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Natural dye: Antiquity to future perspective

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Abstract
Every culture has a tale and a connection to colours. Generally speaking, a dye is a coloured material with an affinity for the substrate it is being applied on. Since the dawn of humanity, colourants have been used to paint and dye objects, people, and clothing. The walls of Spain's Altamira cave contain the earliest documentation of human usage of colourant materials, which goes back to between 1500 and 900 BC. Natural colour shares (39%) over synthetic colour shares (37%). Over 35 million people are directly employed in the industry, which also contributes roughly 17% to the nation's export profits, 14% to industrial production, and 4% to the GDP. India exports textiles for around 27% of its overall foreign exchange earnings. Genetic engineering is required to create effective dye plant production systems and to increase the quality and output of dye from the selection of dye-yielding plants or conventional breeding.

Keywords: Colours, flower, industry, natural dye, textile

1. Introduction
Colour and its numerous applications have been used by all cultural groupings and on all significant geographical masses from prehistoric times. Every society has a tale and a connection to colour. The term "colourant" is used to refer to substances like dyes and pigments. Since ancient times, it has been recognised that natural colouring agents may also be employed as natural dyes. The definition of a dye, in its broadest sense, is "a coloured substance that has an affinity to the substrate to which it is being applied." The dye is often applied as an aqueous solution, and it might be necessary to add a mordant to speed up the dye's absorption by the fibre. Natural dyes have been used to colour food substrate, leather, and natural protein fibres like wool, silk, and cotton from prehistoric times as primary areas of application. Due to growing environmental consciousness and a desire to limit the use of dangerous synthetic dyes, the use of non-allergic, non-toxic, and environmentally friendly natural dyes on textiles has assumed a substantial amount of significance. In contrast to synthetic dyes, which are widely available at enticing prices and produce a variety of colour shades, natural dyes produce very unique, calming, and soft hues (Alemayehu and Teklemariam, 2014) [1]. Synthetic dyes, however, can cause skin allergies, toxic waste, and other problems for people.

2. Sources of Natural Dyes
Various places provide natural dyes. Natural dyes may be made from a variety of plant components, such as roots, bark, leaves, flowers, and fruit, and have been used since ancient times. These colours can be categorised as

1. Natural dyes from plants -Berry, flower, bark, leaf, seed etc (e.g. catechu, *Indigofera*, myrobalan, pomegranate).
2. Natural dyes from insects – Cochineal and lac.
3. Natural dyes from animal – Mollusc, murex snail, cuttlefish and shellfish.
4. Natural dyes from mineral – Clay, ochre and malachite (Verma and Gupta, 2017) [2].

3. Advantages of Natural dyes
Natural dyes have wide viability, huge potential and these are non-toxic, non-polluting, non-carcinogenic, non-poisonous, no disposal problems and environmental friendly, produce harmonizing colours, gentle, soft, lustrous and subtle creating restful and practically no or mild chemical reactions are involved in there preparation (Gulrajani, 2001) [3]. Many are water-soluble facilitates incorporation into aqueous food systems which make the qualities of natural

food colorants attractive. Since the natural dyes are of polygenetic nature, obtaining specialty and rare colour ideas can be achieved by using mix and match system. Natural dyes also have potential positive health effects like antioxidant properties along with aesthetic value and quality. There is no report of health hazard and natural dyes are anti-inflammatory, anti-allergic and radiation-protective (Visalakshi and Jawaharlal, 2013) [4].

4. Limitations of natural dyes

Natural dyes are more expensive than synthetic dyes, have a lower colour value, and are unstable during processing. The collection and extraction processes are laborious. It is challenging to duplicate shadows since agricultural product output depends on the season, location, plant type, and maturity time (Gulrajani, 2001) [3]. With a few notable exceptions, almost all natural dyes require mordants to fix them, which increases dyeing time and costs for mordants and mordanting. Processing and handling after harvest is laborious, and the scientific basis for natural dyeing has not yet been fully investigated. Additionally, synthetic fibres do not respond well to natural colours. Instability during processing as a result of dye's susceptibility to temperature, oxygen, light, and pH is an issue in the food business. When natural dyes are stored, they lose their colour or deteriorate (Visalakshi and Jawaharlal, 2013)[4]. Since there aren't many appropriate dyes available, only wool, natural silk, linen, and cotton may be coloured. The degree of fixing and fastness of natural dyes are insufficient (Gulrajani, 2001) [3].

