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Review on Extraction and Application of Natural Dyes

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ABSTRACT

With the improvement of living standards, everybody is very much conscious about the environmental protection and health safety. Natural dyes have attracted more attention to the industry due to exhibiting better biodegradability and more compatibility with the environment. Characteristic colours that are gathered from common assets can be categorized as either plant, creature, mineral, or microbial colours and can be used for colouring a wide range of regular filaments. Late examination shows that it can likewise be utilized to colour a portion of the manufactured filaments too. Normal colours are not just utilized in the shading of material filaments, they are also utilized for food, prescriptions, handiwork articles, and leather preparing. Extraction and purification play a vital role in the processing of natural dyes. There are different types of extraction process currently available for these natural dyes, such as solvent extraction, aqueous extraction, enzymatic extraction and fermentation, extraction with microwave or ultrasonic energy, supercritical fluid extraction, and alkaline or acid extraction. All these extraction processes have their own advantages as well as some drawbacks depending on the parameters that need to be maintained during the extraction process. Appropriate extraction can be beneficial for specific types of such dyes. In this paper, the classification, characteristics, extraction methods, and the application of natural dyes are introduced in an organized manner.

KEYWORDS

Natural dye, Classification, Extraction, Application

INTRODUCTION

Dyes for textile dyeing can be divided into two main categories, natural and synthetic dyes. Natural dyes, also known as natural pigments, are mainly derived from plant roots, stems, leaves, flowers, fruits, animals, or natural-coloured ores. Although dyes and pigments have distinctive properties of their own, dyes are substantive to the textile substrate while pigments are not. In addition, dyes are mostly organic in contrast to pigments, which are inorganic. Moreover, pigments need a binder for application but in the case of dyes a binder is not necessary [1,2]. While synthetic dyes are extracted from petroleum and coal tar, the pigments of natural dyes come from nature. The use of synthetic dyes is widely due to their bright colours, stable properties, convenient use, and low price. However, the potential unsafe factors of synthetic dye use have aroused widespread concern. Nowadays, attention goes to the natural raw materials for textile processing and the ecological aspect of using such dyes [3].

After dyeing with synthetic dyes, the wastewater is discharged into fields, ponds, or rivers without a proper treatment process, which was brought to our attention by the ZDHC detox campaign in 2011. Such polluted water causes skin diseases when people come in contact with it and likely has a catastrophic effect on the marine ecosystem. Some of these dyes are carcinogenic and allergenic, which is yet another disadvantage of synthetic dyes [4,5]. Many dyes have already been banned, but some are still used in the industry since there has not been any alternative which would be safe for the human skin until now. Synthetic dyes are not completely biodegradable, they create ecological disruption. In contrast, using natural dyes is a completely environmentally friendly approach [6].

Due to frequent changes in fashion trends, the development of natural dye production process, as well as the application of natural dyes, draws major attention in the industry [7]. Researchers are attracted towards a vast range of possibilities in the natural flora/fauna which is full of incomparable, fascinating colours [8]. A massive number of plant and animal/insect sources have been identified as sources for the extraction of colour and their isolated use in textile dyeing and functional finishing. Natural dyes have been collected by different extractions methods. Some methods require additional arrangement to carry out the process. Some require very simple steps. This mainly depends upon the sources as well as the availability. Many scientists are still now looking for cost-effective and easy techniques for natural dye extractions. Despite this, several methods have been already established.

For sustainable dyeing, natural dyes are one of the best alternatives for synthetic dyes. In addition, natural dyes are used in food colouration, cosmetics, dye-sensitized solar cells, histological staining, pH indication, and several other fields of application. In these last few decades especially, researchers have been focusing more and more on the various aspects of natural dyes. In the processing of leather, ultrasound application is practically an eco-friendly technique [9]. Moreover, sono-leather technology is another green method of activation in leather processing [10]. By using power ultrasound, the extraction of beetroot dye gives better exhaustion in leather articles [11]. Thus, in the utilization of manufactured colours, a powerful filtration of wastewater turns out to be fundamental. These days, numerous procedures are utilized to filter the wastewater, such as layer division, particle trade, flocculation, compound oxidation, electrolysis, filtration, microbiological corruption, and photo catalysis. Although these decontamination techniques are easy, highly efficient, and require a low level of energy, the utilization of normal colours dispenses with the refinement cycle of the wastewater [12].

