recorded in pashmina fabric due to *Juglans regia* (leaves) dye with *Punica granatum* (peel) mordant adopting pre mordanting method followed by *Prunus cerasifera* (leaves) dye and *Punica granatum* (peel) mordant (28.90) in wool fabric adopting pre mordanting method, *Tagetes patula* (petals) dye and *Salix alba* (wood extract) (27.99) in silk fabric adopting simultaneous mordanting method and *Prunus cerasifera* (leaves) dye and *Punica granatum* (peel) mordant (16.16) in cotton fabric adopting simultaneous mordanting method respectively.

In pashmina fabric, *Populus deltoides* (wood ash) mordant recorded the highest mean percent dye absorption (27.90) followed by *Punica granatum* (peel) 27.56, *Salix alba* (wood ash) 27.50 and *Salix alba* (wood extract) mordant respectively. The highest mean percent absorption of mordants in wool fabric was recorded in *Salix alba* (wood ash) 26.48, whereas *Salix alba* (wood extract), *Punica granatum* (peel) and *Populus deltoides* (wood ash) recorded 26.47, 26.46 and 26.40 respectively. In silk fabric highest mean percent absorption (26.46) was recorded in *Salix alba* (wood extract) followed by *Populus deltoides* (wood ash), *Punica granatum* (peel) and *Salix alba* (wood ash) with the tune of values 26.41,

26.33 and 26.23 respectively. In cotton fabric the lowest values of percent absorption were recorded and the highest mean percent absorption (15.22) was recorded in *Punica granatum* (peel) followed by *Salix alba* (wood ash) 15.07, *Salix alba* (wood extract) 15.00 and *Populus deltoides* (wood ash) 14.83 respectively (Table-9 to 12).

As depicted in (Table-12), the mean percent dye absorption by pashmina fabric using combination of different dyes and mordants recorded highest (27.97) by *Juglans regia* (leaves) dye, whereas values to the tune of 27.95, 27.93, 27.71, 27.60 and 26.41 were recorded by *Tagetes patula* (petals), *Prunus cerasifera* (leaves), *Juglans regia* (fruit hull), *Quercus robura* (fruit cups) and *Nasturtium officinale* (leaves) dye respectively. The Pashmina wool protein (-NH₂, -OH, -COOH) provides a bridge between the dye and the pashmina wool resulting in increase of the percent absorption than the other fabrics. Temani and Shakyawar, (2011).

In wool fabric the highest mean dye absorption value (27.15) was recorded due to *Prunus cerasifera* (leaves) followed by *Juglans regia* (fruit hull) (27.05), *Tagetes patula* (petals) (26.49), *Juglans regia* (leaves) (26.18), *Nasturtium officinale* (leaves) (26.05) and *Quercus robura* (fruit cups) (25.79) respectively. Gupta *et al.*, (2013) reported percent absorption of 48.37 of *Trichoderma* spp. dyed on the wool fabric while as Sharma *et al.*, (2012) reported percent absorption of 48.37, 54.47 and 55.02 of *Trichoderma virens*, *Curvularia lunata* and *Alternaria alternate* dyed on the wool fabric. Wool has higher percent absorption than silk and cotton. The wool fibre contains equal amount of amino and carboxyl groups which ionize and form zwitter ion. At low pH the hydrogen ions are absorbed by carboxyl groups present in wool. At high pH the protein loses hydrogen ions leaving behind ionized groups. Thus wool absorbs maximum dye in acidic medium (Mathur and Bhandari, 2001) [Table-9].

In silk fabric (Table-11), *Juglans regia* (fruit hull) recorded the highest mean dye absorption (26.83) among all the mordants used while as *Juglans regia*

(leaves), *Tagetes patula* (petals), *Prunus cerasifera* (leaves), *Quercus robura* (fruit cups) and *Nasturtium officinale* (leaves) recorded the corresponding values of 26.75, 26.73, 26.65, 25.95 and 25.22 respectively. Vinod *et al.*, (2010) reported percent absorption of 30.0, 34.04, 35.00 and 35.05 at 1, 2, 3 and 4 % dye concentration of *Terminalia bellerica* bark dyed on silk fabric using Alum and tannic acid as mordants. Gupta *et al.* (2013) reported percent absorption of *Trichoderma* to the tune of 44.58 in silk. Since the dye used is a water soluble dye containing anionic groups would interact ionically with the protonated terminal amino groups of the silk fibres at acidic pH via ion exchange reaction. This ion attraction would increase the dye ability of the fibre.

The cotton fabric recorded the lowest values of the percent absorption and did not show much effect of different natural mordants (Table-10). However highest mean dye absorption value (15.75) recorded due to *Juglans regia* (leaves) followed by *Juglans regia* (fruit hull) 15.45, *Tagetes patula* (petals) 15.07, *Nasturtium officinale* (leaves) 14.99, *Prunus cerasifera* (leaves) 14.97 and *Quercus robura* (fruit cups) 14.14 respectively. Bhuyan *et al.* (2004) carried out dyeing of cotton fabric with *Rubia cordifolia*, *Morinda angustifolia* and *Tectona grandis* and reported percent absorption of 29.91, 25.00 and 20.29 respectively at 4 % of dye concentration while as Divya *et al.* (2013) reported percent absorption of 26.57, 64.22 and 60.13 by the cotton fabric dyed with *Bixa orellana* (seeds) with without mordant, natural mordant and chemical mordant respectively. Dyeing of the cotton fabrics with the combination of the mordants did not show much effect on absorption which may be due to weak and low ability of cotton to form coordination complexes with dye molecules. This low coordination tendency of cotton with the dyes and mordants resulted in low dye absorption. Tiwari *et al.* (2010) also reported lesser dye ability of cotton than that of the wool.

5.4 Colour coordinates of selected fabrics dyed with combination of different dyes and mordants

Colour of the dyed fabrics was measured on the basis of CIE system (International Commission on Illumination) expressed as L^* , a^* and b^* which represent Lightness (L^*), redness (+a), greenness (-b), yellowness (+b) and blueness (-b), Wrolstad *et al.*, (2005). From the L^* , a^* and b^* coordinates, chroma (C^*) and hue angle (h°) values were calculated using equations. Chroma (C^*) is a measure of intensity or saturation while, hue angle (h°) is expressed on 360° grid to show the tonality of colour. Red colours are represented by h° values around 0° (or 360°), blue colours are described by values close to 270° (or -90°) and green colours are found close to 180° (or -80°) (Torskangerpoll and Anderson, 2005). The increased (ΔE) value means the larger colour difference. The lower values of L^* indicate greater depth for dye and the higher values of a^* and b^* indicate brightness, which is more due to redness and yellowness, respectively. Table-13 to 36 shows the colourimetric values of dyed fabrics treated with combination of the different dyes and mordants.

All dyed samples showed variation in L^* , a^* , b^* , C^* and h° values Table-13 to 36, confirmed by the variation in total colour change (ΔE) values. The colourimetric values of dyed fabrics showed significant difference with shades ranging from light yellow to yellow, yellowish green, yellowish brown, brown to reddish brown, pale brownish green, light brown to brown, dark brown and light reddish shades with different mordants. The value of b^* recorded was positive for all the dyed fabrics and the value of a^* also recorded positive except for cotton fabric dyed with *Tagetes patula* (petals) dye with *Salix alba* (wood extract) and *Salix alba* (wood ash) mordants, *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant. The tone of samples were much yellowish and less reddish as indicated by values of a^* and b^* . These changes could be attributed to resonating structures of dyes, Montazer and Parvinzadeh, (2004). Chroma value of all the dyed fabrics recorded highest representing the bright colours of dyed fabrics (Almela *et al.*, 1995).

The lowest lightness L^* value (32.55) was recorded in pashmina fabric dyed with *Juglans regia* L. (fruit hull) in combination with *Punica granatum* L. (peel) mordant with a^* , b^* , C^* , h° and ΔE values of 4.73, 38.84, 39.13, 83.10 and 53.42 respectively, while as highest lightness L^* (92.24) was recorded in cotton fabric with *Nasturtium officinale* R.Br. (leaves) dye and *Populus deltoides* Bartram ex Marsh. (wood ash) mordant with a^* , b^* , C^* , h° and ΔE values to the tune of 1.36, 11.76, 11.84, 83.40 and 5.02 respectively. The value of C^* for all dyed samples ranged from 14.87-91.60 using *Nasturtium officinale* R.Br. (leaves) dye with *Salix alba* (wood extract) mordant, adopting simultaneous mordanting on cotton fabric and highest by using *Tagetes patula* L. (petals) dye with *Salix alba* L. (wood extract) mordant following post mordanting on cotton fabric. Thus, representing fairly good brightness of all the dyed samples.