5. History of use of the dyes

Since the dawn of humanity, colourants have been used to paint and dye objects, people, and clothing. According to Clark *et al*. (1993) [5], the earliest proof of human colourant usage was discovered in the Spanish Altamira cave's walls between 1500 and 900 BC. Tyrian purple, the first animal-derived dye (molluscs) used by Roman emperors and prominent ecclesiastics as early as 1400 BC in the late Bronze Age, was recently unearthed in Lebanon. Another historically significant dye that is being used today is indigo, a blue colour dye made synthetically for the first time by Adolf von Baeyer in 1880 from the plant *Indigofera tinctoria* (Clark *et al*., 1993) [5]. One of the oldest eras for which textile dyeing has been documented is the Neolithic Era, often known as the New Stone Age (10,200 BCE). The coloured fabrics in Egyptian tombs dates dyeing to more than 4,000 years. Alizarin, a madder-derived pigment, was discovered in chemical analyses of red garments discovered in King Tutankhamen's tomb in Egypt. When he overcame Susa, Alexander the Great remembers discovering purple garments from 541 BC in the royal treasury. In the biblical book of Exodus, when allusions to scarlet-coloured linen are made, Kermes is named. Woad, madder, weld, Brazilwood, indigo, and a dark reddish-purple were among the dyes that were well-known by the fourth century AD. Brazil was the location where the wood was discovered, thus the name Brazilwood. Alizarin (1,2,-dihydroxyanthraquinone) was the first natural dye that was commercially made from coal tar by Perkin's firm in 1869. It was obtained from another hydrocarbon known as anthracene. They produced 1 tonne that year, followed by 40 and 220 tonnes each in the next two years, and they proceeded to raise output in consecutive years. Due to the rapid price fall by 1876, the Dutch and French madder growers who supplied the natural dye had lost everything (Clark *et al*., 1993) [5]. The primary colourants accessible for textile dyeing processes up to the end of the nineteenth century were natural plant-based dyes made from roots, stems, leaves, flowers, fruits, seeds, and lichens (Ingamells, 1993) [6]. The groundbreaking synthesis of mauveine by the English chemist William Henry Perkin signalled the beginning of the age of synthetic dyes. Natural dyes had almost entirely been supplanted by synthetic dyestuffs by the turn of the 20th century (Welham, 2000) [7]. Since then, many more dyes have been created by synthetic means, and the dye business now accounts for a sizeable portion of the chemical industry. In 1826, Otto Unver-dorben made the first discovery of the hues based on aniline by distilling indigo with lime and giving the end result the name crystallite. In 1834, F.F. Runge discovered it in coal tar under the name kyanol. When W.H. Perkin tried to make quinine in 1856, the era of synthetic colours officially started. Later, it became simple to produce aniline from benzene (Clark *et al*., 1993) [5].

Table 1: Dye History from 2600 BC to the 20th Century

Year	Findings
2600 BC	Earliest written record of the use of dyestuffs in China
715 BC	Wool dyeing established as craft in Rome
327 BC	Alexander the Great mentions "beautiful printed cottons" in India
55 BC	Romans found painted people "picti" in Gaul dyeing themselves with Woad (same chemical content of color as indigo)
2ND and 3RD Centuries AD	Roman graves found with madder and indigo dyed textiles, replacing the old Imperial Purple (purpura)
Late 4TH Century	Emperor Theodosium of Byzantium issued a decree forbidding the use of certain shades of purple except by the Imperial family on pain of death
700's	Dyeing with wax resist technique mentioned in a Chinese manuscript (batik)
925	the Wool Dyers' Guilds first initiated in Germany
1200	Rucellia, of Florence, rediscovered the ancient art of making purple dye from lichens sent from Asia Minor
1290	The only blue dye of the period, Woad, began to be raised extensively in Germany. The 3 major dyes were now: woad, madder and weld.
1321	Brazilwood was first mentioned as a dye, source from East Indies and India.
Early 15th Century	Cennino Cennini of Padua, Italy described the block printing in his treatise called Method of Painting Cloths by Means of Moulds.
1429	the 1st European book on dyeing Mariegola Dell'Arte de Tentori was published in Italy
1464	Pope Paul II introduced the so-called "Cardinals' Purple" which was really scarlet obtained from the Kermes insect. This became the first luxury dye of the Middle Ages just as Imperial Purple (Murex) had been for the ancient world.
1507	France, Holland and Germany started the industrial cultivation of dye plants