Although many studies regarding the review of natural dyes already exist, there is only a few studies that explain various extraction processes of natural dyes. Guha et al. wrote in their review paper about various sources of natural dyes and their applications, but discussed only a handful of sources of collection and fields of application [13]. Ahsan et al. reported on the extraction and the application of natural dyes, but have not clearly discussed any of the extraction processes [14]. Samanta et al. reviewed a chapter about the application of natural dyes in textile fabrics. In that chapter, the discussion on the application of natural dyes, UV-protection properties and antibacterial properties takes place. No extraction process is discussed [15]. Gobalakrishnan et al. reported a review on the extraction of natural dyes from trees. They discussed the extraction of natural dyes from the bark of different kinds of trees [16]. In their published review paper, they only focused on one or two of the extraction processes as well as some of the applications. There has not been any specific review paper published so far that focuses solely on the mechanism of the extraction process. In this study, the extraction and the application of natural dyes in the textile dyeing process have been investigated. In addition, the classification, the characteristics, and the application of natural dyes were also introduced in an organized manner. Furthermore, various mechanisms for the extraction process of natural dyes were also described.

HISTORY OF NATURAL DYES

In the ancient time of 3000 BC, a Chinese text depicts the list of dye recipes for obtaining red, black, and yellow on silk [17]. At the same time, the Egyptians made coloured mats and hung them on their walls. In 2500 BC, Indian religious and social practices contain references to coloured silk and gold brocades [18]. Antiquated Indian messages additionally portray a few yellow dyestuffs and note the utilization of indigo for dyeing cotton. Without a doubt, "Dyer's Thorn", otherwise called the safflower, was utilized in Egypt for the production of red and yellow shades. In 1450 BC, the Egyptians made materials of incredibly sensitive construction that were ready to be coloured in an entire scope of various tones [19]. In the years between 300 to 400 AD, Greek artifacts known as the Stockholm Papyrus contained dyestuffs details and techniques almost in a manner of modern types of dyeing recipes. The evidence of Egyptian fashion practice featuring great details teaches us that probably it was well practiced for thousands of years. In the Roman Empire, the Tyrian purple produced from mucous gland adjacent to the respiratory cavity, found in some species of Purpura and Murex species of shellfish, was highly valued. Clothes coloured with that dye were indicative of the Roman aristocracy and it is accepted that the practice started in the Phoenician town of Tire. The compositions of Pliny had left a record of a few plans being used during his period. In their first century works, we can find the arrangement and colouring of fleece with different shellfish to deliver shades of red, blue, purple, and violet. There was likewise a dyer's workshop unearthed at Pompeii [20].

In Europe, the dyers formed their independent guild in Florence. This guild had only a short life because it was dissolved in 1382, but soon afterward, dyers' guilds had appeared all throughout Europe. It originated as a trade association for members of the dyeing industry [21]. In 1540, The Plicthode Lartide Tentori by Venetian creator Giovanni Ventur Rosetti (sp - additionally recorded as Giovanventura Rosetti) records directions for utilizing both lac and indigo, as well as 217 different plans for colouring fabric, cloth, cotton, and silk with numerous assortments of dyestuffs. It provided the best colouring guidance for the following 200 years [22]. Until the middle of the most recent century, all colours were acquired from normal sources. Regular colours were removed from plant and creature sources with water, now and then, under conditions including aging [23].

CLASSIFICATION OF NATURAL DYES

Natural dyes can be classified in several ways. Classification based on colours, solubility, chemical constitution, application, and origin are very common [8]. Classification of natural dyes is depicted in Figure 1.

