Status of natural dyes and dye-yielding plants in India

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Indians have been considered as forerunners in the art of natural dyeing. Natural dyes find use in the colouring of textiles, drugs, cosmetics, etc. Owing to their non-toxic effects, they are also used for colouring various food products. In India, there are more than 450 plants that can yield dyes. In addition to their dye-yielding characteristics, some of these plants also possess medicinal value. Though there is a large plant resource base, little has been exploited so far. Due to lack of availability of precise technical knowledge on the extracting and dyeing technique, it has not commercially succeeded like the synthetic dyes.

Although indigenous knowledge system has been practised over the years in the past, the use of natural dyes has diminished over generations due to lack of documentation. Also there is not much information available on databases of either dye-yielding plants or their products. In this article we review the availability of natural dyes, their extraction, applications, mordant types, advantages and disadvantages.

Keywords: Colourants, mordants, natural dyes, plants.

To understand the concepts of natural dyes and dye-yielding plants, there are three basic questions to be addressed: Why only certain plants are able to yield dyes? How does the plant benefit by producing dyes? What is the evolutionary explanation for production of dyes? Answers to the first two questions can be substantiated with two further questions, i.e. 'Why do plants have so many different colours?' and 'What purpose might they serve for the plant?'. Green in most leaves is surely the most ubiquitous plant colour. The green pigment chlorophyll in leaves helps capture the sun's energy and converts it to chemical energy, which is then stored and used as food for the plant. Colours in flowers are adaptations that attract insects and other animals that in turn pollinate and help the plants reproduce. Some plants have colourful fruits that attract animals to eat them, thus inadvertently spreading the plant's seeds as they do so. Scientists believe that other pigments may help protect plants from diseases. Despite what we know about the role of a few of the thousands of plant pigments, the role of most colours in plants remains a mystery to us till date.

Although plants exhibit a wide range of colours, not all of these pigments can be used as dyes. Some do not dissolve in water, some cannot be adsorbed on-to fibres, whereas others fade when washed or exposed to air or sunlight. It remains a mystery, why plants reward us with vibrant dyes.

India has a rich biodiversity and it is not only one of the world's twelve megadiversity countries, but also one of the eight major centres of origin and diversification of domesticated taxa. It has approximately 490,000 plant species of which about 17,500 are angiosperms; more than 400 are domesticated crop species and almost an equal number their wild relatives[1]. Thus, India harbours a wealth of useful germplasm resources and there is no doubt that the plant kingdom is a treasure-house of diverse natural products. One such product from nature is the dye.

Natural dyes are environment-friendly, for example, turmeric, the brightest of naturally occurring yellow dyes is a powerful antiseptic which revitalizes the skin, while indigo gives a cooling sensation[2].

After the accidental synthesis of mauveine by Perkin in Germany in 1856 and its subsequent commercialization, coal-tar dyes began to compete with natural dyes. The advent of synthetic dyes caused rapid decline in the use of natural dyes, which were completely replaced by the former within a century[3]. However, research has shown that synthetic dyes are suspected to release harmful chemicals that are allergic, carcinogenic and detrimental to human health. Ironically, in 1996 Germany became the first country to ban certain azo dyes[4].

In this article, we review the origin of natural dyes, plants and animals yielding dyes, chemical nature of these dyes, their advantages with limitation, technology involved with natural dyes production and present status of these dyes.

History

Natural dyes, dyestuff and dyeing are as old as textiles themselves. Man has always been interested in colours; the art of dyeing has a long past and many of the dyes go back into prehistory. It was practised during the Bronze Age in Europe. The earliest written record of the use of natural dyes was found in China dated 2600 BC. Dyeing was known as early as in the Indus Valley period (2500 BC); this knowledge has been substantiated by findings of coloured

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garments of cloth and traces of madder dye in the ruins of the Indus Valley Civilization at Mohenjodaro and Harappa (3500 BC). Natural matter was used to stain hides, decorate shells and feathers, and in cave paintings. Scientists have been able to date the black, white, yellow and reddish pigments made from ochre used by primitive man in cave paintings. In Egypt, mummies have been found wrapped in dyed cloth. Chemical tests of red fabrics found in the tomb of King Tutankhamen in Egypt show the presence of alizarin, a pigment extracted from madder. In more modern times, Alexander the Great mentioned having found purple robes dating to 541 BC in the royal treasury when he conquered Susa, the Persian capital. Kermes (from the Kermes insect) is identified in the *Book of Exodus* in the *Bible*, where references are made to scarlet coloured linen. By the 4th century AD, dyes such as woad, madder, weld, Brazilwood, indigo and a dark reddish-purple were known. Brazil was named after the woad found there[5].