1614	dyeing cloth "in the wood" was introduced in England: logwood, fustic, etc.
1630	Drebbel, a Dutch chemist, produced a new brilliant red dye from cochineal and tin. It was used at Goblein (Paris) and the Bow Dyeworks (England)
1727	A method of bleaching linen with kelp (seaweed) was introduced in Scotland
1745	Indigo begins to be grown in England, after the Revolution when it became cheaper to import from the East Indies
1774	Swedish chemist, Scheele, discovered chlorine destroyed vegetable colours
1775	Bancroft introduced the use of quercitron bark as a natural dye
1834	Runge, a German chemist, noticed that upon distilling coal tar, aniline would give a bright blue color if treated with bleaching powder which paved the way to the development of aniline (basic) dyes 22 years later.
1856	William Henry Perkin discovered the first synthetic dye stuff "Mauve" (aniline, a basic dye) while searching for a cure for malaria and a new industry flourished. It was a brilliant fuchsia type colour, but faded easily so our idea of the colour mauve is not what the appearance of the original colour was.
1858-59	Magenta (fuchsin) was discovered by Verguin the 2nd basic dye and more widely used than Mauve
1862	Bismarck Brown developed by Martius and Lightfoot, first soluble azo dye
1863	Aniline Black, developed by Lightfoot, a black dye produced by oxidation of aniline on the cotton fibre.
1868	Graebe and Liebermann, German chemists, produced alizarin (synthetic madder). This was the first synthetic substitute of a vegetable dye. W.H.Perkin also synthesized it about the same time, but independently.
1878	Von Baeyer synthesized synthetic indigo. It was not marketed until 1897
1880	Thomas and Holliday, England, synthesized the first azo dye formed on the fabric by coupling. Vacanceine red formed by treating fabric with napthol and then dipping in a diazolized amine, a very fast category of dyes.
1885-89	Chardonnet, France, made the first successful rayon and exhibited at the Paris Exposition of 1889.
1901	Rene Bohn patented his invention of Indanthrene Blue RS, the first anthraquinone vat dye, a category of dyes with extremely good fastness to light and washing.
1921	Bader developed soluble vat colours, the Indigosols.
1924	Indigosol 0, by Baeyer and Sunder, 1st commercial indigosol dye.
1938	Nylon formally introduced to the public.
1948	Textiles became second largest industry in USA. The average consumer consumption per capita of fibers: 27 lbs cotton, 6.3 lbs rayon, 4.9 lbs wool.
1951	Irgalan dyes introduced by Geigy, 1st neutral pre-metallized dyes (less requirement of acid than Neolans) Cibalans are the same type.
1956	ICI in England introduced Procion, first range of fiber reactive dye - this dye had a major impact on industry as well as textile artists worldwide.

(**Source:** Susan, 1982) [8]

In the history of dyeing, there are two distinct periods: "pre-aniline," which started in 1856, and "post- aniline." Some of the earliest dyes come from animal sources. Early on, India used lac dyes derived from a certain insect, but this had the disadvantage of making the cloth sticky and resinous. In 1518, the superb red dye eochincal-a far more beautiful natural colour-was exported from Mexico to Europe (Decelles, 1949) [9]. A Fragments of cotton fabric discovered at Mohenjo-daro show that ancient Indians mastered the practise of clothing dyeing as early as Harappa. With their unique trading routes, specialisations, and colour palettes, Gujarat, Masulipatnam, Kalahasti, Pulicat, and the Tanjore region of Tamil Nadu were key centre of artisanal dyeing. For instance, the eastern coast favoured dye brush painting (also known as Kalamkari) whereas the western shore preferred block printing.

6. Status of Natural dye in World market

Since the invention of synthetic colour, the demand for natural carotenes has shrunk. Additionally, natural hues are more unstable and costly in nature. According to Rymbai *et al.* (2011) [10], the EU's top markets for natural colours are the UK, Germany, France, Italy, and Spain. Recently, the markets in developing nations like China, India, and South Korea have also been expanding (Chattopadhyay *et al.*, 2008) [11]. Between 2007 and 2011, the value of the global market for food colours increased by 13%, reaching €1.6 billion. Shares of natural colours (39%) outnumber those of artificial colours (37%). This trend was particularly apparent in Europe as a result of substantial media attention of the detrimental health consequences of certain synthetic hues. Between 2009 and 2011, over 85% of the colours used in new foods and beverages were natural, and the market in Europe for natural colours was worth between €155 and €193 million (EIBI, 2014) [12].

7. Present status of dyes in Textile Industry in India

One of India's major industries, textiles were mostly unorganised before to 1991. It provides 17% of the export earnings, 14% of industrial output, and 4% of the GDP of the country. It is the second-largest employment in India, and 27% of its total foreign exchange profits come from textile exports. By 2025–2026, the Indian textile and apparel market is projected to increase at a 10% CAGR, totalling US$190 billion. India accounts for 4% of global textile and clothing trade. India is the world’s largest producer of cotton. Till January 2023, ready-made garment (RMG) cotton exports, including accessories, totalled US$7.68 billion. By 2027, it is anticipated to reach more than $30 billion, with an estimated 4.6-4.9% worldwide market share (Anonymous, 2023) [13].

8. Present situation of natural dyes

Indians are pioneers in the field of natural dyeing, which has gained popularity as a result of environmental consciousness. Natural dyes are used to colour food, medicine, cosmetics, and textiles. They come from numerous plant components and provide unusual, calming, and mellow hues. However, due to an overwhelming demand, a lack of documentation, and technical expertise on extraction and dying methods, the usage of natural dyes has been declining (Divya *et al.*, 2013) [14]. India is one of the eight main hubs for the genesis and diversification of domesticated species, one of the twelve nations with the most variety in the world. It has about an equal number of its wild counterparts as well as 400 domesticated crop varieties and 490,000 plant species, 17,500 of which are angiosperms. It is a treasure trove of natural resources with 450 species that can produce colours (Siva, 2007) [15].