Significant colour change (ΔE) between the control and the dyed samples was recorded adopting different mordanting methods. Highest colour change (ΔE) (53.42) was recorded adopting simultaneous mordanting in pashmina fabric using *Juglans regia* (fruit hull) dye with *Punica granatum* (peel) mordant, followed by wool fabric (47.92) using *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant, *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant (43.56) on cotton fabric and *Quercus robura* (fruit cups) dye with *Salix alba* (wood extract) mordant (42.59) on silk fabric, while as lowest colour change (ΔE) (2.14) was recorded by adopting simultaneous mordanting using *Prunus cerasifera* (leaves) dye and *Populus deltoides* (wood ash) mordant on cotton fabric followed by pre mordanting (12.59 and 16.10) using *Nasturtium officinale* (leaves) dye and *Populus deltoides* (wood ash) mordant on pashmina and wool fabric while as post mordanting recorded colour difference (ΔE) of 16.99 on silk fabric using *Tagetes patula* (petals) dye and *Salix alba* (wood extract) mordant respectively (Table-13-36). There is pronounced difference among the dyed samples. This could be correlated with complex forming ability of the metal ions with dye molecules on the fabric. In mordanting some of the

mordant is stripped out in the dye bath, which subsequently forms an insoluble complex with dye molecules in solution. Thus simultaneous mordanting showed less depth in shade (Deo and Desai, 1999). Kampeerapappun *et al.* (2010) reported larger colour difference ($\Delta E = 17.49$) with FeSO_4 mordant adopting simultaneous mordanting compared to pre mordanting and post mordanting with 11.57 and 11.63 values respectively.

Difference in mordant and method mordanting showed difference in colour and shade of the dyed fabrics. The lightness L^* value decreased by the application of mordant in majority of the dyed samples. Significant difference was observed as in CIE $L^*a^*b^*$ and $L^*C^* h^\circ$ values between samples dyed without mordant and sample dyed with mordants. The samples dyed without mordants were light while as mordanted samples recorded bright shades. Mordants used in combination with different dyes showed varying shades on different fabrics. Highest hue angle h° (94.86) was recorded by *Populus deltoides* (wood ash) mordant with *Nasturtium officinale* (leaves) dye on cotton fabric adopting simultaneous mordanting followed by *Salix alba* (wood ash) mordant with *Nasturtium officinale* (leaves) dye (89.30) on silk fabric adopting simultaneous mordanting, *Salix alba* (wood extract) mordant and *Tagetes patula* (petals) (89.00) on wool fabric adopting simultaneous and pre mordanting methods respectively. Mordant enhanced the uptake of colourant during dyeing (Table-13 to 36). Kulkarni *et al.* (2011) reported different shades of yellow on cotton fabric from the dye extracted from chili skin using in different ratios.

In wool fabric values of L^* , a^* , b^* , C^* , h° and ΔE showed significant difference in all the dyed fabrics with higher values of b^* and lower values of a^* and the hue angle h° ranged between 72 to 89 in *Quercus robura* (fruit cups) dye with *Populus deltoides* (wood ash) mordant and *Tagetes patula* (petals) dye with *Salix alba* (wood ash) mordant, indicating light yellow, yellow, yellowish brown, light brown, dark brown and reddish brown shades with good chroma. The lowest lightness L^* 43.10 was recorded due to *Juglans regia* (fruit hull) dye and *Populus*

deltoides (wood ash) mordant with a^* , b^* , C^* , h° and ΔE values of 3.76, 24.08, 24.37, 81.10 and 44.09 respectively adopting pre mordanting method, followed by *Prunus cerasifera* (leaves) and *Punica granatum* (peel) 44.90 with a^* , b^* , C^* , h° and ΔE values of 4.72, 23.67, 24.14, 78.70 and 39.22 respectively by post mordanting, *Tagetes patula* (petals) and *Populus deltoides* (wood ash) 47.88 with a^* , b^* , C^* , h° and ΔE values of 14.27, 48.17, 50.25, 73.50 and 47.92 respectively by simultaneous mordanting, *Quercus robura* (fruit cups) and *Punica granatum* (peel) 48.94 with a^* , b^* , C^* , h° and ΔE (4.29, 20.76, 21.20, 78.30 and 34.97) by post mordanting, *Juglans regia* (leaves) and *Punica granatum* (peel) 53.46 with a^* , b^* , C^* , h° and ΔE (6.99, 36.26, 36.93, 79.10 and 34.83) by simultaneous mordanting, *Nasturtium officinale* (leaves) and *Punica granatum* (peel) 57.70 with a^* , b^* , C^* , h° and ΔE (5.12, 34.82, 35.20, 81.60 and 30.51) respectively adopting post mordanting method while as highest lightness L^* 79.22 was recorded due to *Nasturtium officinale* (leaves) dye and *Punica granatum* (peel) mordant followed by post mordanting method with a^* , b^* , C^* , h° and ΔE values of 3.82, 38.05, 38.05, 84.30 and 19.37 respectively (Table-13 to 36). Abdou *et al.* (2013) reported L^* , a^* , b^* , C and ΔE values of 76.22, -1.85, 47.68, 47.7 and 50.83 of wool fabric dyed with *Curcuma tinctoria*. Narayanaswamy *et al.* (2013) reported L^* , a^* , b^* , C^* and h° to the tune of 46.50, 11.02, 5.78, 57.92 and 59.75 of silk fabric dyed with *Casuarina equisetifolia* bark extract and 2 % Alum mordant adopting pre mordanting and 46.25, 11.09, 3.95, 57.48 and 62.41 adopting post mordanting whereas unmordanted dyed samples recorded 51.21, 09.80, 7.02, 56.41 and 67.06 respectively.

Light yellow shades with low chroma were recorded in dyed cotton fabrics. The cotton fabric showed higher L^* and low a^* , b^* , C^* , h° and ΔE values than wool, silk and pashmina. The hue angle h° of cotton fabric ranged from 68.10-94.80 due to *Tagetes patula* (petals) dye and *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash) mordant indicating pale reddish, pale yellowish and pale yellowish green shades. In cotton fabric, among all the dye and

mordant combinations the lowest lightness L^* 70.15 was recorded due to *Juglans regia* (leaves) dye and *Punica granatum* (peel) mordant with a^* , b^* , C^* , h° and ΔE values of 1.71, 32.69, 32.73, 87.00 and 34.24 respectively adopting simultaneous mordanting followed by *Prunus cerasifera* (leaves) and *Punica granatum* with L^* value of 71.44 and a^* , b^* , C^* , h° and ΔE of 0.86, 20.55, 20.57, 87.60 and 25.36 by pre mordanting, *Quercus robura* (fruit cups) and *Punica granatum* (peel) with L^* value of 73.82 and a^* , b^* , C^* , h° and ΔE of 0.21, 33.33, 33.35, 89.60 and 32.61 by simultaneous mordanting, *Tagetes patula* (petals) and *Salix alba* (wood ash) with L^* value of 74.26 and a^* , b^* , C^* , h° and ΔE of -0.60, 20.39, 20.40, 91.70 and 23.57 by post mordanting, *Nasturtium officinale* (leaves) and *Punica granatum* (peel) with L^* value of 77.05 and a^* , b^* , C^* , h° and ΔE values of 2.96, 47.15, 47.25, 93.60 and 43.56 by simultaneous mordanting and *Juglans regia* (fruit hull) and *Punica granatum* (peel) with L^* value of 77.06 and a^* , b^* , C^* , h° and ΔE of 0.78, 26.90, 26.92, 83.30 and 25.41 respectively by post mordanting while as highest Lightness L^* 92.24 was recorded in *Nasturtium officinale* (leaves) dye and *Populus deltoides* (wood ash) mordant combination followed by post mordanting method with a^* , b^* , C^* , h° and ΔE values of 1.36, 11.76, 11.84, 83.40 and 5.02 respectively (Table-13 to 36). Abdou *et al.* (2013) reported L^* , a^* , b^* and ΔE values of 85.15, -4.14, 13.6 and 51.71 respectively of cotton dyed with *Curcuma tinctoria*. Kampeerappun *et al.* (2010) reported same shade of mordanted and unmordanted samples of cotton fabrics dyed with *Ruellia tuberosa* and copper sulphate and iron sulphate mordants showing yellowish green and reddish brown shade in pre mordanting method while it gave brown shade in meta mordanting and post mordanting methods while as stannous sulphate showed yellowish brown shade in pre mordanting and meta mordanting and brown shade in post mordanting.