Henna was used even before 2500 BC, while saffron is mentioned in the *Bible*[6]. The first use of the blue dye, woad by the ancient Britons, may have originated in Palestine, where it was found growing wild. The most famous and highly prized colour through the ages was Tyrian purple (noted in the *Bible*), a dye obtained from the spiny dye-murex shellfish. The Phoenicians prepared it until the seventh century, when Arab conquerors destroyed their dyeing installations in the Levant. In the prehistoric times man used to crush berries to colour mud for his cave paintings. Primitive men used plant dyestuff for colouring animal skin and to their own skin during religious festivals as well as during wars. They believed that the colour would give them magical powers, protect them from evil spirits and help them to achieve victory in war[7].

Dyes might have been discovered accidentally, but their use has become so much a part of man's customs that it is difficult to imagine a modern world without dyes. The art of dyeing spread widely as civilization advanced[8].

Primitive dyeing techniques included sticking plants to fabric or rubbing crushed pigments into cloth. The methods became more sophisticated with time and techniques using natural dyes from crushed fruits, berries and other plants, which were boiled into the fabric and which gave light and water fastness (resistance), were developed. Some of the well-known ancient dyes include madder, a red dye made from the roots of the *Rubia tinctorum* L., blue indigo from the leaves of *Indigofera tinctoria* L., yellow from the stigmas of the saffron plant (*Crocus sativus* L.) and from turmeric (*Curcuma longa* L.).

Today, dyeing is a complex and specialized science. Nearly all dyestuff are now produced from synthetic compounds. This means that costs have been greatly reduced and certain application and wear characteristics have been greatly enhanced. However, practitioners of the craft of natural dying (i.e. using naturally occurring sources of dye) maintain that natural dyes have a far superior aesthetic quality, which is much more pleasing to the eye. On the other hand, many commercial practitioners feel that natural dyes are non-viable on grounds of both quality and economics. In the West, natural dyeing is now practised only as a handcraft, while synthetic dyes are being used in all commercial applications. Some craft spinners, weavers and knitters use natural dyes as a particular feature of their work.

Types of natural dyes and mordants

Natural dyes can be sorted into three categories: natural dyes obtained from plants, animals and minerals. Although some fabrics such as silk and wool can be coloured simply by being dipped in the dye, others such as cotton require a mordant.

Mordant

Dyes do not interact directly with the materials they are intended to colour. Natural dyes are substantive and require a 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 takes place between the dye and the fibre, so that the dye is absorbed. Containers used for dying must be non-reactive (enamel, stainless steel). Brass, copper or iron pots will do their own mordanting.

Not all dyes need mordants to help them adhere to fabric. If they need no mordants, such as lichens and walnut hulls, they are called substantive dyes. If they need a mordant, they are called adjective dyes. Common mordants are alum (usually used with cream of tartar, which helps evenness and brightens slightly); iron (or copper) (which saddens or darken colours, bringing out green shades); tin (usually used with cream of tartar, which blooms or brightens colours, especially reds, oranges and yellows), and blue vitriol (which saddens colours and brings out greens shades).

There are three types of mordant: *Metallic mordants*: Metal salts of aluminium, chromium, iron, copper and tin are used. *Tannins*: Myrobalan and sumach are commonly used in the textile industry. *Oil mordants*: These are mainly used in dyeing turkey red colour from madder. The main function of the oil mordant is to form a complex with alum used as the main mordent.

Natural dyes obtained from plants

Many natural dyestuff and stains were obtained mainly from plants and dominated as sources of natural dyes, producing different colours like red, yellow, blue, black, brown and a combination of these (Table 1). Almost all parts of the plants like root, bark, leaf, fruit, wood, seed, flower, etc. produce dyes. It is interesting to note that over 2000 pigments are synthesized by various parts of plants, of which only about 150 have been commercially exploi-

Table 1. Sources of different coloured dyes and mordants[20]

Colour	Botanical name	Parts used	Mordants
Red dye			
Safflower	*Carthamus tinctorius* L.	Flower	–
Caesalpinia	*Caesalpinia sappan* L.	Wood	Alum
Madder	*Rubia tinctorium* L.	Wood	Alum
Log wood	*Haematoxylon campechianum* L.	Wood	–
Khat palak	*Rumex dentatus* L.	Wood	Alum
Indian mulberry	*Morinda tinctoria* L.	Wood	Alum
Kamala	*Mallotus philippinensis* Muell.	Flower	Alum
Lac	*Coccus lacca* Kerr.	Insect	Stannic chloride
Yellow dye			
Golden rod	*Solidago grandis* DC.	Flower	Alum
Teak	*Tectona grandis* L.f.	Leaf	Alum
Marigold	*Tagetes* sp.	Flower	Chrome
Saffron	*Crocus sativus* L.	Flower	Alum
Flame of the forest	*Butea monosperma* (Lam) Taubert.	Flower	Alum
Blue dye			
Indigo	*Indigofera tinctoria* L.	Leaf	Alum
Woad	*Isatis tinctoria* L.	Leaf	–
Sunt berry	*Acacia nilotica* (L.) Del.	Seed pod	–
Pivet	*Ligustrum vulgare* L.	Fruit	Alum and iron
Water lily	*Nymphaea alba* L.	Rhizome	Iron and acid
Black dye			
Alder	*Alnus glutinosa* (L.) Gaertn.	Bark	Ferrous sulphate
Rofblamala	*Loranthus pentapetalus* Roxb.	Leaf	Ferrous sulphate
Custard apple	*Anona reticulata* L.	Fruit	–
Harda	*Terminalia chebula* Retz.	Fruit	Ferrous sulphate
Orange dye			
Annota	*Bixa orellena* L.	Seed	Alum
Dhalia	*Dhalia* sp.	Flower	Alum
Lily	*Convallaria majalis* L.	Leaf	Ferrous sulphate
Nettles	*Urtica dioica* L.	Leaf	Alum