9. Potential use of Natural dyes

The food industry, pharmaceutical business, textile industry, leather industry, and cosmetics sector may all employ natural dyes to colour products.

9.1 Textile industry

Dyes can be applied to clothing and used to colour textiles like yarn and silk and wool fabrics. The dyes annatto, indigo and harda kamala are frequently employed. According to Visalakshi and Jawaharlal (2013) [4], natural dyes are substantial and require a mordant to adhere to the cloth. One of the few surviving natural dyeing facilities in the world that specialises in the natural indigo fermentation Process is The Colours of Nature. Environmentally friendly production techniques also conserve water. Tannin, turmeric, and indigo are employed as ingredients with advantageous effects, while alum, a non-polluting mordant, is used to set the colours. Samanta and Agarwal (2009) [16] distinguished between standard and non-conventional techniques for the dying process. In the traditional approach, dying can be done in an acidic, alkaline, or neutral bath, but in the unconventional method, high temperature and high pressure dying as well as ultrasonic dying are employed. According to Mohanty *et al*. (1987) [17], cotton and silk were dyed using various mordants, including babool, tesu manjistha, heena, indigo, marigold, etc. By using different mordants, different hues can be produced, such as black to brown and green to yellow. In Maharashtra, Gujarat, and Rajasthan, a cotton cloth is typically dyed using a combination of dunging, washing, bleaching, steaming, steeping in alkaline lye, rinsing, myrobolan solution-soaking, drying again, and pre-mordanting by dipping it in an alum-and-water solution. However, haldi, babool, madder, palash, and marigold are typically utilised in West Bengal as natural dyes (Mohanty *et al*., 1987) [17]. According to reports, neem leaf dyeing using ultrasonic energy results in more uniform dying, greater dye absorption, and improved light and wash fastness on cotton fabric (Senthilkumar *et al*., 2002) [18]. According to Tiwari *et al*. (2002) [19], cotton textiles were dyed using sappan wood and tulsi leaf extract using ultrasonic dyeing techniques. Ultrasonic dying has several advantages over conventional dying since it uses less heat to produce the same shade (Lokhande *et al*., 1999) [20]. Eco-friendly sonicator dyeing of cotton with *Rubia cordifolia* employing biomordant and conventional and ultrasonic techniques of dying of cotton fabric with aqueous extract of *Eclipta alba* were described by Vankar *et al*. (2008) [21]. Higher colour intensity levels achieved by latter are seen as a result of fading. Using alum, ferrous sulphate, copper sulphate, and stannous chloride as mordants, Jothi (2008) [22] extracted natural dyes from African marigold flowers for textile coloration, resulting in a wide range of colour shades on cotton, silk, and wool fabrics. She also reported that washing did not affect the surface colour, but that some colour change was observed after washing with soap. When applied to textiles, the methods Grover and Patni (2011) [23] examined for aqueous extraction from *Woodfordia fruticosa* flower parts produced a variety of colour colours in the cotton-jute mix sample. According to Sabarudin *et al.* (2016) [24], the betacyanin found in the bract of Bougainvillaea flowers can be utilised as a natural dye in the textile sector. They said that the greatest absorbance was at 2.3 and the optimal SLR for the extraction process was at 0.1. Ramprasath *et al*. (2017) [25] separated natural colours from marigold and *Hibiscus rosa-sinensis* flowers and examined them using GC-MS, UV-Visible, and IR Spectroscopy instrumental analysis. Through GC-MS, they were able to identify several alkaloids, glycosides, flavonoid derivatives, and phenols. The extracted dyes are excellent choices for using in textile dyeing. In order to colour cotton, silk, and wool fabrics, Patil *et al*. (2016) [26] extracted the dyeing pigments from red rose blooms using several solvent extraction procedures. When treated to various mordants, they produced various pink and yellow hues. Using different combinations of mordants, such as myrobolan: nickel sulphate, myrobolan: aluminium sulphate, and myrobolan: potassium dichromate in different ratios, Kumaresan *et al.* (2011) [27] conducted an experiment on the colour fastness properties of the flower of *Cordia sebestena* applied as a dye on silk. They noted that this dye produces a wide range of soft and light colours on silk and observed that test samples exhibited excellent fastness to. In a study done by Baishya *et al*. (2012) [28], it was discovered that fabrics mordanted with ferrous sulphate had good light fastness, rub fastness, and wash fastness properties when dyed with a bio-colorant made from a *Callistemon citrinus* flower. This colourant was extracted through boiling. Various mordants, or perhaps none at all, can be used to successfully dye silk cloth using rein wardtia flowers. Since they have no negative effects on the physical characteristics of coloured cloth, stannous chloride, ferrous sulphate, Indian gooseberry, and babool can be utilised as mordants (Yadav *et al*., 2013) [29]. A commercially effective method for dying Pashmina fabrics may be achieved by employing natural dyes made from saffron flower waste, which provide vibrant greenish yellow and green hues on the cloth at acidic pH levels (Raja *et al*., 2012) [30]. According to Kumari and Neelam (2015) [31], the extraction of dye from *Curcuma longa*, *Bougainvillaea glabra* and *Cassia fistula* with 15% optimised concentration of natural and chemical mordants produced a range of colours on wool and acrylic fabric that may be utilised as naturally occurring commercial dyes.

