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Natural Dyeing with Madder: Exploring Traditional Techniques and Color Characteristics

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Abstract
The color red has a significant presence in cultures around the world. The organic dye madder, derived from plants, has been used throughout human civilization and remains an important natural dye. The research reviews five traditional madder dyeing techniques from China, Europe, Turkey, and Japan. The techniques are applied to cotton, linen, silk, and wool fabrics, and their similarities and differences are compared and analyzed. Additionally, the environmental sustainability, resource conservation, and process efficiency of these dyeing techniques are also evaluated in this article. The chromatic value of dyed textile color was tested by means of an American Hunterlab spectrophotometer, the influence of different dyeing techniques on textile color characteristics was analyzed, and the artistic features of textile color were analyzed from the perspective of visual art.

Keywords
Madder, Traditional dyeing techniques, Textile, Color, Artistic features.

1. Introduction

Red is an integral part of traditional Chinese color culture [1] and is a representative color that symbolizes Chinese style. In ancient China, madder was the primary material used for textile red dyeing during the Zhou and Han Dynasties, until the introduction of safflower, which was considered a red dye that could produce the "True Red" color [2]. Madder has also been used for dyeing in Europe, Japan, and Turkey, where it is known as "Turkish Red". As an important plant dye over the world, madder is studied and applied widely in current researches. At present, the research of madder dyeing on textiles mainly focuses on two aspects, which are natural fiber fabric and synthetic fiber fabric. Jiang Xiaozhen [14] researched the dyeing effects of madder on silk and found that the addition of aluminium oxide during the dyeing process, as a mordant, had a better dyeing effect compared with citric acid and sodium stannate. Moreover, Yang Dongjie applied madder on cellulosic fiber and tested the influence of tombarthite as a mordant on the color fastness of fabrics [15]. Li Qingrong studied the dyeing mechanism of madder in both silk and wool from the aspect of thermodynamics. Qi Qing studied the UV protection function of madder in fabrics [3]. Moreover, Rym Mansour studied the UV protection and dyeing properties of wool fabric dyed with aqueous extracts of madder.

In addition to the current research about the application of madder on natural fibers, researchers and scholars also tried to study the dyeing effects and the mechanism in synthetic fiber fabric. Gupta [16] found that the combination mode between effective pigment in madder and polyamide fibers was in a manner similar to that of disperse dyes. The dyeing properties of madder in polyester fabric were studied by Wang Kun and the best dyeing technique for increasing the dry and wet rubbing fastness and soap-washing color fastness of the fabric was obtained [17]. While modern dyeing processes using madder have been studied extensively, research on traditional madder dyeing techniques has been limited to references in ancient Chinese literature. For example, Sun Yifei restored the ancient Chinese madder dyeing techniques and used acquired textile colors in women's wear design [4]. Wu Manlin [5] compiled the history of the use of madder dye in Europe based on a review of the literature but did not provide any practical implementation information. But it is easy to see that ancient madder dyeing techniques were always applied on natural fiber fabric, which was determined by the pigment characteristics contained in the madder and the way that the madder pigment combined with the fabric.

Traditional madder dyeing techniques used in several different Asian and European countries were explored and examined and the differences between these traditional madder dyeing techniques, which are closely linked to local regional cultures. are described in this article. The differences in terms of environmental protection, energy conservation, and process efficiency between these five restored traditional madder dyeing techniques are compared. In addition, the chromatic values of dyed fabrics were obtained through objective color testing with Hunterlab, and the influence of dyeing techniques on the color characteristics of textiles were discussed as well. Moreover, the color styles of dyed textiles from the perspective of visual art were illustrated to explore the aesthetic and application value of madder dyed textile colors.

