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Review Article

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Advances in Natural Dyeing of Hemp - An approach Towards Sustainability

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ABSTRACT
Using more sustainable materials and products, the textile sector has been able to contribute to the circular economy. Moreover, the textile industry is witnessing a paradigm shift for more sustainable production methods due to enhanced environmental restrictions and rising consumer preferences for eco-friendly textile products by using the natural fibres and natural dyes. Petroleum-derived synthetic colourants are being used extensively in the textile industry due to their wide colour range, fastness, and affordability which resulted utilisation of significant amounts of fossil fuels and resources. In result, synthetic colours contribute to pollution problems and some of them are even hazardous. Industries are actively seeking alternate approaches to mitigate the detrimental impact of manufactured colourants and chemicals on the environment and human health. This article comprehensively reviews the significant developments in the dyeing of hemp with natural dyes. Several plants like inula, agro-food industry leftovers (chestnut and onion), and logwood and madder have been used for dyeing hemp textiles and examined colour strength and the UV protection characteristics which is the growing demand of "eco-friendly" market. Further, Various natural dye extracts such as calendula (Calendula Officialis), common madder (Rubia Tinctorum L.), pomegranate peel extracts (Punica granatum) and dried Buddleja officinalis flower extracts have been utilised for dyeing the hemp fabrics with various metallic, natural mordants with different mordanting condition and assessed the various parameters like colour strength (K/S), colour fastness properties. The dyed fabrics from pomegranate peel extracts have shown significant antibacterial activity and good colour fastness against laundering, water, sea water, and perspiration. Efforts are underway to utilise natural dyes in order to achieve comparable outcomes to those achieved with synthetic dyes. Understanding the various natural materials for dyeing the Hemp and their characteristics provides a new insight for the dyeing industry and inspiring to carry out the research in similar natural materials.

Keywords: Hemp Fabric, Natural Dyes, Natural Mordant, UV Protection, Colour Strength, Colour Fastness, Antibacterial, Sustainability

Introduction
The gradual decline of stratospheric ozone since the 1970s has resulted greater health concerns globally owing to the rise of UVB rays on the surface of the earth. In 1985, the ceasing of ozone layer depletion in certain regions of the world have been detected as like the ozone hole in Antartica [1]. Further to this, the depletion of ozone layer in the lowest stratosphere has still been recorded. However, no discernible additional increase has been observed in the latitude region between 60°S and 60°N outside of the polar regions [1,2]. Because of their interconnections with climate change, ozone dynamics are hard to anticipate for the future. Therefore, it is still vital to take precautionary steps to guard against UV radiation while exposed to the sun. In addition to using sunscreen and sunglasses and adopting recommended behaviours, wearing clothing is one of the primary ways to protect oneself from UV radiation [3]. The adverse impacts of ultraviolet (UV) rays on both the environment and human health haveprompted researchers to seek out environmentally friendly

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resources. Natural materials derived from organisms such as insects, plants, and animals are bioresources that are sustainable, renewable, and have little effect on the environment [4]. An essential rationale for utilising natural goods is their ability to preserve the ecological equilibrium by circumventing any adverse effects on the environment throughout the production process [5]. Petroleum-derived synthetic colourants have nearly fully infiltrated the textile industry owing to their extensive range of colours, durability, and affordability. However, the manufacture of these goods necessitates the utilisation of significant amounts of fossil fuels and resources [6]. In addition, synthetic colours contribute to pollution problems and some of them are even hazardous. Industries are actively seeking alternate approaches to mitigate the detrimental impact of manufactured colourants and chemicals on the environment and human health. Efforts are underway to utilise natural dyes in order to achieve comparable outcomes to those achieved with synthetic dyes. The natural dye market is projected to experience an annualised growth rate (CAGR) of 11% from 2018 to 2024. Cotton fibre is the preferred natural fibre worldwide owing to its unique characteristics such as comfort and breathability. However, lack of land available for its cultivation to meet global demand is the primary disadvantage which is increasing in response to consumers' rising sensitivity to sustainable products [7]. Additional disadvantages of cotton include its substantial water consumption during production, the requirement for pesticide usage, and the specific climate conditions necessary for successful harvest [8,9]. For such reasons, the other natural fibre like hemp is blended with with cotton to produce a final product with attributes comparable to or superior to pure cotton will raise the textile process' sustainability (Milas et al., 2022). Furhter, plant-based pigments have been developed for the colouration of textiles and other materials worldwide from at least 3000 BCE [10]. Extensive research has been carried out on plant dyes, including dyes derived from almond shell, tea date palm, Lyciumruthenicum, Hibiscus mutabilis, the leaves of Ficusamplissima, and Lawsoniainermis, Rubiacordifolia, Parthenocissusquinquefolia, Adhatodavasica(Milas et al., 2022). However, the use of natural dyes gradually decreased over a time period for several reasons, including buyers' demand for strict colour requirements, a limited range of colour options, challenges in reproducing colours consistently, and difficulties in the dyeing process. In contrast, synthetic colourants became more popular than natural ones due to their standardised colour grades, abundant availability in large quantities, and ease of use in colouring textiles.

Dyeing with Aqueous Extracts of Various Vegetable Matrices

Ultra violet protection characteristics of textile materials are influenced by fibre structure, physiochemical properties, colourants and finishing chemicals, thickness, permeability, and moisture [11]. Yet, It has been revealed from the earlier research studies that UV protection properties of textiles are improved with dyes, pigments, or finishing treatments owing to their interaction at the molecular level and reduced the UV transmission. In addition, UV protection level is increased with the dye concentration. The textile industry is witnessing a shift for more sustainable production methods due to enhanced environmental restrictions and rising consumer preferences for eco-friendly textile products which is achieved by using the natural fibres and natural dyes [12,13]. Various research works have been carried out by imparting antibacterial, antioxidant, and Ultra violet protection properties by utilising natural material and colouring resources [14-18]. Several substances from plants like flavones, tannins, lipid fractions, polyphenolic, and flavonoids have been used for absorbing light and UVB radiation. In addition, the application of metallic salt based mordants in natural dyeing for cotton, silk and wool have contributed for higher UV protection properties [3]. The coloration process encompasses the necessity to harness natural resources for the production of environmentally-friendly and harmless products through the establishment of sustainable supply chain system. Therefore, it is important to promote techniques for producing natural dyes at reduced costs per unit, as a substitute for traditional farming methods. Nevertheless, natural dyes in the textile sector are to be employed the production process in a sustainable manner and must adhere to local regulatory standards with minimal environmental consequences [19]. It has been revealed from the earlier findings that colouring substances can be retrieved from agricultural waste, health improving substances used in food additives and nutritional products as a promising method to enhance the environmental sustainability of the entire supply chain [20-22]. In addition, several studies have been carried out on various vegetable sources like recycling of agricultural residues, plants cultivated for dyeing are used for extraction. These extract solutions have been employed for dyeing of hemp fabric with varied concentrations for examining their dyeing behaviour and their effect on UV protection properties in addition to quantitative characteristic analysis for the scope of using them in clothing.