9.2 Food Industry

The potential for natural colourants in the food business looks to be multifaceted (Dufosse, 2004) [32]. Carotene, for instance, may be utilised in food as a source of necessary vitamins, betalains can be used as a supply of essential amino acids, and anthocyanins can be used as a marker for the quality of food products. Colourants known as flavonoids have significant medicinal potential. Because *in vivo* radicals and microenvironments can vary greatly, it is sometimes advised to consume carotenoid combinations rather than simply one specific carotenoid (Quintanan-Hernandez *et al*., 1996) [33].

9.2.1 Food preservatives

The majority of natural bio-colorants have antagonistic action towards certain bacteria, viruses, and fungus to prevent food spoiling due to microorganisms. Some are also effective against insects (*Calliphora erythrrocephala*) and protozoa (*Leishmania brasiliensis*). Carotenoids are also well recognised for acting as sunscreen to preserve food quality by shielding it from harsh light. According to Norton (1997) [34], aflatoxin production by *Aspergillus flavus* (90%) and the majority of *A. parasiticus* (30%) strains is inhibited by corn carotenoids, and tests on 14 bacteria and 6 fungus revealed that *C. fistula* and *M. ferrea* extracts had antibacterial and antifungal properties.

9.2.2 Quality control markers

The amount of anthocyanin is used as an indication to assess the quality of coloured foods as part of good manufacturing practises. Fruit jam quality has been assessed using anthocyanin profiling. The genuineness of black cherry jam may simply be determined from the anthocyanin profile. Additionally, the examination of pelargonidin and cyanidin-3-glucoside levels may effectively identify strawberry and blackberry adulteration in jam. Anthocyanins, which can be extracted from red fruits and vegetables like red grapes, apples, cherries, pomegranates, red onions, red cabbage, and red berries, turn red in acidic conditions, blue in basic conditions, and purple in neutral pH conditions. They can be used as food additives in fruit fillings, snack bar preparations, dairy products like yoghurt, and confectionery products like candies (Solymosi *et al*., 2015) [35].

9.2.3 Nutritional supplements

Bio-colorants include chemical substances known as the vegetal active principles, which are created by plant cells. These are sources for acquiring biologically active pharmacological substances as well as numerous other natural chemicals utilised in a wide range of sectors, including food, medicines, and cosmetics. Since -carotene is the precursor of vitamin A, carotenoids are frequently utilised as vitamin supplements. There is a strong likelihood that rice-based diets in underdeveloped nations will result in an insufficient supply of vitamin A, which can cause night blindness and, in severe cases, xerophthalmia. Another natural food-grade bio-colorant that is an important vitamin source and is found in milk, numerous green vegetables, meat, and fish is riboflavin. In addition to its potential application as food colouring, yellow xanthins may also be employed to provide necessary dietary amino acids to meals.