ted. Nearly 450 taxa are known to yield dyes in India alone[9], of which 50 are considered to be the most important; ten of these are from roots, four from barks, five from leaves, seven from flowers, seven from fruits, three from seeds, eight from wood and three from gums and resins[7]. Some important dye-yielding plant habitats, their distribution and colouring pigments are given in Table 2.

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. Even today, some dyes continue to be derived from natural sources; for example, dyes for lipstick are still obtained from *Bixa orellana* L. and *Lithospermum erythrorhizon* Sieb & Zucc., and those for eye shadow from indigo. Tables 2 and 3 show some of the important dye-yielding plants used traditionally. The content or amount of dye present in the plants varies greatly depending on the season as well as age of the plants[10]. There are also several factors which influence the content of the dye in each dye-yielding plant. In some cases, the dye content has not been thoroughly studied so far.

Medicinal properties of natural dyes: Many of the plants used for dye extraction are classified as medicinal, and some of these have recently been shown to possess antimicrobial activity[11]. *Punica granatum* L. and many other common natural dyes are reported as potent antimicrobial agents owing to the presence of a large amount of tannins. Several other sources of plant dyes rich in naphthoquinones such as lawsone from *Lawsonia inermis* L. (henna), juglone from walnut and lapachol from alkannet are reported to exhibit antibacterial and antifungal activity[12–14].

Singh *et al.*[15] studied the antimicrobial activity of some natural dyes. Optimized natural dye powders of *Acacia catechu* (L.f.) Willd, *Kerria lacca*, *Rubia cordifolia* L. and *Rumex maritimus* were obtained from commercial industries and they showed antimicrobial activities. This is clear evidence that some natural dyes by themselves have medicinal properties.

Another example is lycopene – a carotenoid pigment responsible for red colour in tomato, watermelon, carrot and other fruits; it is also used as a colour ingredient in many food formulations. It has received considerable attention in recent years because of its possible role in the prevention of chronic diseases such as prostate cancer[16,17]. Epidemiological studies have also shown that increased consumption of lycopene-rich food such as tomatoes is