Characteristics Analysis of Dyes in Dye-Baths

Extracts from pre- and post- dye solutions have been obtained by using lyophilizing for the quantitative analysis. It has been revealed that properties of plant species are significant for both the extraction and colouring processes. In general, the dye extracts are represented as a percentage of dye in the pre-dyeing solution on the dry weight of the plant. It is associated with the species of plants and their pigment class. Further, it is important to keep in mind that the extract is actually a blend of pigments due to the method of extraction. It has been observed from the experiments that chestnut and madder have given lower yield than other species such as Onion, Inula and Logwood. Moreover, onion has more extraction percentage with less concentration. It could be due to the maximum quantity of onion used in the post solution which influence the solution saturation and resulted the yield [3].

When measuring the amount of dye attached to the cloth as a percentage of the dye extracted in the pre-dyeing solution, the three resources, namely inula, chestnut, and logwood exhibited the strongest ability to attach the extracts in ascending order. While examining the dye fastening as a percentage of plant dry weight, logwood exhibits highest value and followed by inula and chestnut. But madder exhibits lowest value in both the cases. Nevertheless, the percentages across all the species are comparatively low. The findings validate the importance of discovering cost-effective resources for utilisation as natural dyes. The variations in dye concentration per unit of cloth revealed distinctions among different kinds of plants and the varying affinity between fibres and pigments. But dye fastening is increasing with the concentration for the same plant. Chestnut has shown highest value than other plants. Hence, the it has been suggested from the results that the extraction technique needs to be refined for applying the extract amount.

Spectrophotometric Analysis of Dye-Baths

Spectrophotometric measurements have been carried out to examine the disparities in the dye solution between before and after dyeing in the dye-baths [3]. The absorbance curves of the solutions before and after dyeing have been influenced by the properties of the plant used in the manufacture of the dye bath. The absorbance of the dye-bath reduced gradually when it shifted from UVB to UVA spectrum for all the dyes that have been analysed. Moreover, it is much lower for all post-dyeing solutions than pre-dyeing solutions. The adherence of dye and fabric is just one element in examining UV protection. This protection is closely linked to the interaction between the dye and fabric.

Classification of Dyed Fabrics and Color Fastness to Light

According to the hue component of the Munsell Atlas, the logwood,madder, inula falls in the quadrant of purple, yellow/red, yellow respectively [3]. By increasing the concentration of the dye-bath, a reduction in "value" has been observed in all plants, which indicates a darker colour. However, chroma has remained same for the varied concentrations. It also revealed that the colour fastness is strongly correlated with the plant species. Nevertheless, samples dyed with more concentrated solution have exhibited superior values, except for the chestnut sample which showed the highest colour fastness value even at the lesser concentration.

Fabric Cover Factor

Research has demonstrated that undyed-mordanted fabrics exhibited an increase in the cover factor (CF) of up to 95% compared to undyed fabrics (92.6%) due to fabric shrinkage [3]. The color fastness of undyed-mordanted fabrics surpassed the essential threshold of 94%, indicating that the fabric's UPF value is less than 15, regardless of the UV-absorbing qualities of the fibres and chemicals used. A dyed cloth with a CF of 95% indicates that it has the ability to achieve the highest UPF value i.e. about 20.

Transmittance and UPF Measurements

It has been found out from the experiment that there is a modest decrease in transmittance for undyed mordanted fabrics in comparison to undyed fabrics. This could be due to the changes in cover factor by the fabric shrinkage that occurs in the mordanting process. According to Feng et al. (2007) metallic mordants has not shown any significant UV absorption whereas Griforni et al. has observed that alum and tannin based natural mordants are showing less and strong influence respectively [23]. Similarly, fabrics dyed with higher concentration has exhibited a substantial decrease in UV transmittance in comparison to materials which have not been dyed. Moreover, all dyed samples have exhibited significant reduction in UVA band than UVB wavelength. Thus, consistent and uniform ability for the UV transmittance is observed over the entire range of UV wavelengths. Even though dyes are having more UVB wavelength absorbance properties, it could be due to the interactions among the fabric structure, properties of dyes, and light. Specifically, dyed fabrics with chestnut and onion have shown the lesser transmittance values for the whole range of UV wavelengths which reveals higher UV resistance. Likewise, fabrics dyed with lesser concentration have shown higher transmittance. Thus, Ultra violet A and B band resistance is influenced by the dye bath concentration. But, the UVB reduction is more than UVA for the fabrics with undyed and undyed-mordanted categories. Further, the difference between UVA and UVB reduction has been greatly decreased for the post dyeing treatment which confirms the tested dyes for their UVA resistance. Yet, the UVA reduction is always less than 95 % i.e. UVA transmittance is more than 5 %. As per the European guideline and Chinese standard, dyed fabric with above 5 % UVA transmission can worsen the photosensitive skin conditions [3]. Ultra violet protection factor for the dyed fabrics have exhibited greater value than those of undyed and undyed-mordanted fabrics and also increased with the concentration of the dye-bat. The undyed fabric and undyed mordanted fabric are having lower UPF owing to the low cover factor of the hemp yarns [24]. In spite of higher concentration, maximum UPF values are lesser than minimum threshold value. It has also been confirmed that darker shade fabrics are having higher UV protection properties [25].

The natural dyeing material, namely logwood is exhibiting substantial UPF value than with madder. However, the dyed fabrics with onion and chestnut have reached minimum UPF value [26]. It has been revealed from various research work on UV protection that chestnut is considered either dyeing material or mordant. Though the UPF of fabric has not surpassed the essential threshold, it accounts for significant UV protection. Therefore, it is possible that a higher concentration could result in a relatively small improvement in UPF levels and UVA reduction. Still, in order to get a high level of protection, it is crucial to utilise fabrics that are characterised by greater CF values. For the countrys' in Europe like UK, Italy, etc., and Australia, minimum UPF value of 20 out of 30 is expected for protecting with the exposure less than 1 MED as the threshold level of 1 MED may cause skin reddening [3].

The data from the research work associated with outdoor UPF of undyed hemp fabric, dyed with higher concentration and undyed-mordanted fabrics are being used in the real time applications. In the laboratory, the transmittance test is detected by using artificial direct light source where direct and solar diffuse radiation is used for the assessment. The component, namely solar diffuse radiation modifies the fabric transmittance as it emanates from all directions. Even with small improvements, outdoor UPF readings are verified with the laboratory spectrophotometer readings. The reason for lower increase could be due to lesser diffuse solar radiation instead of considering the specific CF value. However, the findings of the earlier research on natural dyed fabrics reveals that outdoor UPF value is substantially higher than the laboratory value. Furthermore, it has been revealed from the comparison of vitro and vivo test that textiles worn under sunlight offer greater protection than that observed in laboratory experiments [3]. In comparison to data from the spectrophotometer, a smaller standard deviation is clearly visible because the Spectro radiometer evaluated a wider area of fabric surface.