9.2.4 Food colouring

There are more than 600 known naturally occurring carotenoids. These substances, which are plant pigments, give numerous fruits and vegetables their vivid colours; lycopene, which gives tomatoes their red colour, is a subject of ongoing research (Shamima *et al*., 2007) [36]. Annatto seeds are the most popular type of dye used to colour culinary goods. Butter is coloured using oil-soluble extract, whereas ghee, ice cream, and other foods are coloured using water-soluble extract. The biggest users of natural colourants are manufacturers of dairy goods, soft drink, alcoholic, and salad dressing items. Currently, the European Union Council has approved 43 colourants as food additives. For colouring, several fruit and vegetable juices or extracts are employed (Visalakshi and Jawaharlal, 2013) [4]. Aztec civilisation was aware of the use of marigold flowers as a source of culinary colouring. The most common natural source of commercial lutein is the marigold, which is one of the richest sources of carotenoids. Marigold flowers are frequently harvested for its lutein, a yellow-orange pigment (Gong *et al*., 2012) [37]. The yellow-orange pigment is added to animal feed in order to give egg yolks colour. Due to its anti-inflammatory, antioxidant, analgesic, and anti-edematous qualities, marigold is also often used in phytotherapy, dermatology, and cosmetics (Ingkasupart *et al*., 2015; Chkhikvishvili *et al*., 2016) [38, 39]. The bloom from the *Clitoria ternatea* plant is a natural source of colour for both food and cosmetics. The majority of its pigments are anthocyanins, which exhibit strong antioxidant activity and the capacity to alter colour in response to pH. These advantages may be used to create cutting-edge goods like antioxidant drinks and intelligent films that can detect pH change (Kungsuwan *et al*., 2014) [40]. Sugar, confections, and tea are all coloured using *Centaurea cyanus* as one of the ingredients. The cornflower's petals are used as a cuisine garnish as well as in salads and cornbread muffins (Lakshmi, 2014) [41]. Indigotin, a colouring substance made from *Indigofera tinctoria*, is often plentiful in the flowers that provide the blue hue most commonly used to colour linen and hair. Other related substances that are widely distributed in the plant include flavonoids, terpinoids, alkaloids, glycosides, indigotine, indigruben, and rotenoids (Lakshmi, 2014) [41]. Saffron (*Crocus sativus*) is a spice that can be used in cuisine, medicinal, industrial, as a textile colour, and perfumes. Numerous terpenes, including pinene and cineole, as well as carbonyl compounds may be found in saffron essential oil (Lakshmi, 2014) [41]. The most often used bio-colorants in food colouring include curcuminoids from Curcuma longa, paprika oleoresin from the pod of *Capsicum annum*, red cabbage juice, grape skin extract, beet juice, and anthocyanin from banana bract (Kamatar, 2013) [42]. Betalins produce a variety of colour colours at various pH levels, but their maximum level of stability was at a pH of 4-5, where the colour appears red-purple. According to Galaffu *et al*. (2015) [43], betalins can be utilised as food colour for frozen foods, ice cream, flavouring for milk drinks, powdered sweets, sauces, jams, and jellies, among other things.

9.3 Pharmaceutical and Therapeutic industry

Due to the biologically active molecules they contain, which have a multitude of pharmacological qualities including a high antioxidant, antimutagenic, anti-inflammatory, and antiartheritic action, bio-colorants may also have a significant impact on human health (Moriarity *et al*., 1998; Nagaraj *et al*., 2000) [44, 45]. According to Zeb and Mehmood (2004) [46], carotenoids function as biological antioxidants that shield cells and tissues from the destructive effects of free radicals and singlet oxygen. They also serve as an effective anti-tumor agent. Lycopene, which stops the oxidation of low-density lipoprotein (LDL) cholesterol and lowers the risk of atherosclerosis and coronary heart disease, is particularly efficient at quenching the destructive potential of singlet oxygen (Rao and Agarwal, 1998) [47]. In the macular area of the human retina, lutein, zeaxanthin, and xanthophylls are thought to act as antioxidants that provide protection. According to Taylor-Mayne (1996) [48], these substances also combat ageing, macular degeneration, and senile cataracts. Additionally, beta-cyanin has anti-oxidant and free radical scavenging qualities. Red beetroot products may offer defence against several stress-related diseases because betanin exerts a strong bioavailability (Chattopadhyay *et al*., 2008) [11]. It has been proven that flavonoids found in many plant products have strong antioxidant activity, sometimes even outperforming antioxidants sold in stores (Frankel, 1993) [49].

It has been discovered that allomelanins from plants, which are protein-free, inhibit the formation of tumor-causing cells in humans. The main commercial source of oligomeric proanthocyanidins (OPCs), a family of flavonoids commonly known as pycnogenol, a group of potent antioxidants, is grape seed extract. According to Haila *et al*. (1996) [50], canthaxanthin and astaxanthin both exhibit antioxidant properties. According to epidemiological research, ingestion of chlorophylls is connected with a lower incidence of colon cancer (Fernandes *et al*., 2007) [51]. Traditional uses of *Centaurea cyanus* include the management of kidney, gall bladder, and liver functions. Its medicinal benefits include controlling menstrual irregularities, boosting immunity, effectively washing out wounds, treating conjunctivitis, mouth ulcers, bleeding gums, and constipation, in addition to having antioxidant, antibacterial, and astringent properties (Mazza, 2007) [52]. Indigotin, a chemical compound, contains flavonoids, terpinoids, alkaloids, glycosides, indigotine, indigruben, and rotenoids. These compounds are used medicinally for a variety of conditions and have properties that are antihyperglycemic, antioxidant, anti-inflammatory, antibacterial, anti-hepatoprotective, anti-diabetic, and anticonvulsant (Hart and Cox, 2002) [53]. According to a 2003 report from the U.S. Food and Drug Administration (FDA) Dental Plaque Subcommittee of the Non-prescription Drugs Advisory Committee, sanguinarine, the primary active component of *Sanguinaria canadensis*, has been added to dentifrices (used to clean teeth) to reduce plaque and treat gingivitis and periodontal disease [54]. Additionally, it is used to relieve bloating, cure fever, croup, laryngitis, pharyngitis, and inadequate blood flow to the surface blood vessels, nasal polyps, rheumatoid arthritis, achy joints and muscles, warts, and hoarseness (Sincich, 2002) [55]