Table 2. Important dye-yielding plants with pigments

Plant	Colour obtained	Pigment	Dye content	Habitat and distribution
Acacia catechu (L.f.) Willd.	Brown, black	Catechin, catechutanic acid	The chief constituents of the heartwood vary from 4 to 7% and are distributed throughout the heartwood from the root to the branches.	Occurs throughout India in dry types of mixed forest on a variety of geological formations and soils.
Adhatoda vasica Nees.	Yellow	Adhatodic acid, carotein, lutolin, quercetin	–	Distributed throughout India, up to an attitude of 1300 m; grows on waste land and in a variety of habitats and soil. It is sometimes cultivated as hedge.
Bixa orellena L.	Orange, red	Bixin, norbixin	The dye content is 5–6% by weight of seed. A carotenoid bixin comprises 70–80% in each seed.	The small tree is found to thrive at elevations of 600–900 m; native to tropical America, it has become naturalized in the hotter parts of India.
Butea monosperma (Lam) Taubert.	Yellow or orange	Butrin	–	Commonly found throughout India, except in the arid region. It grows on black cotton soil, even on saline, alkaline and swampy badly drained soils and in barren lands.
Carthamus tinctorious L.	Yellow, red	Carthamin	The chief constituent carthamin ranges from 3 to 6% of the flower.	Cultivated throughout India. It requires fertile, moisture-retentive and well-drained soil.
Curcuma longa L.	Yellow	Curcumin	Percentage of curcumin varies from 5.4 to 8.7.	Turmeric grown generally as an annual crop. It is cultivable from sea level up to 1200 m. It thrives in well-drained, fertile, sandy and clayey, black red soil.
Indigofera tinctoria L.	Blue	Indigotin, Indican	Indigotin content varies according to season and age of the plant. Best grade contains 70–90% in dried leaves.	Distributed commonly in the tropical region.
Lawsonia inermis L.	Orange	Lawsone	The principle colouring matter, lawsone is present in dried leaves at a concentration of 1.0–1.4%.	It is mainly cultivated in Tamil Nadu, Madhya Pradesh and Rajasthan. It can grows on any type of soil from light loam to clay loam, but grows best on heavy soil.
Mallotus philippensis Muell.	Red	Rottlerin	The yield of powder rottlerin is 1.4–3.7% of the weight of the fresh fruits.	Found throughout India; occasionally ascending to 1500 m in the outer Himalayas. Commonly found in Sal and certain shrub and mixed forests.
Morinda citrifolia L.	Yellow, red	Morindone	Roots are dug out when the plants are 3–4 yrs old, dried and sorted for use by the dyeing trade.	A small tree distributed throughout the tropics.
Oldenlandia umbellata L.	Red	Alizarin, Rubicholric acid	–	Prostrate herb distributed in the tropical and subtropical region.
Pterocarpus santalinus L.	Red	Santalin	Red sanders contains 16% of a colouring matter, santalin (santalic acid).	Grows typically on dry, hilly, often rocky ground and is occasionally found growing on precipitous hillside.
Punica granatum L.	Yellow	Petargonidon 3,5,diglucoside	–	Mostly found cultivated in many parts of India, the tree is also common and gregarious in the gravel and boulder deposits of dry ravines and similar places in the outer Himalayas up to about 1800 m.
Rubia cordifolia L.	Red	Purpurin	Purpurin per cent vary from 2.0 to 4.0.	A hardy climbers common throughout India, ascending to an altitude of 3750 m.
Semecarpus anacardium L.f.	Black	Bhilawanol	Bhilawanol ranging from 28 to 36% of dry weight of seed.	The tree is common in forests often found occurring with Sal, throughout the hotter parts of India.
Toddalia asiatica (L.) Lam.	Yellow	Toddaline	–	In South India, the plant is common in the Nilgris and Palani hills, and also in the scrubby jungles of Orissa.
Wrightia tinctoria R. Br.	Blue	β-amyrine	Leaves are the source of a blue dye called Mysore pala-indigo and β-amyrine ranges from 3.3–5.0% of dried leaves.	Distributed in Rajasthan, Madhya Pradesh and peninsular India, ascending to an altitude of 1200 m in the hills.

Table 3. Dye-yielding plants with its medicinal value

Botanical name	Family	English name	Parts used	Colour	Medicinal use
Abies spectabilis (D.Don.) Spach.	Pinaceae	East Himalayan silver fir	Cone	Purple or violet	Used for curing cough.
Acacia catechu (L.f.) Willd.	Mimosaceae	Cutch tree	Bark	Brown/black	Kheersal is used medicinally for sore throat and cough.
Acacia dealbata Link	Mimosaceae	Silver wattle	Bark	Brown/black	Used in bronchial infection.
Acanthophonax trifoliatum (L.) Merr.	Araliaceae		Fruit	Black	Used in paralysis; roots cooked and eaten.
Actaea spicata L.	Ranunculaceae	Banberry grape wort	Seed	Black, red, green	Rhizomes are used for nervous disorders and uterine tenderness.
Adathoda vasica Nees.	Acanthaceae	Adalsa	Leaf	Yellow	Used in bronchial infection
Aegle marmelos (L.) Corr.	Rutaceae	Bael fruit	Fruit rind	Yellow	Unripe or half-ripe fruit is astringent, used as digestive and for curing stomachache diarrhoea.
Ailanthus triphysa (Dennst.) Alston.	Simaroubaceae		Leaf	Black	Bark carminative, tonic and febrifuge; juice used for asthma and bronchitis and also for dysentery.
Aloe barbadensis (L.) Burm.f.	Lilliaceae	Curaco aloe; Indian aloe	Whole plant	Red	Fresh juice of leaves is cathartic and refrigerant used in liver and spleen ailments and for eye infections, useful in X-ray burns and other skin disorders.
Althea rosea Cav.	Malvaceae	Holly hock	Flower	Red	Considered emollient, demulcent and diuretic, used in chest complaints.
Ardisia solanacea Roxb.	Myrstinaceae		Berry	Yellow	Roots used in diarrhoea and rheumatism.
Arnebia benthamii (Wall. ex G. Don)	Boraginaceae	Pan	Under-ground parts	Purple	Stimulant, tonic, diuretic, and expectorant used in infection of tongue and throat, and also cardiac disorders and fever.
Arnebia guttata Bunge	Boraginaceae		Root	Red	Roots are also used for cough.
Azadirachta indica A. Juzz	Meliaceae	Neem	Bark	Brown	Skin disorders, leaves considered as antiseptic.
Barleria prionitis L.	Acanthaceae		Flower	Yellow	Juice of leaves given with honey in catarrhal infections of children. A paste of the roots applied to boils and glandular swellings.
Bassia latifolia Roxb./ *Madhuca indica* J.F.Gmel	Sapotaceae	Butter tree	Bark	Yellow, brown	Used in rheumatism and skin infections and as a laxative in cases of habitual constipation and piles.
Bauhinia tomentosa L.	Caesalpinaceae		Leaf	Yellow	Decoction of root bark used for inflammation of liver and as vermifuge. Dry leaves, buds and flowers used in dysentery.
Bauhinia variegate L.	Caesalpinaceae	Mahua tree	Bark	Yellow	Roots carminative, decoction prevents obesity, bark tonic and anthelminitic used in scrofula and cutaneous diseases; also used for ulcer and leprosy. Dried flowers eaten in case of diarrhoea, dysentery and piles.
Betula utilis D.Don	Betulaceae	Himalayan silver birch	Tree gum	Brown	Infusion of bark is aromatic and antiseptic; also used as a carminative.
Briedelia stipularis L.	Euphorbiaceae		Fruit	Black	Decoction of the bark used for cough, fever and asthma. Leaves used in case of jaundice.
Butea monosperma (Lam) Taubert.	Papilonaceae	Flame of the forest	Flower	Yellow, orange	Bark astringent, used for piles, tumour and menstrual disorders. Gum is astringent and used in diarrhoea.
Caesalpinia sappan L.	Caesalpinaceae	Bastard teak, Bengal kino	Wood, bark	Red	Decoction provides relief in mild cases of dysentery and diarrhoea.
Carthamus tinctorius L.	Asteraceae	Safflower	Flower	Red, yellow	Oil applied to sores and rheumatic swelling; also used in case of jaundice.
Cassia auriculata L.	Caesalpinaceae	Tanner's cassia	Flower, seed	Yellow	Leaves and fruit anthelminthic. Seeds used in eye infection. Roots employed in skin disorders.