UV Protection Persistence after Sun Exposure and Washing

Studies reveal that after a certain amount of sun exposure, coloured samples have exhibited a considerable decrease in

UPF [3]. Remarkably, inula, madder, and logwood-coloured fabrics achieved UPF values that are quite similar to the samples of undyed-mordanted fabrics after 20 days. Even though the greater standard deviations suggest a considerable variability among measurements, a less significant reduction has been observed in samples dyed with onion. Additionally noted in the undyed-mordanted fabric samples was a comparatively minor decrease in UPF. The gradual rise of fabric UV transmittance has been observed for the dyed samples exposed to the sun which confirms the UPF behaviour. This transmittance effect of fabrics dyed with inula, madder has become more noticeable at longer UV wavelengths and to a lesser degree for logwood. Though the transmittance of dyed fabrics with inula and madder has reached the value equal to undyed -mordanted samples after exposed to the sunlight for 20 days. Yet, the transmittance value is lesser than undyed-mordanted fabric samples. Despite discolouration, the UPF of dyed fabrics after ten washings have not been decreased whereas it has been mentioned as increase for the onion in few other studies [23,27,28]. This could be owing to the fabric shrinkage, which balances the discolouration. It has also been confirmed in the previous work that fabric shrinkage is more effective than the less cover factor.

Dyeing with Pomegranate Peel Extracts

Natural product find application in textiles in addition to being substances in food and beauty products. Plant parts such as leaf, fruits, seed, bark and root are used to retrieve natural dyes for colouring the materials. The majority of natural dyes constitute tannin colouring component and having antibacterial characteristics. In addition, they have been used as antibacterial, anti-allergy, or deodorant [29-33]. The fruit of the trees with leaves or little trees Punica granatum is the pomegranate. Textiles have been traditionally coloured with its peel since antiquity. Peel from pomegranates is a great source of alkaloids, phenolics, and tannins. Principal constituents are ninephenolic groups [4,34,35]. The pomegranate peel contains a significant quantity of tannin i.e. about 20% [36]. Through a metallic mordant, tannin can bind to textile substrates including proteins (such as those found in wool and silk) and cellulose fibres [37]. The hydroxyl groups of the fabric and the phenolic hydroxyl groups of tannins can form hydrogen bonds. Cotton textiles have been treated bactericidally and dyed with pomegranate peel extraction. With copper and iron mordants, large variety of hues with good fastness qualities, such as yellow, brown, and black can be produced. Still, these are harmful [38,39].

Cotton is the most widely used cellulosic fabric, but the production of the cotton fibre commercially is not feasible in the tropical climates of Thailand and other nations. Hemp, or Cannabis sativa, is a sustainable and economically valuable crop that may be grown in the northern part of Thailand. It has been recognised as an industrial crop in Thailand. Fabrics made from it can be more affordably produced than those made from synthetic polymers [40,41]. The constituents of hemp fibres include cellulose, hemicellulose, pectin, lignin, wax, water-soluble substances, and a small quantity of ash. Raw hemp's cellulose content gives it qualities like stability, comfort, and superior water absorption [42]. On the other hand, absorption of water promotes the growth of bacteria and fungi, which in turn causes odour and stains [41]. There has been less investigation on the textile usage of hemp fibre, in contrast to more common textiles like cotton, silk, and wool [43,44]. Improving the colour yield and colour fastness of hemp cloth is necessary to promote its application in high-value products. In this study, dyeability and antibacterial characteristics of hemp fabrics by applying the natural pomegranate extracts is investigated.

Study on Effect of Dyeing Parameters on Hemp Dyeing

Spectrophotometry has used to examine the colour properties of hemp fabrics in the wavelength range of 380-750 nm. Colour strength or intensity is measured by using the ratio of K/S which is a linear function to reveal the dye quantity in the fabric. Further to this, K/S is influenced by dye concentration, temperature and dyeing time period. In this study, five different concentrations with specific temperature and time has been maintained for conducting the experiments. It has been observed that the highest K/S value is observed at 400-410 nm and increased with the dye concentration up to a specific concentration. It indicates that a greater number of dye molecules are presented in the fabric. Later, the experiment has been carried out by varying seven levels of dyeing time period with specific dye concentration where K/S value is higher and specific temperature. It has been found out that K/S value is higher for the extended time period up to a specific value. It shows that hemp fabric absorbs dye at a slower rate after reaching the equilibrium. Further to the above, it has been observed that dyeing process is restricted with time period as the fibre is decomposed for the excessive heating condition. Similarly, K/S is increased with the temperature up to a specific temperature and colour intensity is changed afterwards. The temperature has influenced significantly on fabric's shade because dye adsorption is accelerated and fibre swelling is enhanced by heat energy, leading to an increase in the amount of dye adsorbed [45-47].

Study on Colour Measurement

It is observed from analysis of the L*, a*, and b* values that brightness of the dyed fabric is reduced in comparison to untreated fabric owing to higher concentration of antimicrobial and dye compounds on their surfaces. Dyeing also increases the K/S, which measures the absorption of antimicrobial compounds and dye. Dyed and antibacterial hemp fabrics are having higher positive b* values in comparison to untreated fabrics whereas no substantial difference is found out for a* values. It indicates the dyed fabric's colour as yellowish brown.

It has been observed from the FTIR spectra that the distinctive peaks of cellulose, hemicellulose, and lignin is visible for all three hemp fabric samples, namely untreated, coloured, and antibacterial finished [18]. The peak in the spectra confirms the presence of O-H and C-H groups in cellulose and hemicellulose. In addition, the presence of C=O group in pectin, waxes, and hemicellulose. The side groups such as C–OH, C–C, and C–H ring groups in cellulose and hemi cellulose are confirmed by the peaks in the FTIR spectra. In the case of hemp fabric with aromatic finish, the presence of CH group of aromatics is confirmed by the peak in lesser wavelength range [39,48]. The appearance of narrow peak has confirmed the bonding of cellulose and tannin with the help of metallic mordant [49]. The aforementioned confirmations has revealed the satisfactory attachment of pomegranate extract with hemp fabric [41].