In silk fabric, among all the dye and mordant combinations the lowest Lightness L^* 48.29 was recorded due to *Prunus cerasifera* (leaves) dye and *Punica granatum* (peel) mordant with a^* , b^* , C^* , h° and ΔE values of 6.14, 21.54,

22.40, 74.10 and 42.41 respectively adopting pre mordanting method, followed by *Quercus robura* (fruit cups) and *Punica granatum* (peel) (48.68) with a^* , b^* , C^* , h° and ΔE 3.72, 24.74, 25.02, 81.40 and 42.59 by simultaneous mordanting, *Juglans regia* (leaves) and *Populus deltoidea* (wood ash) (51.34) with a^* , b^* , C^* , h° and ΔE 4.77, 30.59, 30.97, 81.10 and 42.29 by simultaneous mordanting, *Juglans regia* (fruit hull) and *Punica granatum* (peel) (51.63) with a^* , b^* , C^* , h° and ΔE 3.24, 30.13, 30.31, 83.90 and 41.71 by post mordanting, *Tagetes patula* (petals) and *Salix alba* (wood extract) (62.76) with a^* , b^* , C^* , h° and ΔE 5.80, 27.92, 28.52, 78.30 and 31.44 by simultaneous mordanting, *Nasturtium officinale* (leaves) and *Punica granatum* (peel) (62.83) with a^* , b^* , C^* , h° and ΔE 1.40, 31.30, 31.33, 87.40 and 32.50 respectively by pre mordanting combination while as highest Lightness L^* 79.00 was recorded in *Nasturtium officinale* (leaves) dye and *Salix alba* (wood ash) mordant combination following simultaneous mordanting method with a^* , b^* , C^* , h° and ΔE of 0.34, 26.45, 26.46, 89.30 and 19.16 respectively. The hue angle h° value of the silk fabric ranged between 68.70-89.30 due to *Quercus robura* (fruit cups) with *Salix alba* (wood extract) and *Nasturtium officinale* (leaves) with *Salix alba* (wood ash) indicating shades of reddish brown, pale reddish brown, light brown, dark brown, light yellow and yellow (Table-13 to 36). Narayanaswamy *et al.* (2013) reported decrease in L^* values of silk fabric dyed with bark of *Casuarina equisetifolia* with increase in mordant concentration as compared to without mordant samples and recorded positive values of L^* and b^* in mordanted samples with colour hues (tone) of redder or yellower in mordanted samples adopting pre and post mordanting methods using 2 % and 5 % (owf) solutions of potassium aluminium sulphate and tartaric acid. Vinod *et al.*, (2010) studied colour coordinates of silk fabric dyed with bark of *Terminalia bellerica* dye and Alum (4 %) mordant and reported L^* , a^* , b^* , C^* , h° values of (70.03, 5.25, 11.6, 12.6 and 64.7) following pre mordanting and (69.5, 6.72, 12.0, 13.5 and 59.4) following post mordanting method.

In pashmina fabric, among all the dye and mordant combinations the hue angle h° value ranged from 72.50-87.90 due to *Juglans regia* (leaves) and *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) and *Salix alba* (wood ash) mordant with shades of reddish yellow, yellow, yellowish brown and dark brown. The lowest Lightness L^* 32.55 was recorded in *Juglans regia* (fruit hull) dye and *Punica granatum* (peel) mordant with a^* , b^* , C^* , h° and ΔE values of 4.73, 38.84, 39.13, 83.10 and 53.42 respectively adopting pre mordanting method, followed by *Quercus robura* (fruit cups) and *Populus deltoides* (wood ash) (37.24) with a^* , b^* , C^* , h° and ΔE 5.24, 18.97, 19.68, 74.50 and 43.86 by post mordanting, *Prunus cerasifera* (leaves) and *Punica granatum* (peel) (39.05) with a^* , b^* , C^* , h° and ΔE 3.15, 27.19, 27.38, 83.40 and 43.23 by simultaneous mordanting, *Tagetes patula* (petals) and *Populus deltoides* (wood ash) (42.99) with a^* , b^* , C^* , h° and ΔE 1.57, 48.20, 49.35, 77.60 and 50.41 by simultaneous mordanting, *Juglans regia* (leaves) and *Populus deltoides* (wood ash) (45.41) with a^* , b^* , C^* , h° and ΔE 3.35, 29.98, 30.17, 83.60 and 38.05 by pre mordanting, *Nasturtium officinale* (leaves) and *Punica granatum* (peel) (55.68) with a^* , b^* , C^* , h° and ΔE 5.47, 36.27, 36.69, 81.40 and 32.43 respectively by post mordanting combination while as highest Lightness L^* 71.42 was recorded in *Nasturtium officinale* (leaves) dye and *Salix alba* (wood ash) mordant combination following simultaneous mordanting method with a^* , b^* , C^* , h° and ΔE 1.28, 34.42, 34.45, 87.90 and 20.47 respectively (Table-13 to 36). Chaggaan *et al.* (2011) reported change in colour of the dyed pashmina fabric with different mordants which may be due to difference in coordination complexes formed between dye and metal ions of mordants during mordanting process.

Gupta *et al.* (2013) compared wool and silk samples dyed with *Trichoderma* Spp. through computer colour matching system and reported 85.27, -2.23 and 21.81 values of L^* , a^* , b^* of silk fabric and 82.91, -4.07 and 35.18 of wool fabric. Kampeerapappun *et al.*, (2010) reported L^* , a^* and b^* values of 92.82, -0.03 and 4.44 and 92.51, -0.19 and 4.85 of cotton fabric dyed with *Ruellia*

tuberosa Linn with 0 % and 0.25 % chitosan respectively. They determined influence of dyeing methods with mordants, i.e. pre mordanting, simultaneous mordanting and post mordanting. The incorporation of the metal atoms into the delocalized electron system of the dye results in lowering of the overall energy that affects absorbance of dye mordant complex known as chelate (Baker, 1958). The difference in the shade of dyed fabrics with different mordants and mordanting methods may be due to individual metal ions and different techniques, exhibiting unique complex formation resulting in different shade of the dyed fabrics (Kampeeraappun *et al.*, 2010).

5.5 Colour strength (K/S) and Relative colour strength of dyes and mordants on different fabrics

The colour strength (K/S) is a single numerical value related to the amount of light-absorbing material (colourant) contained in the sample usually based on spectral data. The calculation of colour strength (K/S) value of a sample is based on the reflectance values of the dyed sample and Kubelka-Munk equation is used for calculating the K/S value. The colour strength (K/S value) was assessed by measuring surface reflectance of the sample. The relative strength between a standard and a sample was calculated from the colour strength values of the undyed and dyed samples and is expressed as X % of the sample in relation to 100 % of the standards.

Significant difference in dye, interaction of dye, mordant and method were noticed in colour strength and relative colour strength (K/S) values of the dyed and mordanted samples. Better results of colour strength and relative colour strength of the dyes and mordants were observed on wool fabric followed by pashmina, silk and cotton fabric. Better colour strength results depend on the mordant used, Kamel *et al.* (2009). As depicted in the (Table-37 to 44) highest colour strength (K/S) value 0.930, 0.886 and 0.774 with relative colour strength of 2.54, 1.98 and 2.44 was recorded due to *Juglans regia* (leaves) dye mordanted with *Punica granatum* (peel), *Salix alba* (wood extract) and *Punica granatum*

(peel) mordant on wool, pashmina and silk fabric respectively adopting post, simultaneous and post mordanting methods respectively. However, in the cotton fabric highest colour strength 0.745 with relative colour strength 1.58 was recorded due to *Nasturtium officinale* (leaves) dye and *Populus deltoides* (wood ash) mordant following simultaneous mordanting method. The lowest value of colour strength 0.159 with relative colour strength 0.33 was recorded in cotton fabric due to *Prunus cerasifera* (leaves) and *Populus deltoides* (wood ash) mordant adopting simultaneous mordanting followed by wool with 0.421 and 1.15, silk 0.463 and 1.46 and pashmina fabric with 0.582 and 1.30 values due to *Nasturtium officinale* (leaves) dye with *Populus deltoides* (wood ash), *Salix alba* (wood extract) and *Salix alba* (wood extract) mordant adopting simultaneous, post and pre mordanting methods. Higher colour strength (K/S) value of wool (2.00) than silk (0.90) was also reported by Gupta *et al.* (2013). Abdou *et al.* (2013) reported higher K/S and relative K/S of the printed samples than that of standard samples. This may be due nature of the fabrics and the thickener viscosity.

As per as interaction of dyeing technique with mordant is concerned, simultaneous mordanting recorded highest average K/S value of 0.76 with relative K/S of 1.78 in pashmina fabric followed by post mordanting in wool fabric with 0.711 and 1.85, simultaneous mordanting in silk fabric with 0.638 and 2.01 and without mordanting in cotton fabric with 0.547 and 1.16 respectively. The lowest average value of K/S 0.434 with relative K/S 0.92 and 0.602 with relative K/S 1.89 was recorded in post mordanting method by cotton and silk fabric respectively, followed by pre mordanting method 0.646, 0.70 with relative K/S 1.62 and 1.58 by wool and silk fabrics respectively. Kampeerapappun *et al.*, (2010) reported higher values of K/S 5.86 and 6.81 adopting simultaneous mordanting and post mordanting than those of pre mordanting (3.04) and without mordanting (0.03) respectively using CuSO_4 mordant and *Ruellia tuberosa* Linn dye in cotton fabric. Vinod *et al.*, (2010) reported K/S of 4.83 and 4.63 in silk fabric dyed with *Terminalia bellerica* bark and 4 % alum mordant adopting pre

mordanting and post mordanting. Simultaneous and post mordanting can form more stable dye-mordant complex than pre mordanting (Kampeerapappun *et al.*, 2010). In case of pre mordanting, some of the mordant is stripped out in the dye bath, which subsequently forms an insoluble complex with dye molecule in solution (Deo and Desai, 1999) [Table-37 to 44].