(*Contd...*)

Table 3. (*Contd...*)

Botanical name	Family	English name	Parts used	Colour	Medicinal use
Cassia occidentalis L.	Caesalpinaceae	Negro coffee	Seed	Brown	Seeds used in external application for skin disorders.
Cassytha filiformis L.	Lauraceae		Stem	Brown	Used in bilious afflictions, urethritis chronic dysentery, and eye and skin infections.
Cedrela toona Roxb./ *Toona ciliata* Roem		Red cedar	Flower, seed, leaf	Yellow/red	Bark used for chronic dysentery of infants and also in external application of ulcer.
Citrus medica L.	Rutaceae	Citron, lime	Bark	Black	Used for curing dysentery.
Clitoria ternatea L.	Fabaceae		Flower	Blue	Roots are powerful cathartic and diuretic.
Cordia myxa L.	Boraginaceae		Roots, leaf	Yellow, red	Astringent, anthelmenthic, diuretic demulcent and expectorant, used in diseases of chest and urinary tract.
Coscinium fenestratum (Gaertn.) Clolebr.	Menispermaceae	Tree turmeric	Seed, bark, wood	Red	Root considered bitter tonic and used in dressing wounds and ulcers.
Crocus sativus L.	Iridaceae	Saffron	Flower	Yellow, orange	Used as sedative and emmenagogue.
Cyanometra ramiflora L.	Caesalpinaceae		Wood	Black	Oil from seed used for leprosy, scabies and other cutaneous diseases.
Dioscorea bulbifera L.	Dioscoreaceae	Potato yam, air potato	Tuber	Pale colour	Used for ulcers, piles and dysentery.
Diospyros embryopteris Pers.	Ebenaceae	Gaub persimmon	Fruit	Brown	Seeds used for dysentery and diarrhoea.
Dipterocarpus turbinatus Gaertn.	Dipterocarpaceae	Common Gurjan tree	Twig, bark	Yellow, brown	Oleoresin, an oil is applied to ulcers.
Elaeodendron glaucum (Rottb.) Pers.	Celasteraceae		Bark	Red	To cure stomach pain.
Eugenia jambolana Lam.	Myrtaceae		Bark, leaf	Red	Decoction of bark and seeds used in diabetes.
Euphorbia tirucalli L.	Euphorbiaceae		Wood	Red	Toothache.
Flemingia congesta Roxb.	Fabaceae		Pod	Red, yellow	Roots used for preparation of external application for ulcer and swelling.
Galium aparine L.	Rubiaceae	Goose grass	Root	Purple	Infusion of herb used as an aperient diuretic, refrigerant and antiscorbatic.
Galium rotundifolium L.	Rubiaceae		Root	Yellow, brown	Used for colic, sore throat and chest complaints.
Galium verum L.	Rubiaceae	Cheese rennet	Root	Yellow, red	Considered purgative and diuretic. Decoction used in epilepsy and hysteria.
Garcinia mangostana L.	Guttiferae	Mangosteen	Fruit	Black	Used in diarrhoea and dysentery.
Gardenia jasminoides J. Ellis	Rubiaceae	Cape jasmine	Fruit	Yellow	Roots used in nervous disorder, fruit stimulant, emetic and diuretic used in jaundice and pulmonary disorder.
Geranium wallichianum D.Don	Geraniaceae	Wallich cranesbill	Fruit, root	Yellow, red, brown	Astringent used in toothache and eye infection.
Haematoxylon campechianum L.	Mimosaceae	Log wood	Heart wood	Red	Decoction used in diarrhoea, dysentery, atonic dyspepsia and leucorehoea.
Heliotropium trigosum L.	Boraginaceae		Leaf	Black	Laxative and diuretic. Juice applied to sore eyes; also used for boils, wounds and ulcers.