Study on Colour Fastness Characteristics

The pomegranate peel contains high levels of tannins, phenolics, and alkaloids. Tannins serve as colourants and consist of both water repellence (aromatic) and water affinity (-OH) groups, whereas hemp fabrics consist of water affinity (-OH) cellulose groups [50]. The compound AlK (SO4)2, known as a mordant, is utilised to bind tannin to the hemp fabric by creating a complex that cannot dissolve. This process inhibits the migration of dye, resulting in a consistent and permanent coloration after the dyeing process. Fabrics with high colour fastness maintain their colour without fading when exposed to environmental conditions. Colour fastness refers to the extent to which the colour of a material changes when exposed to various factors such as laundering, water, salt water, and perspiration. The colour change values are consistently evaluated as good to exceptional (4-5) in all tests, except for one test. The only test that deviated from the norm is the laundry test, which received a fair rating of 3. Nevertheless, the alteration in colour have not been due to fading, but rather a transition from yellow to brown. Colour stability has been evaluated by measuring colour staining, which refers to the excessive absorption of dye by a substance caused by exposure to a polluted medium [44,46,47,51]. The multi fibre fabric utilised in colour staining tests consists of cellulose acetate, cotton, nylon, polyester, acrylic, and wool. Every fibre type has polar end-groups, such as the hydroxyl group (-OH) or amino group (-NH2). These end-groups can produce hydrogen bond with the hydroxyl groups of tannin dye molecules that migrate out from the samples and pollute the test media [41]. The colour staining qualities for all materials have been graded as acceptable to exceptional (4-5), except for the acrylic fabric, which is graded as fair (3). The color fastness to crocking has assessed where coloured samples are rubbed against the standard white samples. The coloured textiles have exhibited poor colour fastness to crocking, with a rating of 2 in both the dry and wet state. After washing, the fabrics have shown a bad rating of 2 in the dry state and a very poor rating of 1 in the wet condition. As predicted, the abundance of surplus dye molecules that have been on the outer layer of the fibre which has increased the cloth's susceptibility to colour fading when rubbed. Increasing the concentration of mordant could improve the absorption of dye.

Study on Antibacterial Activity

The study has been examined the percentage of decrease in S. aureus and K. pneumoniae of Gram-positive and a Gram-negative bacterium, respectively, on dyed, antibacterial finished textiles before and after various washing cycles [41]. Controls consisting of untreated cloth and coloured fabric without antibacterial treatment have been utilised. The efficacy of the pomegranate extract against S. aureus is more effective than K. pneumoniae. The observed antibacterial activity aligns with previously published findings for cellulosic textiles. The significant antibacterial action of pomegranate extract is linked to its chemical constituents and biological characteristics, namely the existence of tannins and polyphenols.

Considering antibacterial activity to a single component is challenging when dealing with a complex combination of bioactive chemicals. The antibacterial activities of pomegranate peel are believed to be a result of the synergistic impact of many bioactive components that might cause bacterial death. The inhibitory impact of polyphenolic substances has been attributed to the simultaneous action of many mechanisms targeting specific targets. Hydrolysable tannins, found in pomegranate peel, are the primary compound responsible for reacting with protein sulfhydryl groups in bacterial cell membranes. This reaction leads to the precipitation of bacterial cell membrane proteins, rendering them unavailable for bacterial growth [52,53]. The antibacterial hemp fabric has shown a consistent efficiency of 99.99% against S. Aureus up to 20 wash cycles. However, although the efficacy against K. pneumoniae is similarly 99.99% before to washing, it ceased to be effective after five washing cycles. After washing, the cloth surface appears smooth and pristine, indicating a decrease in the presence of antibacterial chemicals. The remaining antibacterial drugs have shown efficacy against the growth of S. aureus, but not against K. pneumoniae. The larger membrane thickness of the Gram-negative bacteria is the reason for its ineffectiveness.

Dyeing with Common Madder and Calendula using Natural Mordants

Traditionally, hemp fibres have been harvested in longer lengths (50–60 cm) together with a substantial number of small fibres. During the mechanical processing of hemp straw, fibres that are too short are removed during scutching and hackling as these short fibres are not suitable for typical long fibre spinning. However, these fibres might still be effectively used in a different spinning method [54,55]. According to 2013 research by the European Industrial Hemp Association (EIHA), just 0.1% of the total fibres generated from non-textile industrial hemp have been utilised for apparel. This indicates that a significant quantity of textile fibres may be derived from by-products provided suitable spinning method, physical and chemical treatment given to these short fibres [56]. Cottonization is the process of converting technical fibres into finer elementary fibres, enabling hemp to be used as cotton. This process is more challenging for hemp compared to flax due to the lignin content of the fibres harvested after flowering and not from a textile cultivar [57].

The dyeing process is widely recognised as one of the most environmentally damaging processes in the textile industry (Morlet et al.,2022). Consequently, there is significant interest in substituting synthetic dyes with natural dyes. Various biodegradable, renewable and natural sources, including plants, animals, minerals, fungus, algae, microorganisms, and insects, can be used to produce natural colours [58]. The presence of various functional groups in the structure of these dyes confers them with antioxidant, antiviral, antibacterial, antifungal, anti-allergic, and anti-UV effects [59-63]. Furthermore, they possess ecologically conscious attributes, since they are devoid of toxicity, carcinogenicity, and hazardous properties [64,65]. Rubia tinctorum L., often known as common madder, is found in the western, southern, and southeastern regions of Europe, Africa, and South America. Textile dyeing with madder has been practiced from 2000B.C. Common madder roots can be used to extract pigments. The primary constituents of their dye are anthraquinones with alizarin (1,2-dihydroxy anthraquinone), hydrolysis of ruberythric acid. These pigments generate practical hues that possess specific heat and light resistance characteristics. The anthraquinones possibly have a role in the plant's ability to resist fungus in the soil. In addition, Rubia tinctorum has antibacterial properties against several types of bacteria, yeasts, fungi, and actinomycetes, including both Gram positive and Gram-negative bacteria. Calendula officinalis, often known as pot marigold, is indigenous to Asia and southern Europe. It is also referred to as common marigold, garden marigold, English marigold, or Scottish marigold. It has been utilised for its myriad beneficial characteristics, including antibacterial, antifungal, antiviral, anti-inflammatory, and wound healing effects (Sancar Besen and parlakyyigit,2019). The vibrant orange or yellow blooms of the plant contain lutein, a carotenoid pigment that consists of alpha- and beta-cryptoxanthin and hydroxyl groups [66,67].

Usually, plant-derived dyes do not create durable connections with cellulose, therefore requiring a mordant to permanently attach to the textile fibres [68]. This process enhances the colour and colour fastness [64]. Therefore, the use of ecologically friendly mordants, such as tannins and alum, are essential to enhance the sustainability and eco-friendliness of the dyeing process [69,70]. Tannin, a mordant, is present in several plants that also generate colours, such as Acacia nilotica and pomegranate peel [58]. Tannins play a crucial role in the textile industry since they provide mordants that are essential for dyeing plant-based fibres like cotton and linen. Furthermore, these compounds are frequently linked with the colours yellow, orange, red, and violet in plants, and their own pigment enhances these hues in the dye solution. Textile fabrics that are coloured with tannins exhibit excellent resistance to washing and light fading [41]. Alum is widely used as a mordant for dyeing yarn, fabric, and leather in many regions including North America, China,Russia, United Kingdom, Libya, and Turkey from ancient times [71]. Alum, classified as a brightening mordant, does not have an impact on colour but rather has a tendency to enhance or intensify colours. When coloured with madder, this substance is essential for achieving vibrant reds and enhancing the brightness of yellow shades. The study has been conducted to assess the feasibility of dyeing a fabric made from non-textile hemp using natural dyes derived from common madder and calendula. Additionally, the impact of various parameters, such as water hardness and the mordanting process, on achieving vibrant colour intensity and ensuring the dye's resistance to washing and rubbing have been studied.