2. Overview of traditional madder dyeing of textiles

Madder has been a significant source of obtaining red color throughout the world since ancient times. Its importance can be attributed to the fact that red color holds a significant place in various cultures. According to anthropologists, at least 70% of people in the world once considered red as a color totem. Moreover, the ethnic Han of China still worship red as their national color [2]. In China, madder was one of the earliest plant dyes for textiles and held great significance. The use of madder in textile dyeing can be traced back to ancient Chinese literature and poetry. Mr. Du Yansun's book titled "Domestic Dyeing Method of Plant Dye" also mentions madder's use in ancient times. The roots of this perennial trailing plant, with square stems, downward thorns, and four whorled leaves, were used to dye textiles red and purple, which were widely produced in the northwest region of China [8]. The development of plant dyeing in China significantly increased during the Tang Dynasty, which was facilitated by the Maritime Silk Road, allowing for cultural exchange between China and Japan [9]. As a result, traditional Chinese textile dyeing techniques, including the use of madder, were introduced to Japan, where it became prevalent. Even today, the red dyes used in Japan are similar to those used in China.

Madder was also once the most commonly used red dye in Europe [6]. Due to Europe's unique geographical conditions, history, and culture, wool fabric was popular, and textile dyeing was primarily focused on dying wool yarns and fabric. Archaeologists discovered alizarin and purpurin in a scarf excavated in Europe [7], proving that the use of madder for textile dyeing began at least during the Iron Age [5]. In India, plant dyeing was also highly popular, and techniques for dyeing with madder and other plant dyes were documented in books such as "*Memorandum on Dyes of Indian Growth and Production*" by L. Liotard and "*Indigo, Madder, and Marigold: A Portfolio of Colors from Natural Dyes*" by Trudy Van Stralen [4]. Also, the use of madder for textile dyeing can be traced back to ancient times in Egypt and Africa. Archaeologists identified alizin, the primary component of madder, in fragments of leather textiles that were unearthed in Egypt from the 21st to the 19th centuries BC according to current research. Furthermore, the well-known "Turkish Red" dye was obtained through madder dyeing and originated from the printing and dyeing industry in the eastern Mediterranean. By the late 19th century, "Turkish Red" dyeing had become a significant industry in the western part of Scotland.

3. Traditional madder dyeing techniques for textiles

Textiles have been an excellent carrier of art and culture throughout human history, and traditional dyeing techniques reflect a nation's production culture to some extent. The color characteristics of a nation can be easily seen through the development of textile dyeing techniques. Textiles, including clothing, are among the first necessities of human life and an important part of the development of human civilization. With the evolution of social history, specific and profound cultural characteristics have been formed, and the dyeing culture of textiles is one of its important branches. Madder dyeing has developed differently in various countries and regions across the world, exhibiting both differences and commonalities.

Due to differences in geographical environments, political systems, economic models, and social cultures, countries and regions have shown variations in madder species and dyeing techniques, resulting in distinctive color characteristics. China has a long-standing tradition of using madder dye. Owing to its abundant natural resources, vast land area, and diverse cultural structures, China is rich in various types of madder raw materials found in different regions. Madder in China is classified and named according to quality and the region where it grows, including the commonly recognized southwest madder, Tibetan madder, and qualified madder grown in Shaanxi Province, as well as common madder in Jiangsu (Xuzhou), Henan, and Shandong Province, among others. The ancient book "Wu Li Xiao Shi," written in the Ming Dynasty by Fang Yizhi, is a collective record of natural science and techniques in ancient times, which includes the madder dyeing technique, shown in Figure 2. This method is also applicable to all anthraquinone dyes.

During the Song Dynasty, the madder dyeing technique shown in Fig. 3 was popular, which included a special step called "Absorb Yellow." This step involved removing the yellow pigments from madder by boiling and filtering it through rice filter liquor, which had starch that absorbed the yellow pigment of madder. However, this technique was replaced by using starchy substances instead of boiled rice filter liquor, which is now commonly practiced.