Mordants play an important role in imparting colour to the fabrics. In combination with different dyes mordants showed significant difference in colour strength and relative colour strength of the dyed fabrics. Highest average colour strength due to mordants 0.762, 0.723, 0.669 and 0.575 with relative colour strength 1.91, 1.94, 2.10 and 1.22 was recorded due to *Punica granatum* (peel) mordant on pashmina, wool, silk and cotton fabric respectively, whereas *Salix alba* (wood extract) recorded highest average colour strength and relative colour strength of 0.721 and 1.59, 0.658 and 1.63, 0.60 and 1.59 and 0.432 and 0.91 on pashmina, wool, silk and cotton respectively. *Salix alba* (wood ash) recorded highest average colour strength and relative colour strength 0.725 and 1.61 on pashmina fabric followed by wool 0.675 and 1.67, silk 0.588 and 1.87 and cotton 0.425 and 0.92 respectively. *Populus deltoides* (wood ash) recorded colour strength of 0.737 with relative K/S 1.71 in pashmina fabric, 0.671 with relative K/S 1.78 in wool fabric, 0.619 with relative K/S 1.95 in silk fabric and 0.463 with relative K/S 0.98 in cotton fabric respectively (Table-37 to 44). Narayanaswamy (2013) reported increase in the K/S values of the dyed fabrics using different mordants. He reported K/S value of 6.61 of fabric using alum, 6.36 using tannic acid and 4.29 using tartaric acid as compared to the control samples having K/S values 3.90. Similarly Baishya *et al.* (2012) reported significant changes in the K/S values by using mordants. Kampeerapappun *et al.* (2010) examined the effect of mordants on colour strength of chitosan treated and untreated fabric reporting higher colour strength of the chitosan treated fabric than those of untreated fabrics for all mordants. The higher colour strength of the mordanted fabrics may be due

to their ability of forming coordination complexes with dye molecules (Baishya *et al.*, 2012).

Pashmina fabric recorded good colour strength and relative colour strength, however results varied with different mordants adopting different methods. Colour strength and relative colour strength of the Pashmina fabric ranged from 0.582-0.886 and 1.30-1.98 due to *Nasturtium officinale* (leaves) dye and *Juglans regia* (leaves) dye with *Salix alba* (wood extract) mordant adopting without mordanting and simultaneous mordanting method respectively. The highest average colour strength 0.790 with relative colour strength 1.84 was recorded in *Juglans regia* (leaves) dye whereas values to the tune of 0.759, 0.750, 0.728, 0.708 and 0.671 were recorded due to *Juglans regia* (fruit hull), *Prunus cerasifera* (leaves), *Tagetes patula* (petals), *Quercus robura* (fruit cups) and *Nasturtium officinale* (leaves) respectively. The relative colour strength also followed the same trend and recorded values to the tune of 1.75, 1.78, 1.67, 1.64 and 1.54 respectively (Table-43 to 44). Our results are in conformity with the results of, Temani *et al.*, (2011) who reported increased K/S value of dyed/mordanted pashmina woolen yarn ranging from 0.409-0.816 as compared to lower value 0.325 of undyed pashmina woolen yarn. The higher colour strength value of pashmina fabric may be due to formation of coordinate complex between dye and mordant and their aggregation inside the fibre leading to linear increase in colour strength of the pashmina fabric (Temani *et al.*, 2011).

Wool fabric showed colour strength ranging from 0.421-0.930 due to *Nasturtium officinale* (leaves) and *Juglans regia* (leaves) dye with *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant respectively. The relative colour strength also followed the same trend and ranged from 1.15-2.54. The highest mean colour strength (0.762) with relative colour strength (2.54) was recorded due to *Juglans regia* (leaves) followed by *Prunus cerasifera* (leaves) (0.755 and 1.93), *Juglans regia* (fruit hull) (0.707 and 1.84), *Tagetes patula* (petals) (0.669 and 1.72), *Quercus robura* (fruit cups) (0.616 and 1.50) and

Nasturtium officinale (leaves) (0.580 and 1.50) respectively (Table-37 to 38). Gupta *et al.*, (2013) reported colour strength (K/S) value of 2.00 in wool fabric dyed with *Trichoderma* sp. Similarly, Abdou *et al.* (2013) reported K/S 2.01 of wool fabric dyed with *Curcuma tinctoria* dye and Sodium alginate thickener. Similarly, Goodarzian and Ekrami (2010) reported higher relative K/S of extracted form of madder than its unextracted dyestuff and recorded relative K/S of 3.1, 1.85 and 1.37 of wool fabric dyed with 3.33, 10 and 23.33 (gr/lit) concentration of *Rubia tinctorium* L. dye. The increase in colour strength of dyed wool may be due to fiber swelling and the breakdown of the dye molecule aggregates in the solution became more, thus the diffusion of the dye molecules to the fiber became easier causing increase in colour strength value of the wool fabric (Aminoddin and Haji, 2010).

In silk fabric colour strength and relative colour strength ranged from 0.463-0.774 and 1.46-2.43 in *Nasturtium officinale* (leaves) and *Juglans regia* (leaves) dye using *Salix alba* (wood extract) and *Punica granatum* (peel) mordant adopting post mordanting method respectively. The highest average colour strength and relative colour strength 0.703 and 2.21 was recorded in *Juglans regia* (leaves) dye, whereas *Prunus cerasifera* (leaves), *Juglans regia* (fruit hull), *Tagetes patula* (petals), *Quercus robura* (fruit cups) and *Nasturtium officinale* (leaves) dye recorded the corresponding values of 0.633 and 2.00, 0.620 and 1.95, 0.608 and 1.92, 0.603 and 1.90 and 0.547 and 1.71 respectively (Table-41 to 42). Gupta *et al.*, (2013) reported colour strength (K/S) value of 0.90 of silk with *Trichoderma* sp. Similarly, Narayanaswamy *et al.* (2013) reported K/S values to the tune of 3.90 in without mordanted samples and 6.61, 6.36 and 4.29 in samples dyed with *Casuarina equisetifolia* bark adopting pre mordanting method using alum, tannic acid and tartaric acid mordants respectively. The increase in colour strength of the silk fabric may be due to formation of additional linkage of mordants with dye molecules compared to the silk samples dyed without any mordant (McClaren, 1983).

Cotton fabric recorded the lowest values of the colour strength and relative colour strength than pashmina, wool and silk fibres. Values of colour strength and relative colour strength ranged between 0.159-0.745 and 0.33-1.58 respectively due to *Prunus cerasifera* (leaves) dye with *Populus deltoides* (wood ash) and *Nasturtium officinale* (leaves) with *Populus deltoides* (wood ash) mordant. The highest average colour strength and relative colour strength 0.510 and 1.10 was recorded due to *Juglans regia* (leaves) dye followed by *Tagetes patula* (petals), *Nasturtium officinale* (leaves), *Quercus robura* (fruit cups), *Prunus cerasifera* (leaves) and *Juglans regia* (fruit hull) dye with the corresponding values of 0.494 and 1.04, 0.479 and 1.02, 0.454 and 0.96, 0.450 and 0.94 and 0.446 and 0.93 respectively (Table-39 to 40). Abdou *et al.* (2013) reported colour strength values of 3.88, 6.46 and 9.61 and percent K/S of 100, 167 and 248 of cotton fabric dyed with *Curcuma tinctoria* dye and Sodium alginate, 3 % starch and 4 % starch thickeners. The lower values of the K/S of the dyed cotton fabric than pashmina, wool and silk can be explained by the unsaturated moiety of natural dyes bearing ionizable hydroxyl and carboxylic groups. In water with right pH value, they become water soluble due to their presence in anionic forms. Cotton by its nature is negatively charged in water, thus exhibiting poor absorption for natural dyes due to repulsion effect causing poor colour strength (Kampeerappun *et al.*, 2010).

5.6 Fastness properties of natural dyes and mordants dyed on selected fabrics adopting different methods

Colour fastness is the resistance of the dyed material to change any of its colour characteristics or extent of transfer of its colourants to adjacent white materials in touch. The performance of the natural dyes and mordants on the dyeing of the fabrics were evaluated by testing the colour fastness of the dyed fabrics. Among all types of colour fastness properties, light fastness, washing fastness and rubbing fastness are considered generally for any textile (Samanta and Agarwal, 2009). After dyeing and mordanting operations, washing fastness, light fastness and rubbing fastness were determined according to ISO 105-C01,

ISO 105-B02 and ISO 105 X-12. To evaluate the colour fastness of the dyed fabric, colour change and colour transfer of the dyed fabric were determined. Colour change and colour staining due to washing, colour change due to light and dry, wet staining and fading due to rubbing tests were performed in the study. For evaluating the colour fastness, the changes were compared with the colour of the original fabric. Then the degrees of colour change and colour transfer were determined by using grey scales. Grey scale has reading from very poor (1) to Excellent (5). Very poor (1) indicates the highest colour difference and Excellent (5) means no colour difference. The fastness rating was assessed as per ISO-05-A02 (loss of shade depth) and ISO-105-A03 (extent of staining). The results of colour fastness test were rated visually by comparing the difference in colour or the contrast between the untreated and treated specimens with the differences represented by the grey scale. The colour fastness grade is equal to the grey scale step which is judged to have the same colour or contrast difference, Kumaresan *et al.* (2013).