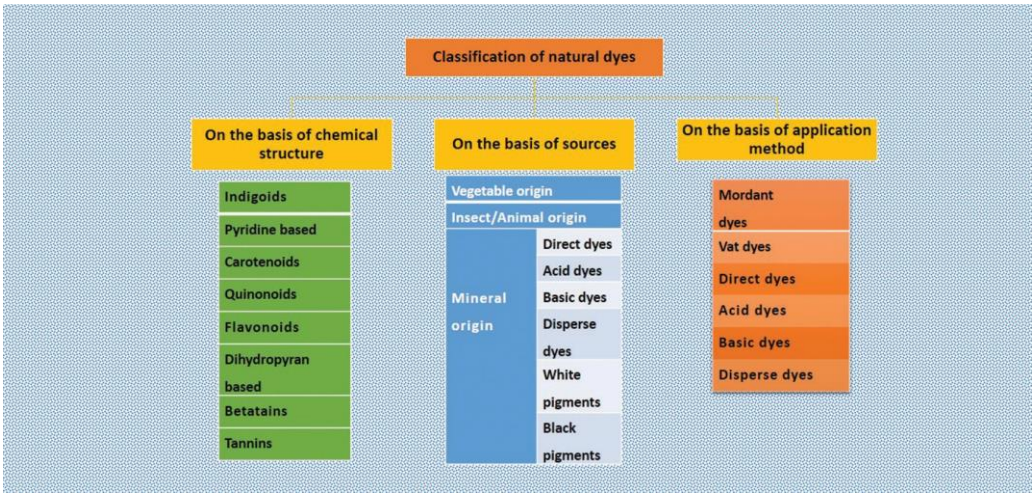

Figure 1. Classification of natural dyes

Classification According to Solubility

Natural pigments derived from plant sources are generally divided into water-soluble, alcohol-soluble, and oil-soluble pigments. Water-soluble pigment refers to the pigment which is easily soluble in water and in aqueous ethanol but difficult to dissolve in absolute ethanol and insoluble in petroleum ether. On the other hand, oil-soluble pigment refers to the pigment that is easily soluble in petroleum ether, dichloromethane, etc. Organic pigment is insoluble in water, ethanol, acetone, and other solvents. Alcohol-soluble pigment is easily soluble in polar organic solvents such as absolute ethanol and acetone [24].

Classification According to the Chemical Composition & Source

Natural dyes can be divided according to their chemical composition, i.e. whether they contain chlorophyll, carotenoids, flavonoids, or other compounds [25]. Traditionally, natural dyes are classified based on the source, which can be an animal, vegetable, or a mineral source [26]. Some of the mineral dyes in ancient times are represented in Figure 2. A predetermined number of characteristic colours were gathered from the root. Carmine red, Indian yellow, and violet are the normal gathering of such tones. Among these, the Carmine red is gathered from the scarabs living in the Cochenille plant.

In India and China, the source of Indian yellow was the urine of camels and elephants. Besides that, sea snails and kermes insects are the source of violet and red colours, respectively [26-30]. Moreover, roots, barks, leaves, flowers, and seeds are the common source of plant-based natural dyes [26,31]. Cinnabar, manganese oxide, and various copper salts were used for wall paintings in the prehistoric era, which are supposed to be the first mineral-based natural dyes [32,33].