(*Contd...*)

Table 3. (*Contd...*)

Botanical name	Family	English name	Parts used	Colour	Medicinal use
Indigofera aspalathoides Vahl.	Fabaceae	Wiry indigo	Leaf	Blue-black	Leaves, flowers and tender shoots demulcent, used in cancer and leprosy.
Indigofera hirsuta L.	Fabaceae		Leaf	Indigo	Decoction of leaves in stomachic and used in diarrhoea and jaws.
Indigofera tinctoria L.	Fabaceae	Indian indigo, common indigo	Leaf	Blue, blue-black	Extract used in epilepsy and other nervous disorders; in the form of ointment used for sores, old ulcers and piles. Root used in urinary complaints and hepatitis.
Jatropha curcas L.	Euphorbiaceae	Physic nut, purging nut	Bark, leaf	Blue	Used in sciatica, dropsy and paralysis, and externally for skin disorders and rheumatism.
Kirganelia reticulate (Poir) Baill.	Euphorbiaceae		Bark, root	Red	Leaves diuretic, used for diarrhoea in case of infants.
Lawsonia inermis L.	Lythraceae	Henna	Leaf	Orange, red	Used as prophylactic against skin disorders.
Lycopus europaeus L.		Gipsy wort	Fruit	Green	Useful for treatment of hyperthyrosis; inhibits the action of thyrotropic harmine and thyroxin output of thyroid.
Mallotus philippiensis Muell.	Euphorbiaceae	Kamala tree	Fruit	Red	Glandular hairs from fruits yield a Kamala powder, employed as an antioxidant for ghee, as an antihelminthic and for cutaneous infections.
Malphigia glabra L.	Malpigiaceae	Barbedos cherry	Flower	Yellow	Fruits used in diarrhoea, dysentery and liver disorders.
Melastoma malabathricum L.		Indian rhododendron	Fruit	Black, purple	Bark and leaves used for skin disorders.
Michelia champaka L.	Magnoliaceae	Champak	Flower	Yellow	Flowers uses as tonic for stomachache and carminative, used in dyspepsia, nausea and fever, also useful as a diuretic in renal diseases.
Mimusops elengi L.	Sapotaceae	Bullet wood	Bark	Brown	Bark and fruits used in diarrhoea and dysentery.
Morinda citrifolia L.	Rubiaceae		Root	Red, yellow	Fruits used for spongy gums, throat infection, dysentery, leucorrhoea and sapraemia.
Morinda umbellata L.	Rubiaceae		Root	Red	Decoction of roots and leaves useful in diarrhoea and dysentery.
Naregamia alata Wight & Arn.	Meliaceae		Leaf	Red	Useful in chronic bronchitis.
Nyctanthes arbortristis L.	Oleaceae	Coral jasmine	Flower	Yellow	Used in rheumatism and fever.
Oldenlandia umbellata L.	Rubiaceae	Chay-root	Root	Red	Used for asthma and bronchitis.
Oxalis corniculata L.	Oxalidaceae	Indian sorrel	Leaf	Blue	Fruit juice of plants given in dyspepsia, piles, anaemia and tympanitis.
Papaver rhoeas L.	Papaveraceae	Corn poppy	Petal	Red	Fresh petals used in preparation of galinicals, syrup or tincture used for colouring medicines.
Peltophorum pterocarpum (DC.) K.Heyne	Caesalpiniaceae	Copper pod	Wood, leaf	Brown, black	Used for eye infection, muscular pains and sores.
Perilla ocimoidea L.	Labiatae	Kumboo millet	Fruit	Black	Herb sedative, anti-spasmodic and diaphoretic, used in cephalic and uterine disorders.
Pistacia intergerrima L.	Anacardiaceae	East Indian mastechae	Flower, leaf	Yellow	Useful for asthma and other respiratory tract disorders and also for dysentery.
Toddalia asiatica (L.) Lam.	Rutaceae	Wild orange	Root	Yellow	Has diaphoretic, stomachache relieving and antipyretic properties. Root is also used for treatment of cough.

associated with a low risk of cancer[18]. Also it is interesting to note that lycopene is the precursor to bixin and norbixin, pigments from *Bixa orellena*, commonly used for colouring foodstuff.