Preparation of HE/CO Fabric

The study has been conducted by using non-textile industrial hemp waste, which is predominantly used for seed and oil extraction and has also been utilised in the paper industry [58]. The use of this material offers an alternative as a primary resource for the textile sector, in accordance with the circular economy principle. Nevertheless, the combination of unprocessed hemp and appropriate quantities of woody debris presents challenges in the treatment process and the acquisition of a material suitable for spinning. Having this information, identifying the appropriate circumstances for obtaining yarns will subsequently facilitate its extrapolation to produce spinnable hemp.

Mordanting Variables

In industrial settings, it is typical to combine two mordanting products into a single process. However, in the laboratory study, mordanting process has been conducted separately [58]. It has been done to assess the behaviour of the substrate for each mordant individually, without any interference. It is important to note that the hemp fibres used in the fabric have not been sourced from a textile variety. The limited durability of natural dyes necessitated the exploration of two pre-mordanting methods: one including both tannin and alum, and another involving solely alum. In this case, the samples with tannin in the mordanting process has exhibited a greater colour difference compared to the untreated cloth. Tannin is an inherent component that possesses chromophore groups which enhance the coloration of the samples. It is worth mentioning that the cloth treated with distilled water and tannin have shown a reduced colour difference compared to the fabric treated with tap water. The presence of electrolytes in tap water facilitates the movement of ions involved in the processes, perhaps enhancing the mordant absorption. For textiles that do not contain tannin, the colour difference between the samples treated with tap water and distilled water is comparatively less, aligning with the observed outcomes.

Upon analysing the colour intensity, it has been observed that samples lacking tannin but containing alum maintained their previous colour or even exhibited a higher level of whiteness. Additionally, these samples K/S values are even lower than the values of the original sample. The observed modifications can be ascribed to the introduction of Na2CO3, which aids in eliminating some contaminants owing to its intrinsic efficacy as a detergent and its ability to regulate pH. However, when samples have been treated with tannin as a mordant, they acquired a brown hue, resulting the improvement in the total K/S value. After completing the pre-mordanting process, the samples have been coloured. Samples which are treated with harsh water have exhibited a little yet noticeable difference. Evidently, the samples including tannin have exhibited elevated K/S values in comparison to the samples treated alone with Na2CO3 and alum, signifying a more substantial absorption of dye, as previously noted. The colour permanence of the coloured materials has been assessed by rubbing and washing fastness tests. Overall, every fabric exhibited a significant colour variation. This phenomenon can be attributed to the presence of unabsorbed dye on the surface of the fibres after the dyeing process. Due to the absence of subsequent washing, this residual dye is eventually eliminated during the washing resistance test, resulting in a significant alteration in colour. Nevertheless, it might be argued that the samples have treated with tannin and distilled water yielded superior outcomes. Furthermore, all fabrics have a comparatively minimal tendency to cause discoloration on cotton fabric. Regarding the dry rubbing fastness, nearly same outcomes have been achieved. Dry rubbing fastness scores consistently exceeds the wet counterparts in all circumstances.

The fabric samples coloured with calendula exhibited comparable changes in colour differentiation compared to those dyed with ordinary madder. The K/S values confirmed that there was a slight variance in the coloured textiles based on the kind of water utilised. The samples treated with tap water had somewhat higher values compared to those treated with distilled water, suggesting that the former is darker. In relation to the washing and rubbing fastness tests, materials that were treated with tannin using tap water exhibited a little alteration in colour. Simultaneously, the sample treated with distilled water exhibited a significant alteration in colour. Nevertheless, all of the outcomes were comparable, and all types of cloth exhibited minimal stains, even becoming completely absent after being washed. The reason for this might be attributed to the chemical composition of calendula, which shares similarities with cellulose in terms of its linear and planar molecular structure. This structural similarity enables calendula to be inserted between the cellulose layers of hemp fibre and increasing its absorption thereby. All fabric samples have shown good dry rubbing fastness. The most optimal outcome has been achieved when tannin and distilled water is employed during the pre-mordanting procedure in wet conditions. The dry rubbing fastness consistently outperformed the wet rubbing fastness in all instances. When examining the factors related to mordanting, it has shown that the calendula sample treated with tannin and tap water prior to mordanting yielded the most favourable outcomes. Similarly, when it comes to common madder, the cloth that produced the most favourable colorimetric outcomes has treated with tannin and tap water as a mordant. The kind of water does not have a substantial impact on the wash and rubbing fastness. Therefore, it has deemed that the optimal circumstances for the subsequent stages are the use of tannin as a mordant and the utilisation of tap water.

Study of the Best Conditions for Mordant Application

Several researchers have conducted studies on the effect of administering mordanting at various phases of the dyeing process. This study investigated the impact of the mordant (tannin) on the dyeing process [58]. The mordant has been applied in different conditions like prior to dyeing, during (meta-mordanting), after dyeing whereas common madder and calendula is used as dye. Tannin and alum are the predominant mordants utilised for natural colourants. The results demonstrate that the sample treated with the mordant prior to dyeing exhibited a more pronounced difference in colour compared to the untreated cloth. By adding a mordant before dying, it is possible to produce more bonding sites without any interference from other products or substances, leading to increased absorption. Therefore, tannin, rather than the dye, is the primary element causing the most significant impact on absorption. Regarding the K/S values of the dyed samples, it is interesting that the fabric subjected to pre-mordanting exhibited a greater K/S compared to the fabric subjected to post-mordanting. This suggests that performing the mordanting process after dyeing led to a reduced ability to absorb colour. In addition, colour fastness to rubbing and washing is better for the sample that underwent mordanting during the dyeing process. Each of them has exhibited minimal or no discoloration on the cotton and wool materials. When conducting rubbing tests, it has shown that higher levels of fastness were achieved in both dry and wet conditions when mordanting has been employed in the dyeing process.

The fabric samples that underwent dyeing with calendula, using tannin as the mordant, has the most significant difference in colour and the highest K/S values. One possible factor that might have influenced the results is the temperature of the procedure. The mordanting process has been conducted at a temperature of 100 °C, which is the same as the dyeing process. In contrast, the pre- and post-mordanting processes have been carried out at a temperature of 60 °C in the other two cases. The aforementioned findings are consistent with the washing and rubbing fastness properties. Generally, greater values have been observed for rubbing fastness when the material is dry rather than wet.