Tables-45 to 56 depicts the fastness grades of different natural dyes in combination with mordants adopting different methods applied on different fabrics. All the dyes and mordants recorded acceptable fastness grades. Natural dyes and mordants dyed on different fabrics adopting different mordanting methods showed significant results of washing fastness, light fastness and rubbing fastness. The use of natural mordants exhibited significant properties and showed an increase in fastness properties of the fabrics in majority of the dye and mordant combinations. The results indicate that the use of mordant was advantageous. Methods adopted also showed a significant differences in fastness properties. The unmordanted samples showed Fair to Good (3/4) to Excellent (5) grade in different dyes whereas the mordanted samples recorded Fair (3) to Excellent (5) grades in majority of the combinations of dyes and mordants. All fastness values due to *Quercus robura* (fruit cups), *Juglans regia* (leaves), *Juglans regia* (fruit hull), *Prunus cerasifera* (leaves), *Nasturtium officinale* (leaves) and *Tagetes*

patula (petals) dye without mordant and with *Salix alba* (wood extract), *Salix alba* (wood ash), *Populus deltoides* (wood ash) and *Punica granatum* (peel) mordant showed significant fastness properties on all the fabrics. Mordants used and methods adopted showed a marked difference on fabrics. The post mordanting method recorded satisfactory grades with majority of the dye and mordant combinations on selected fabrics followed by pre mordanting and simultaneous mordanting method respectively. The higher grey scale rating in post mordanting method could be attributed to strong coordination complexes of mordants in comparison to complexes formed by the mordants having low grades (Bhattacharya and Shah, 2000).

5.6.1 Fastness properties of natural dyes and mordants dyed on wool fabric

The evaluation of colour fastness to light, washing and rubbing of dyes and mordants on wool fabric adopting different mordanting methods showed significant results and fastness grades of dyed wool samples showed significant fastness properties. All the dyes and mordants recorded satisfactory grades. Mordants and mordanting methods recorded significant variation in fastness grades of wool fabric and grades of washing fastness recorded slightly lower than the grades of light and rubbing fastness (Table-45 to 47).

5.6.1.1 Washing fastness

In wool fabric colour change and colour staining showed Fair (3) to Excellent (5) and Good to Excellent (4/5) to Excellent (5) grade adopting pre mordanting method, simultaneous mordanting and post mordanting methods. The colour change recorded Fair (3), Fair to Good (3/4), Good (4), Good to Excellent (4/5) and Excellent (5) grades, whereas in colour staining Good to Excellent (4/5) and Excellent (5) grades were recorded. Values of colour staining recorded higher than colour change values and almost all the dye and mordant combinations recorded Excellent (5) grade. The grade of washing fastness varied with each mordant and with each combination. Samples dyed in presence of mordant

showed better fastness to washing. The two values for the samples dyed with mordanting were higher by one scale and two were equal. But the effect was not much pronounced in comparison to washing fastness of samples without mordant (Table-45 to 47).

5.6.1.2 Light fastness

Light fastness of wool fabric recorded colour change ranging from Good (4) to Excellent (5) in pre mordanting and post mordanting methods while as grades in simultaneous mordanting ranged from Fair (3) to Excellent (5). The simultaneous mordanting recorded Fair (3) grade due to *Tagetes patula* (petals) dye with *Populus deltoides* (wood ash) mordant. Light fastness of wool fabric recorded Fair (3), Good (4), Good to Excellent (4/5) and Excellent (5) grades respectively. The grades of light fastness indicate good quality of dyes and mordants. Mordants used and methods adopted showed slight variations in light fastness grades. Though wool samples dyed without mordant also recorded significant results of fastness, however mordanted samples recorded most significant grades with majority of the dye combinations (Table-45 to 47).

5.6.1.3 Rubbing fastness

In rubbing fastness dry staining ranged from Good to Excellent (4/5) to Excellent (5) and wet staining ranged from Good (4) to Excellent (5) by adopting pre, simultaneous and post mordanting methods, while as dry fading ranged from Good to Excellent (4/5) to Excellent (5) adopting pre and simultaneous mordanting and Excellent (5) grade following post mordanting method, while as wet fading ranged from Good to Excellent (4/5) to Excellent (5) respectively. The grades of dry staining and dry fading recorded better than grades of wet staining and wet fading in most of the dye and mordant combinations. Dry staining recorded grade of Good to Excellent (4/5) due to *Nasturtium officinale* (leaves) dye with *Punica granatum* (peel) mordant and Excellent (5) grade due to rest of the dye and mordant combinations. Wet staining recorded grade of Good to

Excellent (4/5) and Excellent (5). Dry fading recorded Excellent (5) grade whereas dry staining recorded Good to Excellent (4/5) and Excellent (5) grade. The post mordanting method recorded best grades with most of the dye and mordant combinations (Table-45 to 47).

Haji (2010) reported higher fastness properties of bio mordanted wool fabric with *Berberis vulgaris* (wood) dye and *Rumex hymenosepolus* (root) bio mordant dyed samples in comparison to non mordanted samples and lower grades of wet rub fastness than dry rub fastness. The dyed wool without bio mordant and with bio mordant recorded light fastness of 5-6, wash fastness (colour change) of 3 and 4, wet rubbing fastness of 2-3 and 3 and dry rubbing fastness of 3-4 and 4 respectively. Similarly, Gupta *et al.* (2013) reported Good to Excellent (4/5) fastness of washing, Excellent (5) dry rub fastness and Good to Excellent (4/5) wet rub fastness of wool fabric dyed with *Trichoderma*.

5.6.2 Fastness properties of natural dyes and mordants dyed on cotton fabric

Fastness properties of different dyes and mordants on cotton fabric with respect to wool, silk and pashmina fabric recorded low. No significant changes were observed due to low quality of dyed fabric. The fastness properties of cotton fabric were recorded satisfactory however, the affinity of different dyes in combination with different mordants was very poor, thus the changes in the dyed fabrics were not much differentiated (Table-48 to 50).

5.6.2.1 Washing fastness

The colour change in cotton fabric due to washing adopting pre, simultaneous and post mordanting methods ranged from Fair (3) to Excellent (5) and colour staining ranged from Good to Excellent (4/5) to Excellent (5) grade. Good to Excellent (4/5) grade recorded only due to *Quercus robura* (fruit cups) dye without mordant. The grades in colour change recorded Fair (3), Fair to Good (3/4), Good (4), Good to Excellent (4/5) and Excellent (5) respectively, whereas colour staining recorded Good to Excellent (4/5) and Excellent (5) grade. Grades

of colour change recorded higher than colour staining grades and significant variation in grades due mordanting method were also recorded (Table-48 to 50).

5.6.2.2 Light fastness

Light fastness of cotton fabric ranged from Good (4) to Excellent (5) grade adopting pre mordanting, simultaneous mordanting and post mordanting methods. The colour change recorded Good (4), Good to Excellent (4/5) and Excellent (5) grades in all the three mordanting methods reflecting satisfactory light fastness of the dyes and mordants. Significant variations in the grades of different dyes and mordants on cotton fabric was recorded. The majority of the combinations recorded Excellent (5) grades (Table-48 to 50).

5.6.2.3 Rubbing fastness

Cotton fabric recorded significant results for rubbing fastness. Grades of dry staining ranged from Good to Excellent (4/5) to Excellent (5) adopting pre, simultaneous and post mordanting methods, whereas wet staining grades ranged from Good to Excellent (4/5) to Excellent (5) adopting pre mordanting method and Good (4) to Excellent (5) adopting simultaneous and post mordanting methods respectively. Grades in dry and wet staining recorded Good (4), Good to Excellent (4/5) and Excellent (5) respectively with Excellent (5) dry staining values in majority of the dye and mordant combinations and methods. Grades of dry fading recorded Excellent (5) due to all dye and mordant combinations and in without mordant dyes also adopting pre, simultaneous and post mordanting methods, whereas grades in wet fading ranged from Good to Excellent (4/5) to Excellent (5) respectively. The dry and wet fading recorded grades of Good to Excellent (4/5) to Excellent (5) and higher grades of dry fading than wet fading were noticed in all the dye and mordant combinations adopting pre, simultaneous and post mordanting methods respectively (Table-48 to 50).

Kampeerappun *et al.* (2010) carried out dyeing of cotton fabric with *Ruellia tuberosa* Linn treated with ash mordant. The light fastness and washing

fastness of untreated sample reported 3/4 and 4, whereas with ash mordant values recorded 3/4 and 2 adopting pre mordanting, 3 and 3/4 adopting simultaneous mordanting and 4 and 4/5 adopting post mordanting method respectively and also reported effect of different mordanting methods on the fastness properties of the cotton fabric. Similarly, Abdou *et al.* (2013) studied fastness properties of 100 % cotton fabric using commercial paste and reported colour change of 4 and colour staining 4 in washing fastness, grade of 1 in light fastness and dry and wet rubbing 4-5 and 4 respectively. By using 5 % starch/chitosan printing paste, washing fastness of 4 and 4 due to colour change and colour staining, light fastness of 3 and dry and wet rubbing fastness of 4-5 and 3 respectively was reported.