Apart from dye-yielding property, some plants are also used traditionally for medicinal purposes[9,11–18] (Table 3).

Natural dyes obtained from minerals

Ocher is a dye obtained from an impure earthy ore of iron or ferruginous clay, usually red (hematite) or yellow (limonite). In addition to being the principal ore of iron, hematite is a constituent of a number of abrasives and pigments.

Natural dyes obtained from animals

Cochineal is a brilliant red dye produced from insects living on cactus plants. The properties of the cochineal bug were discovered by pre-Columbian Indians, who dried the female insects under the sun, and then ground the dried bodies to produce a rich red powder. When mixed with water, the powder produced a deep, vibrant red colour. Cochineal is still harvested today on the Canary Islands. In fact, most cherries today have a bright red appearance through the artificial colour 'carmine', which is obtained from the cochineal insect.

Characterization of dyes

A dye can be defined as a highly coloured substance used to impart colour to an infinite variety of materials like textiles, paper, wood, varnishes, leather, ink, fur, foodstuff, cosmetics, medicine, toothpaste, etc. As far as the chemistry of dyes is concerned, a dye molecule has two principal chemical groups, viz. chromophores and auxochromes. The chromophore, usually an aromatic ring, is associated with the colouring property. It has unsaturated bonds such as –C=C, =C=O, –C–S, =C–NH, –CH=N–, –N=N– and –N=O, whose number decides the intensity of the colour. The auxochrome helps the dye molecule to combine with the substrate, thus imparting colour to the latter[19].

Chemistry of natural dyes

Dyes are classified based on their chemical structure, sources (Table 1), method of application, colour, etc. As a model study here we explain the chemistry as described by Vankar[20]. They are classified into the following groups based on chemical structure (Scheme 1).

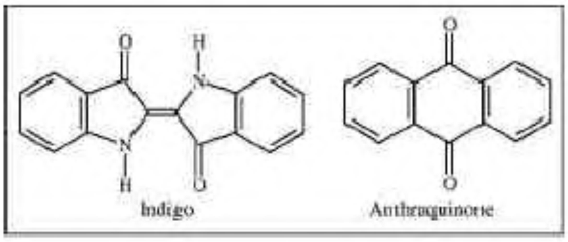
Indigo dyes: This is considered to be the most important dye obtained from the plant *I. tinctoria* L.

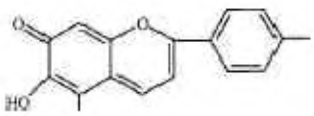
Anthroquinone dyes: Some of the most important red dyes are based on the anthroquinone structure. These are obtained from both plants and insects. These dyes have good fastness to light. They form complexes with metal salts and the resultant metal–complex dyes have good fastness.

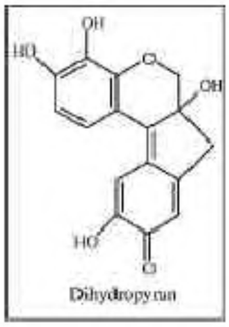
Alpha-hydroxy naphthoquinones: The most prominent member of this class of dye is henna or lawsone (*L. inermis* L.).

Flavones: Most of the natural yellow colours are hydroxy and methoxy derivatives of flavones and isoflavones.

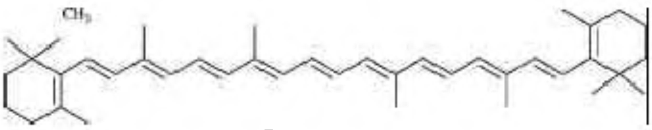
Dihydropyrans: Closely related to flavones in chemical structure are substituted dihydropyrans.



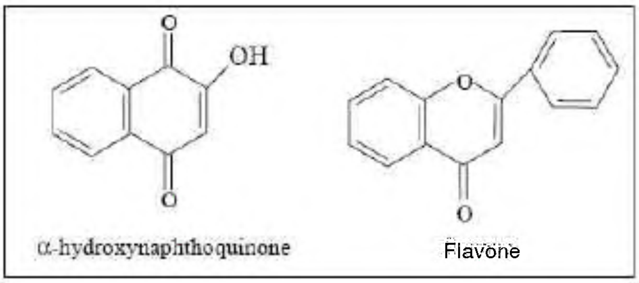




OCH_3 Anthocyananidin



Beta-carotene



Molecular structure of lycopene.

Scheme 1.

Anthocyananidins: Carajurin obtained from *Bignonia chica* Bonpl.

Carotenoids: In these the colour is due to the presence of long conjugated double bonds. Typical examples for this group are annato (*B. orellena*) and saffron.