When common madder has been mordanted during dyeing, it led to a cloth with the greatest difference in colour, the highest K/S values, and thus the greatest dye intensity. Nevertheless, this particular sample has exhibited the poorest washing and rubbing fastness, indicating a significant uptake of colour but inadequate fixation. Furthermore, it may be inferred that when the mordant is used during the dyeing process, the cloth absorbs an equivalent amount of tannin compared to pre-mordanting. The increased absorption of tannin might lead to a greater impression of colour intensity. When dyeing calendula with the process of mordanting showed the greatest colour intensity and the most favourable results in terms of wash fastness, but the lowest results in terms of rubbing fastness. Ultimately, materials treated with meta-mordanting has revealed more favourable outcomes.

Study on the Need for Rinsing after Dyeing

The impact of a post-dye rinse has been investigated between the samples that are coloured with common madder, with and without a subsequent rinse, and the untreated sample [58]. The washed sample has exhibited the least amount of colour variation, whereas the cloth that has not been rinsed showed fading of colour, indicating the existence of absorbed and loosely attached residual dye on the textile. Just like ordinary madder, the colour of calendula also slightly faded after rinsing. The rinse process eliminates the colour that has been absorbed and is not fixed in the fibres. The K/S values have exhibited a substantial increase in the sample that is not rinsed. To summarise, when dying with common madder and calendula, not rinsing immediately after completing the dyeing process resulted in enhanced dye absorption on the fibre.

Dyeing with Natural Yellow Colorant from Flower Extracts

While plant dyes are no longer employed in extensive industrial manufacturing, they continue to be extensively utilised by some ancient ethnic communities and for the creation of ethnic goods. Indigofera tinctoria is a frequently utilised plant for obtaining blue dye, whereas saffron crocus (Crocus sativus) is typically utilised for yellow dye. Indigofera tinctoria is especially renowned globally and continues to be extensively employed by many ethnic communities in China [72-75]. Unlike natural colours, synthetic dyes are derived from non-renewable sources and their extraction and usage result in adverse environmental impacts. Considering the growing importance of ecologically friendly goods, lifestyles with low carbon footprints, and environmental conscious consumption, there is a rising demand in natural products, that includes natural dyes. In order to effectively apply plant dyes to textile textiles, a companion chemical known as a mordant is necessary. This is because conventional plant dyes do not have a natural attraction to the cellulose in fabrics [76,77]. Mordants are chemicals, either natural or manmade, that attach to cellulose and interact with the dye, leading to enhanced colour and colour fastness [78-80]. The use of metal salts as mordants is widespread, however, it is important to note that most of these salts are not biodegradable and highly toxic, which presents a substantial danger to both the environment and human health. Thus, employing eco-friendly mordants in the process of dyeing textiles with natural colourants would be a sustainable and economically feasible method. The utilisation of natural mordants enhances the sustainability and ecological friendliness of the dyeing process [70,81]. The bio-mordants exhibit variability in their chemical composition. Tannin is a kind of mordant that is present in some plants that may also produce dyes, such as Acacia nilotica and pomegranate peel [82,83]. Euryaacuminata plants have more amounts of aluminium, which are linked to an additional of ions that enhance colour fastness and strength. The biopolymeric mordants employed for pre-treating textile fabrics possess remarkable ability to eliminate radicals and enhance the colorimetric properties of various fibre compounds, which includes the environmentally friendly chitosan fibre [84,85]. Textiles are commonly dyed with synthetic dyes due to their affordability and vibrant hues. Nevertheless, the process of creating dyes and using them on textiles results in the production of wastewater that contains substances that resulting to the water pollution. The increased use of natural dyes has occurred as a result of their enhanced biodegradability [79,80,86,87]. Various yellow dyes derived from plants, such as Scutellariabaicalensis, Curcuma longa, Gardenia jasminoides, and Rheum emodi, are utilised in the dyeing process of textiles [72-74,88-93]. Extract derived from the Buddleja officinalis plant, which belongs to the Scrophulariaceae family, is utilised by many ethnic minority communities in southwestern China as both a yellow dye and a medicinal substance [94,95]. Ethnobotanical research suggests that the yellow extract derived from a plant fibre, namely Boehmerianivea and rice is utilised as a dye. Multiple studies have employed different techniques to isolate and categorise the pigments found in this particular species. These studies have primarily concentrated on examining the durability of these pigments. Notably, through spectral analysis, it has been determined that the yellow pigment present in this extract is crocin [96-98]. B. Officinalis has been shown to contain bioactive chemicals with therapeutic characteristics [96]. Nevertheless, there is a scarcity of research that specifically examines the use of B. Officinalis for fabric dyeing purposes. The studies have examined the application of conventional methods to determine the best conditions for dyeing hemp with floral extract from B. officinalis. The main objectives are: (1) enhancing dyeing techniques using natural mordants through three different mordanting methods; (2) broadening the utilisation of conventional dye plants in textile dyeing; (3) investigating a novel yellow colourant derived from a traditional dye plant for potential use in the textile industry.

Study on Physicochemical Evaluations: UV–vis Spectroscopy

The UV–vis absorption spectra of dehydrated B. Officinalis flowers following water extraction has exhibited outcomes that closely resembled the documented findings for crocin. The pigment exhibited its UV-protective effect by displaying its highest absorption peak in the ultraviolet (UV) region [99]. The conjugated system has exhibited pronounced absorption bands in the ultraviolet (UV) region. The conjugated double bond system has produced absorption bands within the wavelength range of 200 to 250 nm. Additionally, the absorption in the ultraviolet (UV) region of several conjugated systems have seen at wavelengths of 260, 300, or 330 nm. These values align with the established molecular structure of crocin.

Optimization of the Dyeing Process

An orthogonal array experiment has been conducted to analyse the most suitable conditions for dyeing hemp cloth using extract derived from B. Officinalis flowers. An analysis has been conducted to determine the relative impact of several parameters on colour strength (K/S). The results revealed that pH has the highest level of effect, while dyeing time has the lowest level of influence. The most optimum conditions for dyeing hemp are a pH level of 5 with 600C temperature for the time duration of 90 minutes.