5.6.3 Fastness properties of natural dyes and mordants dyed on silk fabric

In silk fabric different dyes and mordants recorded satisfactory grades of washing, light and rubbing fastness by adopting different mordanting methods. The rubbing fastness and light fastness of all the dyes and mordants recorded satisfactory on the silk fabric whereas the washing fastness recorded slightly lower (Table-51 to 53).

5.6.3.1 Washing fastness

The rating for colour change on silk fabric ranged from Fair (3) to Excellent (5) grade adopting pre, simultaneous and post mordanting methods respectively, whereas ratings for colour staining recorded Excellent (5) grade due to all dye and mordant combinations with mordant and without mordant respectively. Washing fastness recorded Fair (3), Fair to Good (3/4), Good (4), Good to Excellent (4/5) and Excellent grades with different dyes and mordants adopting different methods and colour staining recorded Excellent (5) grades with all dye and mordant combinations. The grade of colour change in all the three mordanting methods recorded lower than grades of colour staining. Significant variations in the colour change grades were observed with different dye and mordant combinations and in each dye without mordant also. The mordanting

method also recorded significant changes in colour fastness properties of dyed silk fabric (Table-51 to 53).

5.6.3.2 Light fastness

The light fastness of the silk fabric adopting pre, simultaneous and post mordanting methods ranged from Good to Excellent (4/5) to Excellent (5) confirming satisfactory results of colour change due to light and negligible changes in dyed samples. The grades in colour change recorded Good to Excellent (4/5) and Excellent (5) respectively. All the dyes and mordants used show no significant variation in the light fastness of the silk fabric (Table-51 to 53).

5.6.3.3 Rubbing fastness

Silk fabric recorded satisfactory grades of colour staining and colour fading and negligible variations were recorded due to all dye and mordants adopting different mordanting methods. All the dyes and mordants recorded satisfactory grades of rubbing fastness and the mordanting methods also recorded slight variation. In rubbing fastness all the grades of staining and fading ranged from Good to Excellent (4/5) to Excellent (5) adopting pre, simultaneous and post mordanting methods respectively. Grades in rubbing fastness were recorded Good to Excellent (4/5) and Excellent (5) adopting pre, simultaneous and post mordanting methods respectively (Table-51 to 53).

Wang *et al.* (2012) studied the fastness properties of natural dye extracted from *Alpinia blepharocalyx* K. Schum dyed on silk fabric, adopting dyeing methods without mordant, with pre mordanting and post mordanting and reported washing fastness of 4 without mordant, 4-5 with $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ mordant adopting pre mordant and 5 with $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ mordant adopting post mordant was reported. Light fastness 3 of without mordant and dry and wet rubbing fastness of 4-5 and 4 without mordant, 5 and 4-5 with $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ mordant adopting pre mordant and 5 and 5 $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ mordant adopting post mordant respectively. Similarly, Narayanaswamy *et al.* (2013) dyed silk

fabric with *Casuarina equisetifolia* (bark extract) dye and 2 % alum mordant adopting without mordant, pre and post mordanting methods and reported 2 and 5 colour change and colour staining grade in washing fastness, colour change grade of 2 in light fastness and wet and dry rubbing grade of 3 and 4 without mordant. Adopting pre mordanting using alum mordant colour change and staining grade of washing to the tune of 3 and 5, light fastness grade 2-3 and wet and dry rubbing grade 3 and 4 respectively were reported, whereas adopting post mordanting using alum mordant washing fastness grade of 3-4 and 5 for colour change and staining, 2 grade in light fastness and in wet and dry rubbing 4 and 5 grades respectively were reported.

5.6.4 Fastness properties of natural dyes and mordants dyed on pashmina fabric

Pashmina fabric recorded satisfactory rating of washing, light and rubbing fastness. Rubbing fastness and light fastness of dyes and mordants applied on pashmina fabric recorded best grading whereas washing fastness recorded slightly lower grades. The mordants and mordanting methods showed significant variations with each dye (Table-54 to 56).

5.6.4.1 Washing fastness

The colour change grade of pashmina fabric adopting pre, simultaneous and post mordanting method ranged from Fair (3) to Excellent (5), colour staining recorded Excellent (5) grade adopting pre and post mordanting method whereas in simultaneous mordanting colour staining ranged from Good to Excellent (4/5) to Excellent (5) rating. Grades of colour change varied with mordant and mordanting method and grades of colour staining showed no significant differences adopting pre and post mordanting methods whereas in simultaneous mordanting colour staining grades due to *Juglans regia* (leaves) with *Salix alba* (wood extract) and *Punica granatum* (peel) mordant recorded slightly lower grades. The grades of washing fastness recorded Fair (3), Fair to Good (3/4), Good (4), Good to Excellent (4/5) and Excellent (5) respectively (Table-54 to 56).

5.6.4.2 Light fastness

Grade of light fastness ranged from Good (4) to Excellent (5) adopting pre, simultaneous and post mordanting methods. The grades of light fastness recorded Good (4), Good to Excellent (4/5) and Excellent (5) respectively and overall rating of light fastness recorded satisfactory with each dye and mordant combination. Significant variation in light fastness grades due to mordant and mordanting method were observed in majority of the dyes (Table-54 to 56).

5.6.4.3 Rubbing fastness

Rubbing fastness of selected dyes with combination of mordants applied on pashmina fabric recorded satisfactory grades and grades of dry and wet staining ranged from Good (4) to Excellent (5) whereas grades of dry and wet fading ranged from Good to Excellent to Excellent (5) adopting pre, simultaneous and post mordanting methods respectively. In dry and wet staining significant effect of mordants and mordanting methods were observed with each dye combination. The grades of staining and fading due to rubbing recorded Good (4), Good to Excellent (4/5) and Excellent (5) respectively where the grades of dry and wet fading recorded maximum than grades of dry and wet staining (Table-54 to 56).

Temani *et al.* (2011) worked on dyeing condition of cochineal extract on the pashmina fabric and reported washing colour change of 4-5, 4-5, 4-5, 5, 4-5 and 4-5 at 30, 40, 50, 60, 70, 80 and 90 °C respectively and colour staining on cotton with grade of 5 at all temperatures. The light fastness of 6, 6, 6-7, 6-7, 6-7, 6-7 and 6 at 30, 40, 50, 60, 70, 80 and 90 °C temperatures respectively using grading (AATCC, 2007). Similarly, Chaggaan *et al.* (2011) carried out dyeing of pashmina fabric with *Juglans nigra* (coat husk) and reported Good to Very Good washing fastness properties with and without mordant in acidic condition with Good light fastness. Improvement in the washing fastness and light fastness properties of pashmina fabric using mordants was also reported.

The fastness requirements are largely determined by the end use of dyed fabrics. 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 (Samanta and Agarwal, 2009).

Wool and silk fabric is more receptive towards mordants due to nature of wool due to which they can form ascorbic acids and bases equally and effectively. When wool is treated with a metallic salt it hydrolyses the salt into an acidic and a basic component. The basic component is absorbed at the $-\text{COOH}$ groups and the acidic component is removed during washing: Like wool, pashmina and silk is also amphoteric and can absorb both acids as well as bases. Pashmina wool protein ($-\text{NH}_2$, $-\text{OH}$, $-\text{COOH}$) provide the bridge between dye and wool. The cochineal-aluminium complex inside the pashmina wool fibre matrix is probably stable and witnesses the satisfactory fastness results, (Stintzing and Carle, 2005). Cotton is a cellulosic fibre and cotton lacks affinity for the natural dyes (Prabhu and Bhute, 2012).

The post mordanting appears to be preferred method of mordanting as it was confirmed by strong colour change, more fastness to washing and less fading on light exposure. Simultaneous mordanting and pre mordanting is not as effective method as post mordanting because a large proportion of the mordant gets leached into the dye liquor. The satisfactory results of post mordanting may be due to the mordants which chelate several dye molecules together, thus creating a larger complex and providing a link between the dye and the fibre. (Cardon, 2007). These insoluble complexes formed within the fibre resulting in increasing depth of shade and fastness of colour (Gordon and Gregory, 1983).

Mordants play a very important role in fastness properties of the fabrics and are used to increase the colour fastness behavior of the natural dyes (Samanta and Agarwal, 2009). The increase in the fastness properties of the dyed fabrics due to mordants may be attributed to increase in size of dye molecules when connected to tannin molecules into the fibre (Haji, 2010).

The washing fastness of the dye is influenced by the rate of the diffusion of the dye and state of the dye inside the fibre (Jothi, 2008). The change in hue on washing may be due to the alkaline nature of washing mixture mainly the pH. The fastness of a colour can vary with the type of dye, the particular shade used, the depth of the shade and the dyeing process and mainly the nature of the washing mixture (Prabhu and Bhute, 2012).