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9.4 Cosmetic Industry

Due to their advantages of having no side effects, being suitable for all skin types, UV protection, not being tested on animals, and possessing anti-aging characteristics, natural dyes are frequently used in the cosmetic industry (Joshi and Pawar, 2015) [56]. Numerous cosmetics have been created, including those for skincare, hair care, and fragrance. To name a few, the carotenoid from annatto oil has antioxidant properties that make body care products beneficial in addition to giving creams, shampoos, and lotions a bright yellow hue, and turmeric's yellow pigment has powerful antibacterial properties that can revitalise skin (Molnar and Garai, 2005; Venugopalan *et al*., 2011) [57, 58]. The anthocyanin concentration of roselle colour is widely used as a natural colourant in lipstick since it helps to reduce wrinkles, fine lines, and dry lips (Masri *et al*., 2002) [59]. Carrot oil's ß-carotene, which gives it its orange colour, may be converted into Vitamin A, a key anti-aging, revitalising, and rejuvenating agent (Gediya *et al*., 2011) [60]. Since countless years ago, henna, also known as mehendi, has been utilised as an excellent colouring agent in cosmetics. The primary pigment in henna is lawsone, which is used to colour hair and nails and is popularly used in shampoos and conditioners because to its conditioning effects. It may also be used to create temporary tattoos on the skin (Qaisar *et al*., 2019) [61]. When *Caesalpinia sappan* is young, it is yellow in colour and turns red by changing its pH, which is employed to good effect in the creation of lipsticks in eye-catching hues (Xu *et al*., 2004) [62]. According to Suganya *et al*. (2016) [63], beta vulgaris extract is widely used to manufacture goods including bleaching agents, face moisturisers, acne treatments, skin toners, astringents, shampoos, scrubs, and lip balm. According to a Japanese Chemical (Raw Material for Cosmetics) DAITO KASEI KOGYO firm, black to brown hue from extracted *Camellia thea* is employed in the cosmetic sector (Sincich, 2002) [55].

9.5 Leather Industry

By employing n-hexane to extract natural colour from onion skin, Adem (1996) [64] found that it is efficient and long-lasting for the leather sector. *Parkia biglobasa* bark and pod husk extract were used to colour leather in a number of investigations of natural dyes, for example (Campbell-Platt, 1980) [65]. Kermes dye was tested on leather during the *Hellenistic* era (Koren, 1993) [66]. *Tagetus erecta* extract was examined on sheep leather, and rhubarb (*Rheum rhabarbarum*) dye was shown to be appropriate for colouring leather (Karolia and Dilawar, 2004) [67]. Okwuchi (2006) [68] investigated the natural colouring properties of the following plants: *Khaya senegalensis* (Savanna mahogany), *Bixa orellea* (Annatto), *Allium cepa* (Red Onion), *Mangnifera indica* (Mango), and *Hibiscus sabdariffa* (Zobo). Different solvents, including acetone, ethanol, methanol, water, and chloroform, were used to extract the dye. It was discovered that the extracted materials include chromophores that affect colour and may be utilised to successfully colour leather. According to the study's findings, the zobo dye that was isolated had no microbial activity. In terms of colour fastness against rubbing, the findings indicated that the dye had been applied to the leather well. Both the quantity of dye extracted using various solvents and the percentage of dye adsorption had shown promising results. Four distinct flower species were used in extraction of dyes (Pervaiz *et al*., 2016) [69]. They examined the use of goat leather dyes from *Tagetes erecta*, *Lantana camara*, *Rosa damascena*, and *Celosia cristata*. Pre-mordanting was used to create forty hues with 10 distinct mordants, and four shades were produced without them. Using a spectrophotometer (Spectra-flash SF-650X), the colour coordinates (CIEL* a* b*) of coloured leather specimens were also investigated. The findings of their investigation demonstrated that both with and without mordants, soft and dark colours could be produced, and it was discovered that flower dyes had exceptional potential for leather dyeing as well as a chance to advance the development of sustainable fashion. Pant and Gahlot (2012) [70] conducted research on the use of cutch (*Acacia catechu*) as a natural dye for colouring chrome-tanned sheep crust leather. For the extraction of the dye, aqueous medium was used. They investigated the ideal time for dye extraction, dyeing and mordanting, and the ratio of mordants. Natural and synthetic mordants were employed to mordant leather for comparative examination, and it was shown that cutch dye combined with both types of mordants may produce a variety of brown colours. The findings of the utilised dye's colour fastness were similarly rated as acceptable to good. Amarnath and Radhika (2015) [71] investigated the leaves of *Indigo tinctoria* L. and the wood of *Haematoxylon campechianum* L. for the extraction of dye. On wet blue cow leather, the effects of two distinct natural dye applications were assessed. Metallic mordants were used as part of the pre-mordanting procedure. The chosen raw material was discovered to be an excellent source for producing a number of leather hues, including green, red, brown, and orange.