Study on Evaluation of Colour Strength and Colorimetric Parameters

Study on Effects of Metallic Mordants

The colour strength, measured as the K/S value, and the colour features, represented by the L, a, and b values, have been determined for hemp dyed with B. officinalis plant extracts and metallic mordants. Significant variations in colour intensity have been observed for every metallic mordant when using the three different mordanting procedures. The coloured hemp materials exhibited superior colour strength (K/S) values when mordanted with alum, irrespective of the duration of the mordanting process. Due to the influence of intrinsic fabric qualities, the colour characteristics (L, a, b) have not been utilised for analytical assessment of the impact of the mordant treatments. When comparing the colour properties of the three mordant treatments, it has been found that using KAl(SO4)2 in post-mordanting resulted in a greater brightness value (L). This procedure is the only one that provided a higher L than dyeing hemp without a mordant. The redness–greenness values (a) and the yellowness–blueness values (b) for the metallic mordants have been lowered compared to dyeing hemp without mordant. Nevertheless, the yellowness–blueness values (b) achieved through the use of KAl(SO4)2 for simultaneous mordanting are the greatest, suggesting a minor yellow tint for both metallic mordants across all three mordanting methods. The colour features and colour strength (K/S) values of dyed hemp treated with KAl(SO4)2 mordant suggested that this treatment yielded the most favourable outcome. The results suggest that the use of metal mordants resulted in the creation of a durable coordination complex that includes both the mordant and the yellow dye. Metallic mordants create metal coordination complexes and bind with pigments derived from plant dyes [31,69]. After analysing the colour strength (K/S) values, colorimetric characteristics, and colour fastness for each metallic mordant, it has been found that mordanting with alum is the best choice. The strong interactions between alum and crocin, as well as the functional groups present in the textiles, might explain this phenomenon. The crocin molecule is characterised by the presence of several hydroxyl (-OH) and carbon-carbon (C-C) groups, resulting in significant steric hindrance. Because of its bond angle of 120◦, the six-membered ring is more stable than the seven-membered ring because it lowers a repellent force between chemical bonds. In addition, a cyclic structure consisting of six atoms, including aluminium ions and two remaining hydroxyl groups, can be created [27,100]. Due to the coordination number of aluminium ions being 6, the remaining coordination sites are filled by functional groups of the substances. This results in the creation of coordination complexes between the dye's functional group and hemp. Ferrous sulphate is commonly employed as a metallic mordant in order to enhance the durability and colour retention of natural dyes during the dyeing process. Ferrous sulphate has a coordination number of 6, which allows it to easily form coordination complexes with the functional groups found in dyes and fibres like silk, cotton, and wool [101-103]. However, it has been observed that when hemp is coloured with B. officinalis extract, alum has proved to be a more effective mordant than ferrous sulphate in all three mordanting techniques.

Study on Effects of Natural Mordants

The dyeing procedure produces wastewater that contains unused metal ions. The release of wastewater has detrimental effects on both ecology and human health. In order to resolve this issue, the use of metallic mordants might be substituted with natural mordants. In order to enhance the speed and colour stability of fabrics during natural dyeing,three natural mordants, namely, gum rosin, C. Speciosa fruit, and plant ash have been employed with specific weight which contain metallic ions and various acid bases that enhance the mordanting process. The mordanting is carried out in various stages like pre-mordanting, meta mordanting, and post-mordanting. The fruits of C. speciosa, a plant indigenous to Yunnan, are a sustainable resource that possess both culinary and therapeutic benefits. A variety of bioactive substances, including as papain, carpaine, and other chemical components, have been found in C. Speciosa fruit. These compounds possess strong antineoplastic and lipolytic capabilities [104,105]. A study carried out by ethno botanists in Xishuangbanna, Yunnan, discovered that the acidic substance derived from the fruit of C. Speciosa is utilised as a mordant to enhance the color-fixation characteristics of plant dyes [106]. Gum rosin serves as a mordant, as evidenced by an ethnobotanical investigation conducted in Dali, Yunnan. Gum rosin powder consists of groups like hydroxyl, amino, carboxyl and unsaturated double bonds. These chemical components react with groups on dyes and fibres, forming hydrogen bonds and other intermolecular interactions. This reaction enhances the colour fastness of the materials [107]. Plant ash is widely employed in China for the purpose of dyeing. Plant ash is rich in minerals, including potassium carbonate, calcium, and magnesium ions, as well as trace amounts of microelements including copper, zinc, iron, manganese, boron and molybdenum. The Yao people in Jianghua, Hunan, utilise plant ash for dyeing rice dumplings, whereas in the Hakka area, it is employed for dyeing yellow glutinous rice cake. In Dali, Yunnan, plant ash is utilised as a mordant due to its alkali and metal ions. A study has been carried out to analyse the colour strength (K/S) and colour features (L, a, and b) of hemp stained with B. officinalis flower extract using three different natural mordants. The colour intensity of the dyed hemp materials varied significantly depending on the three natural mordants used. The colour strength (K/S) values declined in the descending order for pre-mordanting process as: rosin, plant ash, no mordant, and C. speciosa. For meta mordanting, the descending order is: plant ash, gum rosin, no mordant, and C. speciosa. Finally, for post-mordanting, the descending order is: gum rosin, plant ash, C. speciosa, and no mordant. Therefore, irrespective of the duration of mordanting, the plant ash and gum rsoin is used as most effective mordant for dyeing hemp cloth, as determined by the colour strength (K/S) values. The most favourable outcomes for dyeing hemp have been attained using rosin with post-mordanting, resulting in a K/S value. This has been followed by plant ash with meta mordanting, plant ash with post-mordanting, and gum rosin with meta mordanting. Furthermore, there is a distinct variation in the colour properties across the three mordanting treatments. The luminosity (L) is the greatest for plant ash (which exhibited excellent luminosity), followed by gum rosin, both of which yielded superior luminosity compared to the metallic mordants. The cloth has shown a noticeable reddening when exposed to C. Speciosa, which matched the somewhat higher redness–greenness value (a) associated with this mordant. Furthermore, the yellowness value (b) has reached its peak for C. speciosa. In general, gum rosin and plant ash has exhibited superior colour strength (K/S) and L values, whereas C. speciosa had the greatest values for a and b. Overall, the three natural mordants and their respective mordanting procedures yielded superior results compared to $FeSO4$ in terms of colour strength (K/S) and colour attributes L, a, and b. The colour strength (K/S) and colour attributes L, a, and b are often improved by the use of natural mordants in three mordanting procedures, compared to KAl (SO4)2.