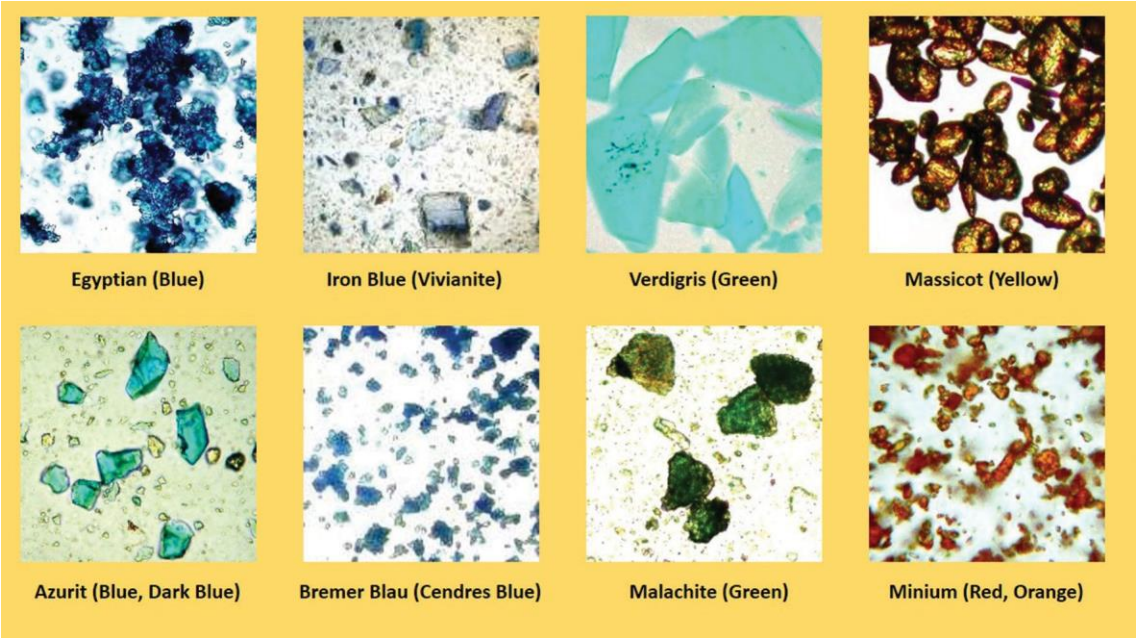

Figure 2. Mineral dyes in ancient times. Adapted from Volkert Emrath (http://www.emrath.de/pigmente.htm)

Ochre was used to dye nuns' clothes that contain hydrated alumina oxide, silica, and hydrated iron oxide. Secondary metabolites from bacteria are another source of the colouring material [3,26]. Common bacteria, such as Bacillus Brevibacterium, Flavobacterium, Achromobacter, Pseudomonas, and Rhodococcus spp also have the potential to produce colour [34]. Due to their economic viability, natural dyes were extracted from bacteria, microorganisms, and fungus which can be found in the ancient pieces of literature [26]. Polyamide

texture dyeability was explored by Vigneswaran et al. with prodigiosin shade extricated from Serratia Marcescens [35]. Monascus Purpureus shades separated from Fungstan were utilized for the hue of food sources and textures which is researched in another examination [36]. Trichoderma sp. gives high wash fastness properties in silk and wool dyeing [37].

CHARACTERISTICS OF NATURAL DYES

Natural dyes have the following advantages [38-42]**:**

i. They have few side effects and a high safety factor.
ii. They are biodegradable and environmentally friendly.
iii. Some natural dyes have certain therapeutic and health effects also.
iv. Natural dyes are generally extracted from minerals, plants, and animals, as well as natural pigments.
v. The tone is harmonious and natural, with a soft and beautiful feeling.
vi. Effluents of natural dye processing are biodegradable.
vii. Many natural dyes have the potential to absorb a significant amount of ultraviolet light.
viii. Natural dye poses functional properties, such as anti-bacterial, antifungal, and antimicrobial properties.
ix. Since some natural dyes have antioxidants in their structure, they enhance antioxidant properties of the treated materials.
x. Some of the natural dyes have inherent insect repellent properties.

Natural dyes also have some disadvantages [42-45]:

i. They are sensitive to metal ions and pH, not resistant to light, and have poor heat stability.
ii. Low dye uptake, poor fastness, and uneven dyeing.
iii. Affected by the change of natural conditions due to their complex physical and chemical structure.
iv. The extraction process is complex and expensive.
v. Limited sources for extraction.
vi. Shade diversification is limited.
vii. Mordant is needed to improve fastness which is sometimes not ecological.
viii. Reproducibility is a major concern.
ix. They can only be use for natural fibres.
x. Some natural dyes create allergic reactions in contact with the skin.
xi. The availability of natural dyes is seasonal.

EXTRACTION AND SEPARATION OF NATURAL DYES

While processing natural dyes, extraction and purification are the most important steps [26]. Before starting the extraction process, it is essential to determine the solubility of the natural dyes since the processing is very complex. The traditional chemical separation method is commonly used for the extraction and separation of natural products, which is still used up to date. It is mainly designed according to the principles of different solubility of active components in different solvents, and crystallization and other methods can be considered as well. This method needs no special equipment and is easy to operate. Following are the main natural dye extraction methods [26,46].

- Solvent extraction
- Aqueous extraction
- Enzymatic extraction and fermentation
- Extraction with microwave or ultrasonic energy
- Supercritical fluid extraction
- Alkaline or acid extraction

Solvent Extraction

This process is simple, investment of equipment is low, the technology is easy to learn and grasp, and has the most practical applications. Extracted dye purification and solvent removal, as well as reuse, is easier. The efficiency of water/alcohol extraction is higher compared to the aqueous method [26,47].

In this method, water-soluble pigments are usually extracted using water or hydrophilic organic solvents such as ethanol, methanol, and acetone, depending on the structure of the natural colourant. On the other hand, fat-soluble pigments are extracted by hexane, dichloromethane, and petroleum ether. The solubility of the solvent to the solute to be dissolved should be high, and the solubility of other solutes should be high as well.