Madder has different verticillation according to its biological feature. The madder of Europe is generally referred to as western madder by the Chinese, and the verticillation of western madder is six, which differs from Chinese madder, with a verticillation of four or eight. In Europe, madder is mainly used to dye wool fabrics, and there was a classical dyeing process known as the classical European process. The process was created by the French Academy of Sciences in 1669, founded in 1666 by Jean Baptiste Colbert, the famous finance minister of Louis XIV's reign. The key material used in the classical European process is tartaric acid, the main component of which is potassium hydrogen tartrate. Ancient European water contained abundant calcium carbonate, which could hinder the absorption of mordant alum. To avoid this, Europeans extracted tartaric acid from tartar, a by-product of winemaking. It is evident that the use of tartaric acid is closely related to the production of ancient European red wine. Nowadays, some researchers use a food swelling agent called tartar powder, which also contains potassium hydrogen tartrate, for madder dyeing. However, the starch in tartar powder may affect the final dyeing effect. To improve the dying outcome, potassium acid tartrate can be

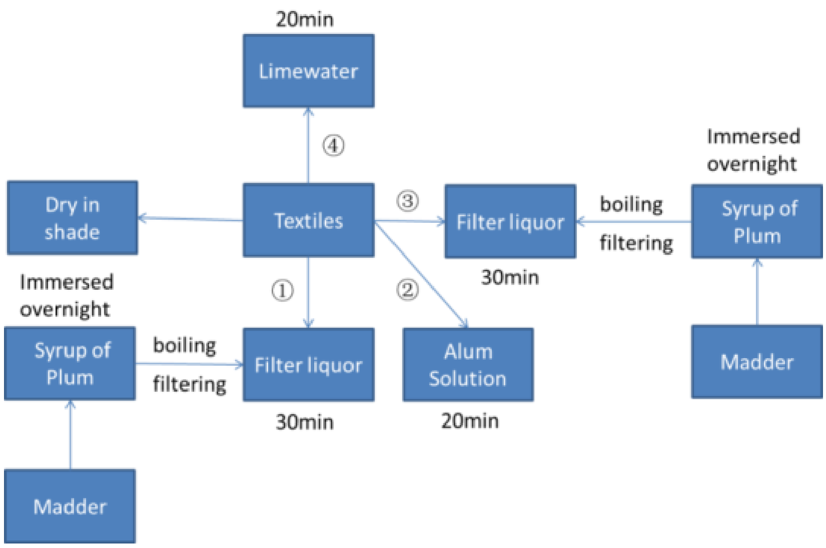


Fig. 1. Process of ancient Chinese madder dyeing technique (I)

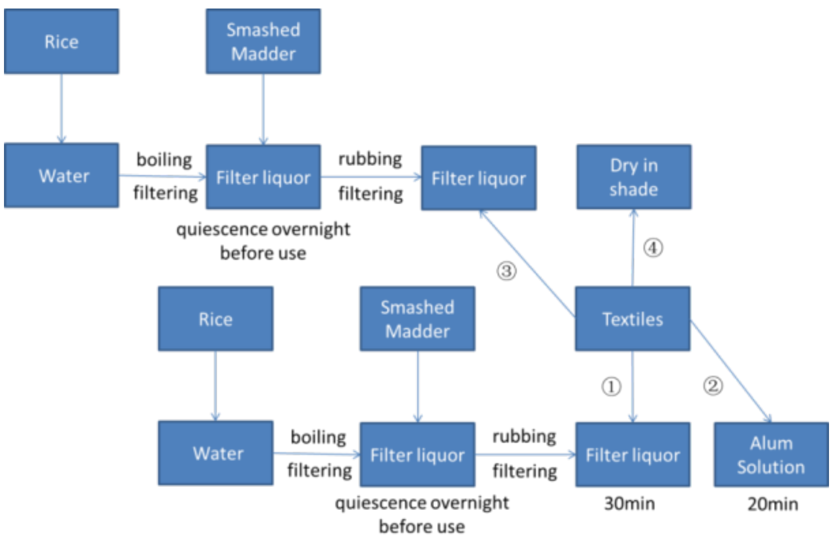


Fig. 2. Process of ancient Chinese madder dyeing technique (II)