Study on Effects of Natural Versus Metallic Mordants on Colour Strength

A study has been conducted to compare the colour strength (K/S) values of dyed hemp using metallic and natural mordants. The colour strength (K/S) value achieved by utilising gum rosin in the post-mordanting process is better than other methods. The descending sequence of colour strength (K/S) values are as gum rosin with post-mordanting, plant ash with meta mordanting, plant ash with post-mordanting, gum rosin with meta mordanting, KAl(SO4)2 with post-mordanting, gum rosin with pre-mordanting, C. speciosa with post-mordanting, plant ash with pre-mordanting, and without mordanting. According to the colour strength (K/S) values from the post mordanted samples, alum is the best metallic mordant and gum rosin is the best natural mordant. The results can be described by the fundamental characteristics of these mordants in combination with crocin and the reactive groups of the different compounds. Crocin mostly utilises hydrogen bonds and Van der Waals forces to form bindings with fibres. In addition, the nature of these interactions varying according on the pH level. Experimental study has been carried out with a total of 16 processes which consists of two metallic mordants, three natural mordants, and three mordanting types, including no mordanting. This study involved examining the effects of mordanting on various materials. Out of these, eight mordanting techniques have produced greater colour strength (K/S) values compared to operations without mordanting. One of these procedures involved the use of a metallic mordant, while the other seven procedures involved natural mordants. Out of the seven natural mordanting approaches, six of them utilised gum rosin and plant ash mordants in the three mordanting processes. The remaining procedure included post-mordanting utilising C. speciosa. The use of natural mordants yielded superior outcomes compared to most metallic mordanting techniques, particularly when applied to gum rosin and plant ash. The use of bio-mordant enhances the value of the process by facilitating hydrogen bonds and Van der Waals interactions among molecules and between the colourant and fabric [69,70,108]. Plant ash has traditionally used as a natural mordant in several ethnic communities in Yunnan, China which is a potent alkaline mordant that contains metal ions. The crocin molecule exhibits varying chemical structures due to its polyhydric nature, which in turn affects its dyeing characteristics depending on the pH value. The pH value is a crucial component that affects the fixation of crocin in this dyeing procedure for hemp fabric. In acidic circumstances, the hydroxyl groups in hemp get protonated and may then establish hydrogen bonds with crocin's hydroxyl group. The pH value of the plant ash solution used in the study is very high alkaline pH, i.e.11.26. Thus, when crocin-dyed hemp is mordanted with plant ash, the reversible reaction shifts towards the right. This causes the hydroxide radicals at sites 7 and 9 to lose water and become negative oxygen ions. These ions then react with the functional groups of important chemicals in natural mordants. This results in the creation of a stable molecule, which in turn stabilises the colour. The same procedure takes place for other hydroxide radical locations in crocin, specifically at positions 2 and 4. Furthermore, given the significant presence of metal ions, including iron, manganese, copper, etc., in plant ash, it is plausible that the process of mordanting operates through the same mechanism as the creation of metal complexes. Likewise, crocin's the hydroxyl groups can interact with hemp through ion-dipole Van der Waals interactions. The primary process by which gum rosin powder adheres to the fibre surface and forms intermolecular bonds with the dye and fibre with hydrogen bonding, as indicated by earlier research. Gum rosin acts as a colloidal mordant by creating a coating on textile fibres by the chemical bonding of gum components with each other, as well as with dyes and fibres. This process effectively attaches the dye molecules to the fibres, ensuring their fixation [94,95]. To summarise, plant ash is an excellent mordant which is an alternative to metallic mordants. The dyeing process employing gum rosin as a natural mordant mostly relies on physical adsorption due to the absence of metal ions and chemical reagents. However, it is still highly successful. Moreover, gum rosin and plant ash are cost-effective, readily available, and sustainable natural resources. Using rosin as a plant dye would allow for completely natural dyeing. Natural mordants and dye plants are ecologically friendly, safe, healthful, and important resources when used together.

Evaluation of Colour Fastness

Study on Effects of Metallic Mordants

The effectiveness of two metallic mordants on various colour fastness to laundering, rubbing, and perspiration in hemp has been investigated for the three mordanting procedures. All three metallic mordanting processes produced similar levels of perspiration fastness to those obtained without the use of a mordant; however, the application of $FeSO_4$ during the pre-mordanting process resulted in a lower fastness to acidic perspiration. The colour staining on multi fibres remains same in terms of washing and perspiration fastness, regardless of the mordanting procedure used or the kind of mordant employed. The washing fastness of the colour has not been improved irrespective of type of metallic mordants used and remains in low level. Despite variations in the mordants and dyeing conditions employed, the issues observed throughout the washing process are quite similar across all treatments including dye and metallic mordants. Due to the alkaline nature of the washing procedure (pH = 10), the hydroxyl groups that initially formed hydrogen bonds and Van der Waals interactions between the crocin and the cloth have been readily disrupted. Consequently, the dyestuff became unattached from the cloth. The evaluation of color fastness to washing has been conducted using soap or soap and soda, in accordance with specified standards. One of the reasons for the low colour fastness in soaping experiments is the high concentration of soap; however, as this concentration is much greater than that of regular washing applications, which indicates the colour fastness of B. Officinalis dye may be higher during normal usage. Overall, the use of two metallic mordants in three mordanting techniques have not resulted a substantial improvement in colour fastness compared to dyeing without mordant. Instead, it actually, decreases the colour fastness.

Study on Impacts of Natural Mordants

A study has been carried out to examine the influence of three different natural mordants, applied by three distinct mordanting techniques, on the color fastness of hemp fabric when subjected to washing, rubbing, and perspiration. The influence of natural mordants on colour durability following washing and acid perspiration have exhibited similarities to those of metallic mordants. Natural mordants have exhibited superior colour change and colour stain characteristics in terms of rubbing and perspiration fastness compared to metallic mordants. The washing fastness of natural mordants have revealed a colour change value of 1 which is equivalent to that of metallic mordants. In summary, the three natural mordants in three different mordanting procedures considerably increased colour fastness when compared to dyeing without a mordant and with metallic mordants, particularly gum rosin and plant ash [108-119].

Conclusion

Logwood, chestnut, and inula-dyed hemp textiles have exhibited superior fastness. In addition, fabrics dyed with onions and chestnuts have achieved satisfactory UPF ratings in both lab and outside environments. The physical properties of the dyes, fabric structure, light and interactions have influenced the UV protection capabilities. The pomegranate peel has yielded very good colour strength and a yellowish-brown appearance. The coloured materials have been rated from good to excellent for various conditions like laundering, water, sea water, perspiration to acid and alkaline condition. The development of an insoluble tannin complex on the fabric surface, have resulted the restriction for dye leaching. A notable antimicrobial effect has been found against S. aureus, and this effect persisted for a duration of 20 washing cycles whereas the effect on K. pneumoniae has been found only prior to washing. So, it has been revealed from the research findings that the non-textile industrial hemp can be dyed with natural dyes and resulted the sustainable process under the circular economy. For this kind of dyeing, the mordant is a crucial factor, and the results have demonstrated the efficacy of the tannin–alum combination. Compared to the calendula-dyed fabric, the common madder-dyed fabric exhibited a significantly greater colour difference. As calendula has produced better colour fastness results in terms of laundering and rubbing fastness, it can be inferred that it is an excellent choice for dyeing the hemp/cotton fabric. In addition, it has been suggested to rinse after twenty-four hours. Dried B. officinalis flower extract has the potential to be used as a natural dye source for textile dyeing owing to the presence of crocin. After conducting various dyeing methods by using orthogonal array testing strategy, appropriate dyeing method has been identified with the process parameters such as pH of 5, a temperature of 60 ◦C, and a 90-minute dyeing time may successfully dye hemp fabric. Although its limited washing fastness may limit its applications, B. officinalis natural dye has significant market potential as a commercial natural dye. However, more research is required to enhance this dye's colour fastness to laundering is required. Furthermore, considering that the natural mordants examined in this work are non-toxic to people and have antibacterial qualities in addition to other possible uses in medicine, it is worthwhile to investigate them further for their applications in dyeing and finishing. Owing to their natural abundance, quick decomposition, and renewability, such mordants are extremely environmentally benign substitutes for metallic mordants.

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