The solubility of impurities is low, solvent sources are wide, non-toxic, and the boiling point is appropriate, which is conducive to recycling. The specific extraction methods include leaching method, percolation method, decocting method, reflux extraction method, and continuous reflux extraction method, which are very common. The factors affecting the extraction include the degree of grinding, extraction time, temperature, equipment, and solvent selection. Less degradation occurs at low-temperature processing. The main disadvantages of this method are toxic residues; greenhouse gas as well as chlorophyll and waxy substances together create processing difficulties [26,48].

Aqueous Extraction

The aqueous extraction method is conventional, simple, and suitable for the extraction of plant components that can be distilled with steam without changing the molecular structure. To escalate the extraction efficiency the coloured materials are cut into small pieces then crushed into powder form and stored overnight in a steel container or even longer to loosen the cell structure [26,49]. These compounds are incompatible with water or slightly soluble and have a certain vapor pressure at the boiling point of 100 °C. The substance can be carried out with the steam when the water boils. After condensation, it is isolated by an oil-water separator to separate the water to obtain the required plant components. The boiling and separation process may be repeated depending on the extraction outcomes. A trickling filter can easily separate the dye and thin plant residues. However, the colour yield of temperature-sensitive dyes may be affected by boiling, so low temperature is recommended. Dyes obtained by this process can be used for textile applications. Like all methods, this method also has some disadvantages like, long processing time, high water usage, and temperature [50]. Similarly, the fractionation method uses the different boiling points of liquid components for fractionation, and then refining and purification. Flowers from plant sources are extracted by this method easily. One researcher successfully extracted dye from the African marigold flower simply by boiling it in distilled water for 2 hours and using a simple filtration process [51].

Enzymatic Extraction & Fermentation

Recent developments in biotechnology for the extraction of effective components from natural plants are becoming popular. There is a selection of appropriate enzymes that can decompose plant tissues mildly, accelerate the release of effective components, and improve the extraction rate. For example, cellulase can degrade cellulose, hemicellulose, and other substances, and can cause localized loose and swelling changes of the cell wall and cytoplasmic structure, thus increasing the diffusion of effective components in the cell to the extraction medium and promoting the efficiency of pigment extraction. Temperature and pH are

the main factors affecting the effect of the enzyme. The enzyme extraction method has the advantages of milder extraction conditions and stable physical and chemical properties of active components. The structure of Geniposide in natural gardenia yellow pigment can be changed by an enzymatic reaction to produce gardenia red and blue pigment. The extraction of anthocyanins by the enzymatic method is about 72% higher than that by the solvent method [52,53]. This method is suitable for the dyes extracted from hard plant materials like the bark and roots. Fermentation methods of indigo dyes are represented in Figure 3.

Figure 3. Fermentation of Indigo dyes. Adapted from Microbial communities associated with indigo fermentation that thrive in anaerobic alkaline environments by Aino K, Hirota K, Okamoto T, Tu Z, Matsuyama H, Yumoto I, 2018, Frontiers in microbiology, 9, 2196. Copyright CC-BY terms, 2018..

Ultrasonic Extraction

Ultrasound is supposed to be one of the most efficient and energy conservative sources of power and assists the extraction as well as dyeing much faster [11]. Power ultrasound (20-100 kHz) and diagnostic ultrasound (1-10 MHz) are the two types classified according to the frequency range. Once the acoustic pressure stands in an elevated range the microbubbles become visible, increase, and oscillate in a higher frequency and finally collapse, in the case of ultrasound technology. Due to this phenomenon, micro jets and shock waves will collapse near a solid surface [55].

Ultrasonic extraction is one of the modern extraction technologies. Strong cavitation effect, high acceleration, mechanical vibration, emulsification, diffusion, crushing, and stirring of the ultrasonic wave can increase the frequency and speed of material molecules, and increase the penetration of the solvent. The breaking of cells caused by the microwave is based on the selectivity of microwave heating, instantaneous generation, and high-efficiency control of appropriate microwave conditions. There are significant differences in the ability to absorb microwave energy in different parts of biological cells, which leads to the local heating of cells in the microwave field. The parts which are rich with free water, such as liquid cells, are heated rapidly under the action of a microwave field, and the water vaporizes [56]. The cell wall or cell membrane cannot bear such large internal pressure. Therefore, the cells undergo deformation under microwave irradiation. Microwave-assisted extraction (MAE) has the advantages of having good quality, high yield, high selectivity, low time and low energy consumption [57,58]. The extraction diagram is depicted in Figure 4.