The light fastness properties were improved by the use of mordant. It is observed that during the exposure of dyed fabric to light cause absorption of energy through this light. Then this absorbed energy by dye molecule may bring about the self-destruction of the dye which cause fading of colours. Reaction pathways available for light excite dye molecules which may include ionization and dissociation into free radical oxidation, reduction and isomerization. To combat these photochemical reactions mordant play an important role by the formation of submicroscopic particles that are formed into the fabrics (Zollinger, 1991). The lower grade of light fastness implies that metal ligand chealates formed by the mordant are not much resistant to photo degradation as by other mordants having Excellent (5) grades (Gupta *et al.*, 2004). The post mordanting process increases the light fastness of natural dyed samples. Poor light fastness can be attributed to propensity of the dye chromophore to the photochemical oxidation. The photons sorbed by the chromophoric group dissipate their energy by resonating within the ring and hence dye is protected (Prabhu and Bhute, 2012). Good light fastness is due to the formation of complex with the mordant which protects chromatophore from photolytic degradation (Kulkarni *et al.*, 2011).

It was observed that mordanting in pre and simultaneous methods showed slightly lower fastness grades than post mordanting method and the samples dyed with mordant showed better rubbing fastness properties in comparison to sample dyed without mordant. This may be due to the improved depth of shade due to mordanting and formation of an insoluble colour complex of dye in fabric which

remained as aggregate of molecules on fabric surface and showed better rub fastness of the dyed fabrics. The higher grades of the wet rub fastness than dry rub fastness may be to the dissolving of water soluble dye molecules by the water which make them easier to be removed from the fibre by rubbing (Haji, 2010).

Chapter – 6

SUMMARY AND CONCLUSION

The present investigation entitled “Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley” was carried out during the year 2012-2013 at Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar, Srinagar (J&K). In this study different plant parts were used as source of natural dyes and mordants. All the related experiments of dye extraction and dyeing were carried out without using any chemical agent. The plant material for dyeing were collected from university campus and for mordants from outskirts. After characterization and identification pigment content of all the test material were estimated. The natural dye was extracted using Soxhlet extraction method and natural mordants were prepared using distilled water. The extracted natural dyes were applied on pashmina, wool, silk and cotton fabrics adopting different mordanting methods, including and excluding a mordant. Quality parameters of dyes (percent dye yield) and dyed fabrics were assessed (percent absorption, colour coordinates of dyed fabrics, colour strength (K/S), relative colour strength and colour fastness to washing, light and rubbing). The findings of the present study are summarized below :

- Photosynthetic pigments (Anthocyanins, Carotenoids and Chlorophyll) of different plant materials varied significantly. Highest (215.50 mg/100g) was recorded in leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea* and lowest anthocyanin content (71.30 mg/100g) in *Nasturtium officinale* R. Br leaves. Highest value of total carotenoids (0.18 mg g⁻¹fw) was recorded in *Juglans regia* L. (leaves) and lowest (0.05 mg g⁻¹fw) in *Quercus robura* L. (fruit cups). Highest total chlorophyll (0.58 mg g⁻¹fw) was recorded in *Juglans regia* L. (leaves) and lowest (0.12 mg g⁻¹fw) in *Quercus robura* L. (fruit cups).

- Highest (5.114) percent yield of the natural dye powder was recorded in leaves of *Prunus cerasifera* Ehrh. var. *atropurpurea*, while as lowest (2.026) was recorded in petals of *Tagetes patula* L.

Percent absorption values

- Percent dye absorption of all natural dyes recorded satisfactory. The highest average percent dye absorption (27.97) was recorded due to *Juglans regia* L. (leaves) in pashmina fabric. In wool fabric *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) recorded highest (27.15) average dye absorption value. Silk recorded highest percent absorption (26.83) due to *Juglans regia* L. (fruit hull), while as cotton fabric recorded highest mean percent dye absorption (15.75) due to *Juglans regia* L. (leaves).
- Mordanted samples showed better percent dye absorption than the unmordanted samples The highest average percent absorption of mordants 27.90 was recorded in *Populus deltoides* Bartram ex Marsh. (wood ash) in pashmina fabric, *Salix alba* L. (wood ash) 26.48 in wool fabric, *Salix alba* L. (wood extract) 26.46 in silk fabric and *Punica granatum* L. (peel) 15.22 in cotton fabric.
- Methods adopted recorded significant variation in percent absorption. The pre mordanting method of dyeing showed the highest average percent absorption (28.66) in pashmina and (27.07) in wool fabric and simultaneous mordanting recorded highest average percent absorption values (26.92 and 15.29) in silk and cotton fabric.

Colour coordinate values (CIE L*, a*, b*, C*, h° and ΔE)

- The colourimetric values of dyed fabrics differ significantly with varying shades and colour tones due to different dyes, mordants and methods.
- The lowest lightness L* value (32.55) was recorded in pashmina fabric dyed with *Juglans regia* L. (fruit hull) dye and *Punica granatum* L. (peel)

mordant while as highest lightness L^* (92.24) was recorded in cotton fabric due to *Nasturtium officinale* R. Br. (leaves) dye and *Populus deltoides* Bartram ex Marsh. (wood ash) mordant.

- In wool fabric hue angle h° value ranged between 72 to 89 due to *Quercus robura* L. (fruit cups) dye with *Populus deltoides* Bartram ex Marsh. (wood ash) mordant and *Tagetes patula* L. (petals) dye with *Salix alba* L. (wood ash) mordant, indicating light yellowish, yellow, yellowish brown, light brown, dark brown and reddish brownish shades. In cotton fabric hue angle h° ranged between 68.10-94.80 in *Tagetes patula* L. (petals) dye and *Nasturtium officinale* R.Br. (leaves) dye with *Populus deltoides* Bartram ex Marsh. (wood ash) mordant indicating pale reddish, pale yellowish and pale yellowish green shades. Hue angle h° value of the silk fabric ranged from 68.70-89.30 due to *Quercus robura* L. (fruit cups) with *Salix alba* L. (wood extract) and *Nasturtium officinale* R.Br. (leaves) with *Salix alba* L. (wood ash) indicating shades of reddish brown, pale reddish brown, light brown, dark brown, light yellow and yellow. Pashmina fabric recorded hue angle h° value ranging from 72.50-87.90 in *Juglans regia* L. (leaves) and *Nasturtium officinale* R.Br. (leaves) dye with *Punica granatum* L. (peel) and *Salix alba* L. (wood ash) mordant with shades of reddish yellow, yellow, yellowish brown and dark brown.
- Highest colour change ΔE (53.42) was recorded adopting simultaneous mordanting in pashmina fabric due to *Juglans regia* L. (fruit hull) dye and *Punica granatum* L. (peel) mordant. While as the lowest colour change ΔE (2.14) was recorded by adopting simultaneous mordanting due to *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant in cotton fabric.

Colour strength and relative colour strength (K/S values)

- Colour strength and relative colour strength of all selected dyes and mordants showed significant variations on each fabric and mordanting methods also showed variations in colour strength K/S and relative K/S.
- Highest colour strength (K/S) value 0.930, 0.886 and 0.774 with relative colour strength of 2.54, 1.98 and 2.44 was recorded due to *Juglans regia* L. (leaves) dye mordanted with *Punica granatum* L. (peel), *Salix alba* L. (wood extract) and *Punica granatum* L. (peel) mordant in wool, pashmina and silk fabric adopting post, simultaneous and post mordanting methods respectively. In cotton fabric highest colour strength 0.745 with relative colour strength 1.58 was recorded due to *Nasturtium officinale* R.Br. (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant adopting simultaneous mordanting method.
- Lowest value of colour strength 0.159 of natural dyes with relative colour strength 0.33 was recorded in cotton fabric due to *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) and *Populus deltoides* Bartram ex Marsh (wood ash) mordant adopting simultaneous mordanting method followed by wool 0.421 and 1.15, silk 0.463 and 1.46 and pashmina fabric 0.582 and 1.30 due to *Nasturtium officinale* R.Br. (leaves) dye with *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood extract) and *Salix alba* L. (wood extract) mordant adopting simultaneous, post and pre mordanting methods.
- Highest average colour strength (K/S) and relative colour strength of mordants in pashmina fabric was recorded due to *Punica granatum* L. (peel) followed by *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood ash) and *Salix alba* L. (wood extract) with values to the tone of 0.762 and 1.91, 0.737 and 1.71, 0.725 and 1.61, 0.721 and 1.59.

- In wool fabric highest value recorded due to *Punica granatum* L. (peel) were 0.723 and 1.94 followed by *Salix alba* L. (wood ash) 0.658 and 1.63, *Populus deltoides* Bartram ex Marsh (wood ash) 0.671 and 1.78 and *Salix alba* L. (wood extract) 0.658 and 1.63. In silk fabric *Punica granatum* L. (peel) recorded highest value followed by *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood extract) and *Salix alba* L. (wood ash) with colour strength and relative colour strength values 0.669, 0.619, 0.600, 0.588 with relative colour strength 2.10, 1.95, 1.59 and 1.87. In cotton fabric highest value was recorded due to *Punica granatum* L. (peel) followed by *Populus deltoides* Bartram ex Marsh (wood ash), *Salix alba* L. (wood extract) and *Salix alba* L. (wood ash) with colour strength values to the tone of 0.575, 0.463, 0.432 and 0.425 and relative colour strength values 1.22, 0.98, 0.91 and 0.92 respectively.
- Simultaneous mordanting recorded highest average K/S value of 0.76 with relative K/S 1.78 in pashmina fabric, post mordanting in wool fabric 0.711 and 1.85, simultaneous mordanting in silk fabric 0.638 and 2.01 and without mordanting in cotton fabric 0.547 and 1.16. The lowest average value of K/S 0.434 with relative K/S 0.92 and 0.602 with relative K/S 1.89 was recorded by post mordanting method in cotton and silk fabric and without mordanting 0.646 and 0.70 with relative K/S 1.62 and 1.58 in wool and pashmina fabric.