Table 2: Some flowers used for natural dying and their colour observed

Sl. No.	Common name	Botanical name	Family	Colour observed
1	African Marigold	*Tagetes erecta*	Asteraceae	Yellow
2	African tulip	*Spathodea campanulata*	Bignoniaceae	Red
3	Bottle brush	*Callistemon citrinus*	Myrtle	Purple
4	Pink Hollyhock	*Alcea Rosea*	Malvaceae	
5	Saffron	*Crocus Sativus*	Iridaceae	Dark Yellow
6	Nightflowering jasmine	*Nyctanthes arbor-tristis*	Oleaceae	Brown
7	Aparajita	*Clitoria ternatea*	Fabaceae	Blue
8	Flame of the Forest	*Butea monosperma*	Papilonaceae	Yellow
9	Yellow flax	*Rein wardtia*	Linaceae	Yellow
10	Fire Flame Bush	*Woodfordia fruticosa*	Lythraceae	Yellowish Brown
11	Scarlet Cordia	*Cordia Sebestena*	Boraginaceae	Brown
12	Cosmos orange	*Cosmos sulphureus Cav*	Asteraceae	Yellow, orange, brown
13	Khanghi	*Abution indicum*	Malvaceae	Brown
14	Bel Palash	*Butea Superba*	Fabaceae	Yellow
15	Indigo	*Indigofera tinctoria*	Fabaceae	Blue
16	Red Sandalwood	*Pterocarpus Santalinus*	Fabaceae	Red
17	Pomegranate	*Punica granatum*	Punicaceae	Yellow
18	Holly hock	*Althea rosea*	Malvaceae	Red
19	Porcupine flower	*Barleria prionitis*	Acanthaceae	Yellow
20	Tanner's cassia	*Cassia auriculata*	Caesalpinaceae	Yellow

(Jothi, 2008; Lokesh and Swamy, 2013; Baishya *et al.*, 2012; Raja *et al.*, 2012; Deka *et al.*, 2014; Siva, 2007; Yadav *et al.*, 2013; Grover and Patni, 2011; Kumaresan *et al.*, 2010; Kale *et al.*, 2005; Upadhyay and Choudhary, 2012) [22, 73, 28, 30, 74, 15, 29, 23, 27, 75, 76]

10. Conclusion

In comparison to synthetic colours, natural dyes are more ecologically responsible, culturally meaningful, and sustainable. They offer distinctive hues, assist regional economies, and encourage mindful and sustainable dyeing practises across a range of sectors. In order to generate a wide range of tints and hues, artists might experiment with various mordants and dyeing procedures. Each plant or source of natural dye provides a specific range of colours. Products coloured with natural dyes gain value and individuality from this variety of colours. Natural dyes are also beneficial to regional economies and traditional arts and crafts. Small-scale farmers and craftspeople grow or collect many natural dye sources, which pays them and protects their traditional expertise and cultural legacy. We can support these communities and assist the continuance of conventional dyeing methods by encouraging the use of natural dyes. It's crucial to remember that natural colours have certain drawbacks as well. They may fade over time or when exposed to sunshine since they might be less colorfast than synthetic dyes. To get the desired effects and improve colour fastness, some natural dyes may additionally need further processes like the use of mordants or modifiers.

11. Future Perspectives

Any industry's adoption of a technology at a large-scale depends on public demand, viability, economics, and governmental policy. Long before synthetic dyes were developed, the natural dye business was a small-scale industry. As a result, governments supported the synthetic dye-based dyeing industry. However, there were no restrictions on the testing or disposal of dye wastewater, which in the 1990s prompted a warning to assess the sustainability of synthetic dyes. The dyeing industry implemented numerous cutting-edge techniques to reduce the water, energy, and chemicals used in processing cotton textiles by 50% after selective synthetic dyes were outlawed. For instance, in the 1990s, 130–200 L of water/kg of fabric were used to dye 1 kg of cotton fabric; in the 2000s, this amount dropped to 65–70 L, and the amounts of chemicals and energy consumed fell to 40 and 50%, respectively. The textile dyeing business has been subject to several limitations in the twenty-first century, including certification and the purchase of raw materials. However, because to investments in expensive machinery, purification systems, and effluent treatment facilities, many dyeing firms in developing nations like India, Bangladesh, and Cambodia have not abided by these regulations. They relocate their activities without observing the guidelines for sustainability in order to supply the demand for apparel throughout the world. By clearly managing the supply chain of fashion textiles, all participants in the dyeing business may create a sustainable impact (Ammayappan *et al*., 2016) [72]. To build effective systems of dye plant production (e.g. nutrition, pest, weed, and disease management, husbandry, proper rotations, and soil type), it is necessary to increase the quality and yield through selection, traditional breeding, genetic manipulation, and transformation. It is vital to look for "new" local sources for natural dyes. Waste from the usage of dye plants should be repurposed for other purposes, such as the production of food or lumber (Visalakshi and Jawaharlal, 2013) [4].

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