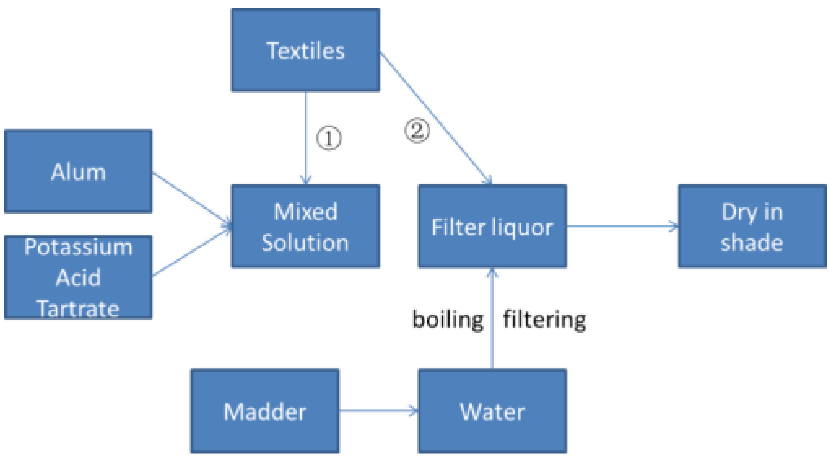


Fig. 3. Classical European process of madder dyeing

used to ensure the original dyeing effect of madder with the classical European process, shown in Fig. 4.

'Turkish Red' is a carmine color that was imported to Europe from Turkey in the 18th century. This delicate, bright, and long-lasting color is achieved using the roots of the madder plant as a dye. The key to obtaining 'Turkish Red' is the use of a plant called club moss (also known as Lycopodium clavatum) as a leveling agent, and the madder must be polished into powder before use. The dyeing process is shown in Fig. 5. The method of dyeing 'Turkish Red' was later used as a reference by many other countries around the world. In China, symplocos leaves are used instead of club moss during the dyeing process. In Peru, wild peony is used as a substitute, and the Japanese prefer the burned ash of camellia leaves because the withered camellia symbolizes the aesthetic of death advocated by unique Japanese culture.

Oriental madder, also known as Japanese madder, has a wide range of applications in Japan. The roots of Japanese madder have a yellowish hue and share a similar appearance with the Chinese common madder discussed earlier. One significant ancient record, "*Engishiki*", written in the Heian period of Japan, has been completely preserved to this day, which documented the basic method of using madder in Japan. The unique feature of this method is the pretreatment of madder, which involves soaking it in a weak acid solution overnight and then rubbing it until the surface turns red, thereby removing mud and yellow pigments. It is worth mentioning that the entire subsequent dyeing process, shown in Fig. 6, should also be carried out in a weak acid environment..

After examining the five methods introduced above, it becomes evident that regional differences in traditional madder dyeing techniques stem from a combination of factors, including geography, history, and culture. These differences result in distinct regional characteristics that are unique to each country and region around the world. Although each region uses a type of madder plant, their individual