Colour fastness properties

- All the dyes and mordants recorded acceptable fastness grades. Mordants and mordanting methods showed significant results of washing fastness, light fastness and rubbing fastness properties.
- Methods adopted showed significant difference in fastness properties. The unmordanted samples showed Fair to Good (3/4) to Excellent (5) grades with different dyes whereas the mordanted samples recorded Fair (3) to

Excellent (5) grades in majority of the combination of dyes and mordants. The post mordanting method recorded satisfactory grades with majority of the dye and mordant combinations on selected fabrics followed by pre mordanting and simultaneous mordanting methods.

- In wool fabric washing fastness due to colour change and colour staining ranged from Fair (3) to Excellent (5) and Good to Excellent (4/5) to Excellent (5) adopting pre, simultaneous and post mordanting methods. In rubbing fastness dry staining ranged from Good to Excellent (4/5) to Excellent (5) and wet staining ranged from Good (4) to Excellent (5) by adopting pre, simultaneous and post mordanting methods, while as dry fading ranged from Good to Excellent (4/5) to Excellent (5) adopting pre and simultaneous mordanting and Excellent (5) following post mordanting method, while as wet fading ranged from Good to Excellent (4/5) to Excellent (5) respectively.
- In cotton fabric colour change due to washing ranged from Fair (3) to Excellent (5) and colour staining ranged from Good to Excellent (4/5) to Excellent (5). Light fastness ranged from Good (4) to Excellent (5). Rubbing fastness in dry staining ranged from Good to Excellent (4/5) to Excellent (5), whereas wet staining ranged from Good to Excellent (4/5) to Excellent (5) adopting pre mordanting method and Good (4) to Excellent (5) grade adopting simultaneous and post mordanting methods.
- In silk fabric washing fastness for colour change ranged from Fair (3) to Excellent (5), whereas in colour staining Excellent (5) grade was recorded due to all dye and mordant combinations with and without mordant. Light fastness of dyed silk fabric ranged from Good to Excellent (4/5) to Excellent (5). In rubbing fastness all the fastness grades of staining and fading ranged from Good to Excellent (4/5) to Excellent (5).

- In pashmina fabric washing fastness recorded colour change grade ranging from Fair (3) to Excellent (5). Colour staining recorded Excellent (5) grade adopting pre and post mordanting method whereas in simultaneous mordanting colour staining ranged from Good to Excellent (4/5) to Excellent (5). Light fastness properties of pashmina fabric ranged from Good (4) to Excellent (5) and Rubbing fastness grades of dry and wet staining ranged from Good (4) to Excellent (5) whereas grades of dry and wet fading ranged from Good to Excellent (4/5) to Excellent (5).

CONCLUSION

It is concluded from the study that anthocyanins are higher than carotenoids and chlorophyll in the selected test species and *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) recorded highest content and *Nasturtium officinale* R.Br (leaves) recorded lowest value of anthocyanins. Carotenoids and chlorophyll content were recorded highest in *Juglans regia* L. (leaves) and lowest in *Quercus robura* L. (fruit cups). Percent yield of dye powder was recorded highest in *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) and lowest in *Tagetes patula* L. (petals). Percent dye absorption of all natural dyes was satisfactory. However, *Juglans regia* (leaves) recorded highest percent absorption in pashmina and cotton fabric, *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) recorded highest in wool fabric and *Juglans regia* L. (fruit hull) recorded highest in silk fabric. Mordanted samples showed better percent dye absorption than the unmordanted samples. *Populus deltoides* Bartram ex Marsh recorded highest average percent absorption in pashmina fabric, *Salix alba* L. (wood ash) in wool fabric, *Salix alba* L. (wood extract) in silk fabric and *Punica granatum* L. (peel) in cotton fabric. In methods, pre mordanting method showed the highest average percent absorption in pashmina and wool fabric and simultaneous mordanting recorded highest average percent absorption in silk and cotton fabric. Dyed fabrics were endowed with very good dye adherence as seen from CIE L*, a*, b*, C*, h*, ΔE and K/S values. *Juglans regia* L. (fruit hull) and *Punica granatum* L. (peel)

mordant recorded highest colour change (ΔE) in pashmina fabric and *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant recorded highest colour change (ΔE) in cotton fabric. Highest colour strength (K/S) value was recorded due to *Juglans regia* L. (leaves) dye mordanted with *Punica granatum* L. (peel), *Salix alba* L. (wood extract) and *Punica granatum* L. (peel) mordant in wool, pashmina and silk fabrics adopting post, simultaneous and post mordanting methods and *Nasturtium officinale* R.Br. (leaves) dye and *Populus deltoides* Bartram ex Marsh (wood ash) mordant in cotton fabric adopting simultaneous mordanting. Lowest value of colour strength was recorded by *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves) and *Populus deltoides* Bartram ex Marsh (wood ash) mordant in cotton fabric adopting simultaneous mordanting. Highest average colour strength of mordants was recorded in *Punica granatum* L. (peel) on pashmina, wool, silk and cotton fabric respectively. Simultaneous mordanting recorded highest average K/S value on pashmina fabric, post mordanting on wool fabric, Simultaneous mordanting on silk fabric and without mordanting on cotton fabric. The lowest average value of K/S was recorded by post mordanting method in cotton and silk fabric and without mordanting in wool and pashmina fabric. All the dyes and mordants recorded acceptable fastness grades. Mordants and mordanting methods showed significant results of washing fastness, light fastness and rubbing fastness properties. The selected dyes recorded acceptable fastness grades with mordant and without mordant. The affinity of the dyes and mordants recorded best on pashmina, wool and silk fabric while as cotton fabric showed very poor affinity for the selected dyes and mordants. The mordanted samples showed better dye quality than the unmordanted samples.

Thus, it is concluded from the present study that all the selected plant species are good source of natural dyes and can be used for the dyeing of the pashmina, wool and silk fabrics adopting different dyeing methods. The selected mordants showed major influence on the properties of selected fabrics and can be

used for attaining the varieties of beautiful shades which can also facilitate the colour strength, colour fastness properties against washing, light and rubbing. The selected natural mordants can be used for attaining better results when used in combination with different natural dyes. All the selected dyes and mordants can be used as an alternative for synthetic dyes which are carcinogenic and banned in majority of countries of the world.

Recommendations

On the basis of experiments conducted, it is recommended that *Quercus robura* L. (fruit cups), *Juglans regia* L. (leaves), *Juglans regia* L. (fruit hull), *Prunus cerasifera* Ehrh. var. *atropurpurea* (leaves), *Nasturtium officinale* R.Br. (leaves) and *Tagetes patula* L. (petals) can be used as good source of dyes and *Salix alba* L. (wood extract) and (wood ash), *Populus deltoides* Bartram ex Marsh. and *Punica granatum* L. (peel) can be used as effective natural mordants as these dyes are eco-friendly. Dyes applied in combination with mordants on pashmina, wool and silk fabrics showed excellent but varied effects. Since the combinations are fabric specific, *Juglans regia* L. (leaves) dye and *Salix alba* L. (wood extract) mordant can be used for dyeing pashmina and silk fabrics. *Juglans regia* L. (leaves) dye and *Populus deltoides* Bartram ex Marsh. mordant for dyeing wool. No satisfactory results were recorded on cotton fabric. Hence, further investigation in this context is recommended. These natural dyes and mordants are recommended as commercial viable sources for the dyeing of pashmina, wool and silk fabrics.

Future prospectus

1. Need for proper knowledge, assessment and documentation of dye yielding plants and mordants of Kashmir valley.
2. Selection of optimum dyeing conditions and dyeing techniques for getting better results.
3. More research and developmental efforts are needed to test the stringent standards of performance that are applied to synthetic dyes, on natural dyes.
4. Traditional practices of extraction and dyeing need to be substituted by modern and more scientific methods.
5. Application of dyes with other mordants for getting varying shades and tones.
6. Extracted mordants can be used in combination with other natural dyes.
7. Application on other fabrics other than wool, cotton, silk and pashmina.

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Certificate

Certified that all the corrections/amendments as suggested by External Examiner Dr. P.K. Mishra, Professor, Department of Chemical Engineering and Technology, Indian Institute of Technology, Banaras Hindu University (IIT-BHU), Varanasi during Viva-Voce examination held on 28th of May, 2014 have been incorporated in the manuscript entitled **“Fabric dye yielding potential of selected Herbaceous and Arboreal plant species of the Kashmir valley”** submitted by **Mr. Syed Maqbool Geelani** (Regd. No. 2010-331-D).

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