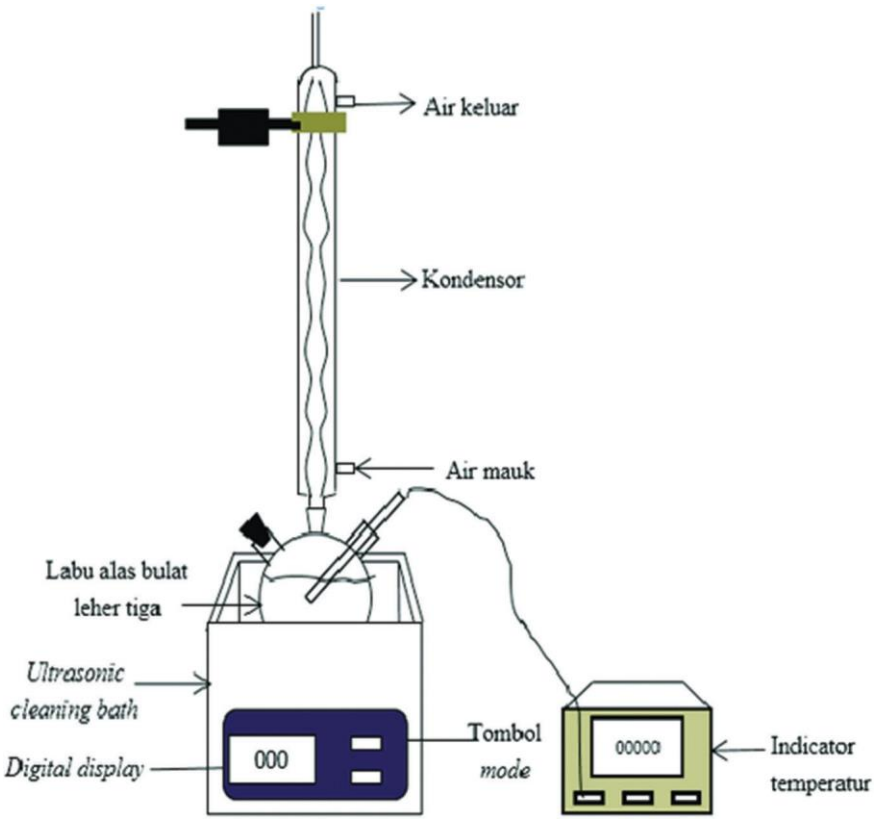

Figure 4. Diagram of the ultrasonic extraction method. Adapted from Basis of virulence in enterotoxin-mediated staphylococcal food poisoning by Fisher EL, Otto M, Cheung GY, 2018, Frontiers in Microbiology, microbiology, 9, 436. Copyright CC-BY terms, 2018.

Supercritical CO_2 Extraction

Supercritical fluid is the most complex process but has the advantages of both liquids and gasses, high density and viscosity, lower surface tension and higher solubility, which enhance rapidly with the increase in pressure. It can penetrate the matrix of extraction materials and be a very effective extraction mechanism [60]. Extraction separation and solvent removal are combined into one unit that identifies the process flow and improves the production efficiency. The extraction diagram is depicted in Figure 5.

In addition, it also has a few advantages, such as fast extraction speed, good selectivity, extraction and segregation can be carried out at room temperature or a low temperature [47]. There is no residual solvent pollution, no environmental pollution, e.g., some natural products are sensitive to heat emitted during the process, or the chemically unstable components are easily destroyed, which can preserve the original flavour and nutritional components of natural products. The research on supercritical fluid extraction technology was found earlier in the developed countries, and it was mostly found in the extraction process of hops, caffeine, and other substances. Japan started to apply supercritical technology in the extraction and purification of raw materials for food flavours, cosmetics, pharmaceutical products, and cigarettes since 1984, whereas the application of supercritical technology in China started respectively late. But better results have been achieved in China, several textile and agricultural universities in China have started to use supercritical technology to extract chlorophyll [61].