Preparation of dyes

The dye is generally prepared by boiling the crushed powder with water, but sometimes it is left to steep in cold water. The solution then obtained is used generally to dye coarse cotton fabrics. Alum is generally used as a mordant. Flowers of *Butea monosperma* (Lam) Taubert. yield an orange-coloured dye, which is not fast and is easily washed away. For the purpose of colouring, the material is steeped in a hot or cold decoction of the flowers. A more permanent colour is produced either by first preparing the cloth with alum and wood ash, or by adding these substances to the dye-bath. The dye indigo is produced by steeping the plant in water and allowing it to ferment. This is followed by oxidation of the solution with air in a separate vessel. *Mallotus philippinensis* Muell. yields an orange colour, used for dyeing silk and wool. To prepare the annatto dye from *B. orellena* L., the fruits are collected when nearly ripe. The seeds and pulp are removed from the mature fruit and macerated with water. Thereafter, they are either ground up into an 'annatto paste' or dried and marketed as annatto seeds. Sometimes when the seeds and pulp are macerated with water, the product is stained through a sieve and the colouring matter which settles out is collected and partially evaporated by heat and finally dried in the sun[21].

Advantages and limitations of natural dyes

Natural dyes are less toxic, less polluting, less health hazardous, non-carcinogenic and non-poisonous. Added to this, they are harmonizing colours, gentle, soft and subtle, and create a restful effect. Above all, they are environment-friendly and can be recycled after use.

Although natural dyes have several advantages, there are some limitations as well. Tedious extraction of colouring component from the raw material, low colour value and longer time make the cost of dyeing with natural dyes considerably higher than with synthetic dyes. Some of the natural dyes are fugitive and need a mordant for enhancement of their fastness properties. Some of the metallic mordents are hazardous. Also there are problems like difficulty in the collection of plants, lack of standardization, lack of availability of precise technical knowledge of extracting and dyeing technique and species availability. Tyrian purple is obtained from the rare Mediterranean molluse *Murex brandavis*. In order to obtain 14 g of the dye about 1200 molluses are needed.

Technology for production of natural dyes and colourants

Technology for production of natural dyes could vary from simple aqueous to complicated solvent systems to sophisticated supercritical fluid extraction techniques depending on the product and purity required. Purification may entail filtration or reverse osmosis or preparatory HPLC, and drying of the product may be by spray or under vacuum or using a freeze-drying technique. Use of biotechnological methods to increase the yield of colourants in plants is also being attempted in several laboratories in India.

Genetic variation and dye content

Siva and Krishnamurthy[22] studied an important dye-yielding plant, *B. orellena*, for understanding the relationship between degree of genetic diversity (using isozymes) of various populations and their pigment content. Bixin ($C_{25}H_{30}O_4$) and norbixin ($C_{24}H_{28}O_4$) are carotenoid pigments that form the main components of *B. orellena*. The total amount of these two pigments in seed materials collected from ten different geographical localities was estimated using HPLC. It was interesting to learn that the lowest band frequency shows the least total pigment and bixin content. Similarly, greater band frequency (i.e. genetic diversity) shows greatest dye content. In other words, it is likely that individuals with greater genetic diversity may have high dye content. Further critical study is needed to establish the relationship between the geographical localities with the dye content[23].

Conclusion

Nowadays, fortunately, there is increasing awareness among people towards natural products. Due to their non-toxic properties, low pollution and less side effects, natural dyes are used in day-to-day food products. Although the Indian subcontinent possesses large plant resources, only little has been exploited so far. More detailed studies and scientific investigations are needed to assess the real potential and availability of natural dye-yielding resources and for propagation of species in great demand on commercial scale. Biotechnological and other modern techniques are required to improve the quality and quantity of dye production.

Due to lack of availability of precise technical knowledge on the extraction and dyeing technique, it has not commercially succeeded like synthetic dyes. Also, low colour value and longer time make the cost of dyeing with natural dyes considerably higher than with synthetic dyes.

Mahanta and Tiwari[2] identified a few rare, endangered and endemic dye-yielding plant species during their study in Arunachal Pradesh. They reported that species of *Ilex* *embelioides*, *Phaius tankervilliae* and *Entada purseatha* are rare treasures amidst the rich floral diversity of Arunachal Pradesh. Numerous plant species are found to have an important role in the day-to-day life of the ethnic and local people. However, it is a matter of concern that the indigenous knowledge of extraction, processing and practice of using of natural dyes has diminished to a great extent among the new generation of ethnic people due to easy availability of cheap synthetic dyes. It has been observed that the traditional knowledge of dye-making is now confined only among the surviving older people and few practitioners in the tribal communities of Arunachal Pradesh. Unfortunately, no serious attempts have been made to document and preserve this immense treasure of traditional knowledge of natural dye-making associated with the indigenous people. Lack of a focused conservation strategy could also cause a depletion of this valuable resource.

It is time that steps are taken towards documenting these treasures of indigenous knowledge systems. Otherwise, we are bound to lose vital information on the utilization of natural resources around us.

To conclude, there is an urgent need for proper collection, documentation, assessment and characterization of dye-yielding plants and their dyes, as well as research to overcome the limitation of natural dyes.

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