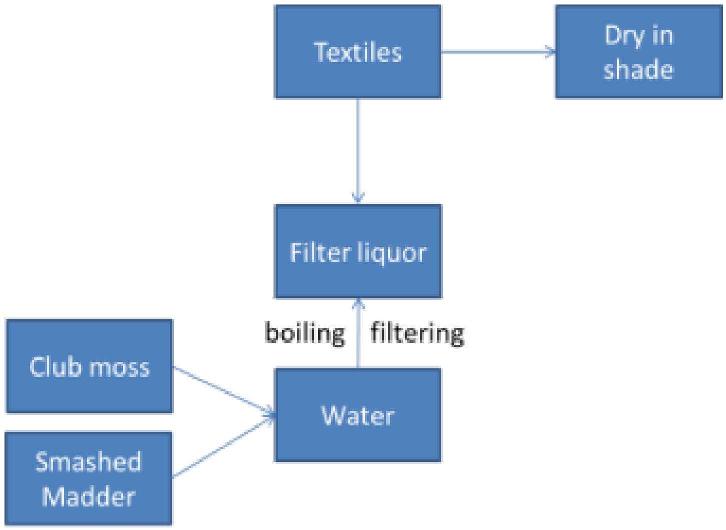


Fig. 4. Process of Turkish technique of madder dyeing

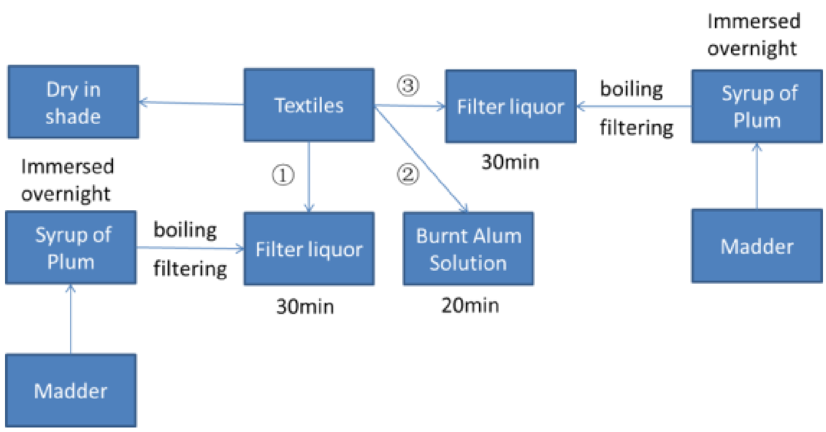


Fig. 5. Process of ancient Japanese madder dyeing technique (a)

characteristics vary due to the different growing conditions and environments, leading to differences in their growth morphology and physiological properties. Consequently, even though these plants share the same botanical classification, they differ in their dyeing effects, further contributing to the unique methods and characteristics of madder dyeing in each region.

4. Common pre-treatment methods for cotton fabrics

Madder dye is a versatile coloring agent suitable for a wide range of textiles. In Europe, wool was the primary textile dyed with madder, whereas silk dyeing was common in China and Japan. While, madder was preferred for dyeing cotton fabrics in Turkey. However, plant dyes generally have lower dyeing rates and fastness in cellulose fibers compared to protein fibers, except for indigo dyeing. To overcome this limitation, cotton fabrics are usually pretreated with various methods. Haoran Wang, an expert on natural dyeing and a plant dyeing technique inheritor in China, stated in an interview that four traditional methods are commonly used to pretreat cotton fabrics in different regions around the world. These are presented in Table 1, summarizing the common pretreatment methods for cotton fabrics in different countries and regions.

The surface properties of cotton fabrics can be effectively modified through pretreatment with these methods. For instance, scouring and bleaching can remove impurities and improve the wettability of cotton fabrics, while the use of mordant can create binding sites for dye molecules, resulting in better color fastness. These modifications can lead to different reactions between fabrics and pigments during the dyeing process, which ultimately affect the resulting textile color. For example, using an alum mordant with madder dye produces a vibrant red hue on cotton, while the same dye on untreated cotton produces a lighter shade.

5. Lab process and results

The process of five ancient dyeing techniques for textiles and four modifying process for cotton fabric are displayed in Part 2 and Part 3, respectively, according to which, a clear, precise presentation of the work sequence, with clearly presented recipes and process parameters, is also given in this part.

5.1. Raw material of madder

Various dyeing techniques require different dyeing conditions, such as temperature, pH, time, dye concentration, and operation steps. Even if the same dyeing materials and techniques are used, different textile types can result in different visual color effects. Traditional dyeing techniques can be reconstructed based on historical records. However, the natural habitat of madder in different regions has been irretrievably lost. Moreover, textile production and development have progressed, and water quality has inevitably changed over time, making it impossible to replicate the raw materials, fabrics, and water quality of ancient times. Therefore, qualified madder cultivated in Shaanxi and Shanxi provinces was chosen as the dyeing material for this study.