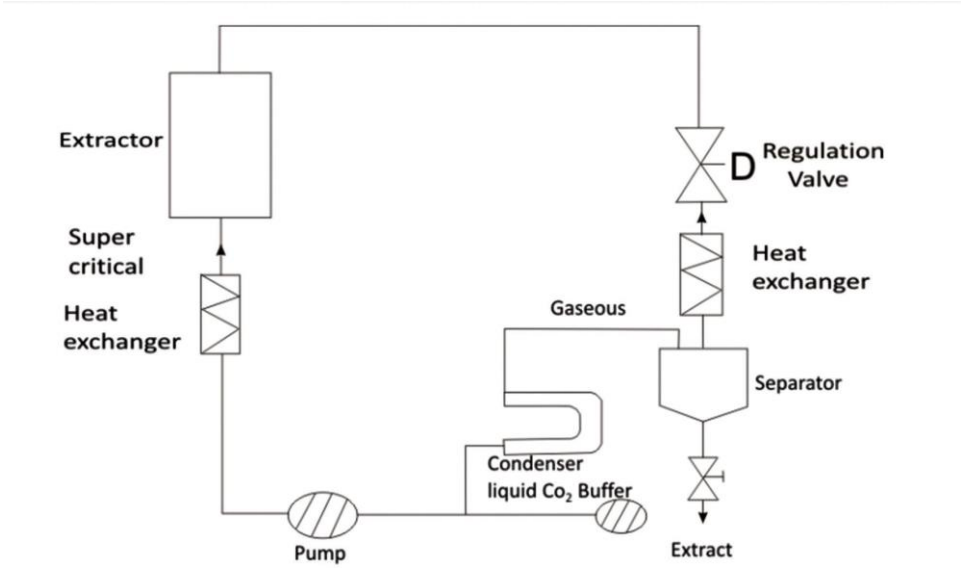

Figure 5. Diagram of the supercritical CO_2 extraction

Alkaline and Acid Extraction

Weak acid and alkali can be used for such natural dyes that contain glycosides in their structure. With the addition of these acids and alkalis, the extraction process boosts up due to the hydrolysis of glucosides. Moreover, this process increases the colour yield. With dyes containing phenolic groups, alkaline extraction gives better results [62]. Once the extraction process is completed, precipitation can be carried out using acids. Besides that, alkaline extraction can be used for the extraction of lac dye from the lac pest and the safflower leaf. Since some of the natural dyes are pH sensitive there is a possibility of losing colour yield by this process which is a major disadvantage of this process [20].

APPLICATION PROSPECT OF NATURAL DYES

After the invention of synthetic dye by Henry Perkin in 1856, natural dyes have gradually withdrawn from the field of textile colouration. When synthetic fibres appeared, natural dyes were rarely used in textile dyeing. Natural dyes were used only for cotton, linen, silk, wool, and other natural fibres. At present, with increasing attention to safety issues like health safety and environmental safety, natural dyes have been brought back to our attention, and people started to dye synthetic fibres with some natural dyes [63]. Natural dyes are especially suitable and comfortable for the development of value-added green products and for the environment in general. The application and development prospects of dyes are very good. The following aspects are particularly prominent.

Health Safety of Lingerie Product

Nowadays, with the development of living standards, people started to pay attention to health safety. Health safety is a requirement for dyeing and finishing especially for underwear, pyjamas, and other close-fitting clothing, as well as baby wear [64]. Most of the natural dyes have medicinal effects, some can resist bacteria and inflammation, some can activate blood circulation and remove stasis, some can prevent ultra-violet rays and do no harm to the human body [65]. Therefore, textiles dyed with natural dyes will become the new force of underwear and baby wear.

Health Safety of Home Textiles

Home textile products transformed from being economic and practical to being functional and environmentally friendly with the technological development. Bed sheets coloured with natural dyes, as well as quilt covers, bath towels, and other home textile products are bound to meet the ecological and environmental standards and have health care functions [66].

High Grade Silk & Wool Fabric

Natural dyes have an excellent affinity for both silk and wool. Most of the vegetable dyes can be absorbed by silk fibres under mild conditions. Some dyes can be directly applied in silk colouration. The colour effect is good, bright, and rich [67]. Only natural dyes can meet the requirements of high count, light weight and diversified functions of high-grade silk and wool fabrics, and meet the requirements of environmental protection at the same time [68]. Wool fabrics can be dyed successfully by the mordanting process followed by the regular dyeing method. The extraction of mordant can be done by both aqueous and ultrasonic extraction. Ultrasonic extraction gives better colour yield and fastness compared to the aqueous extraction process [55]. In another research wool fabric was dyed using the dyes extracted by the aqueous extraction process from wastes generated by the food and beverage industry. In this case, the mordanting process was followed, although there were some fastness issues on the dyed woollen fabric [69]. SEM characterization depicts that using the mordanting process for wool dyeing does not alter the fibre characteristics. But the extraction process is affected by pH, time, temperature and liquor ratio. So, for better dyeing performance and K/S, these variables have to be optimized [70]. Silk can be dyed using the exhaust dyeing method with dye extracted from Alpinia blepharocalyx K. Schum. by the aqueous extraction and ultrasound extraction method in the presence of alkali. The dyeing process is carried out in three directions, pre-mordanting and post-mordanting, and simultaneous mordanting-dyeing. All the dyed fabrics have excellent tinctorial properties as well as fastness [71]. However, optimum extraction conditions have to be maintained for better performance.

Modern Textiles

Many natural dyes are used in the development of new functional modern textiles because of their special composition and structure, such as Rhubarb anti-ultraviolet fabric and soybean protein fabric. The colour is bright and stable, which makes the fabric aesthetic and functional [20,72].

Different Colouration of Clothing Products

Natural dyes are especially popular in Europe and America for the colouration of decorative products. For example, natural dye is combined with traditional tie-dyeing and batik art process [73]. China will greatly improve the product grade. These dyed articles are equally popular all over the globe. Tie-dyed products with natural dyes have become inspection-free products when they enter Japan and other countries [74].

Food Colouration

The serious pollution caused by synthetic dyes and pigments is not only environmental but also food pollution which is harmful to humans as well. Some synthetic pigments have been proved to have an obvious impact on human health and have been banned from the market. The shortage of food pigments has prompted

people to turn their attention to natural dyes. Various natural pigments are extracted from nature and used as pigment additives in food and beverage colouration. Natural pigments are rich in colour, safe for humans, and non-toxic. Some natural pigments have certain physiological functions and have the effect of disease prevention and treatment [75].

Application of Natural Dyes in Daily Life

Natural dyes can be used as a lipstick colour to enhance the beauty of lips as well as for hair colouration. It can replace the additives containing harmful substances, such as heavy metals. Due to the skincare effect of some dyes, more effective products are expected to be developed. Natural dyes are not only safe and environmentally friendly but also have a distinct fragrance. They can also be used in the paper industry. In addition, it is also found that the pigments produced by bacteria, fungi, moulds, and other microorganisms can also be used as a source of natural dyes. This will diversify the sources and colours of natural dyes and application fields and greatly enrich the product range [76,77].

CONCLUSION

Natural dyes are advantageous in environmental protection, biodegradable by virtue, non-toxic, and do not cause allergies or cancer when in contact with the human skin. In the 21st century, people have fully realized that the unique nature and effect of natural dyes and their modified products are the fundamental guarantee for the sustainable development of our society. Under the impact of the wave of advocacy for green consumer goods, it will have a broader development prospect. The synthesis of synthetic dye is a complex process and needs lots of additional raw materials, such as H-acid, K-acid, J-acid, vinyl sulphone etc. In addition, it must maintain a lot of parameters for effective processing, which requires sophisticated arrangement and diversified technology. In contrast, natural dye extraction process does not need such type of toxic acids and chemicals. Utilizing an appropriate extraction process for a specific natural dye the processing cost can be minimized to an extent. In addition, further research should be carried out to overcome the drawbacks associated with natural dye application and extraction process. The development of modern extraction process and user-friendly approach will draw the attention of different industries and entice them to use natural dyes in their supply chain. Similarly, the effluent footprint generated by the natural dye processing will be advantageous for our surrounding atmosphere due to its lower environmental impact. In addition, comparative life cycle assessment of synthetic and natural dyes can also be studied by the researchers to reveal the advantages in brief. Finally, utilizing state-of-the-art technology can overcome the drawbacks associated with natural dye extraction as well as its application.

Author Contributions

Conceptualization – A.H., AL.M.; methodology – S.SK and R.M.; formal analysis – A.H. and AL.M.; investigation – R.M.; resources – R.M.; writing-original draft preparation – S.SK., A.H. and AL.M.; writing-review and editing – S.SK. and R.M.; visualization – S.SK.; supervision – R.M. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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