5.2. Fabric types

Nine types of fabrics were chosen for the lab process in this study, five of which

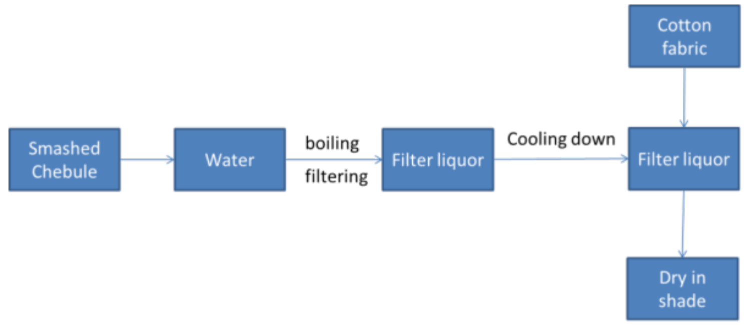
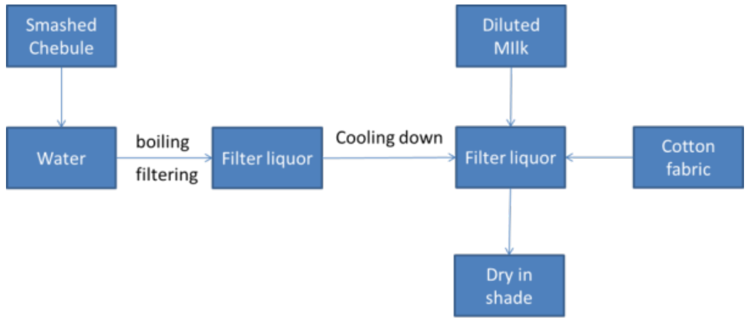
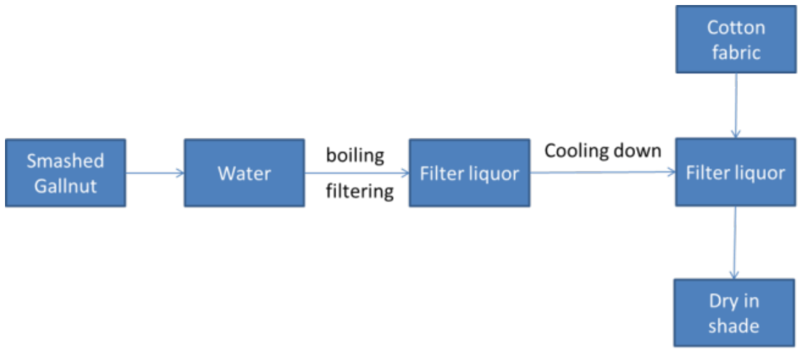
Pretreatment Material	Method Origin	Pretreatment Process
Chebule	Japan	
Chebule & milk	Indian	
Milk	Turkey	
Gallnut	Europe	

Table 1. Methods of cotton fabric pretreatment in different regions of the world

Pretreatment Material	Recipes and procedure of pre-treatment	
Chebule	5 pieces of cotton fabric (2g/piece)	Chebule: 250g; distilled water: 2.5L
Chebule & milk		Chebule: 125g; milk: 125g; distilled water: 2.5L
Milk		Milk: 250g; distilled water: 2.5L
Gallnut		Gallnut: 250g; distilled water: 2.5L

Table 2. Recipes of pre-treatment procedure of cotton fabrics

were cotton fabrics, linen fabrics, raw silk, boiled-off silk and wool. The other four fabrics were cotton fabrics pre-treated with the four traditional methods mentioned in Section 3: cotton fabrics pre-treated with chebule, cotton fabrics pre-treated with chebule & milk, cotton fabrics pre-treated with milk, and cotton fabrics pre-treated with gallnut.

① 45 pieces of textile were prepared firstly, which included 25 pieces of cotton fabric, 5 pieces of linen fabrics, 5 pieces of raw silk, 5 pieces of boiled-off silk and 5 pieces of wool fabric. All the textile samples were cut with scissors to a weight of 2 grams each.

② 20 pieces of cotton fabric were pre-treated according to the pre-treatment methods shown in Section 3. The specific recipes of this procedure are shown below in Table 2.

5.3. Dyeing procedure of madder

All 45 pieces of fabric were divided into 5 groups, each group containing 9 pieces of different fabric respectively. Then 5 ancient dyeing processes were implemented on the 5 textile groups, respectively, according to the 5 dyeing methods shown in Section 2. The specific recipes of this procedure are shown below in Table 3.

Recipes of Dyeing Process	Type of Method				
	Chinese (I)	Chinese (II)	European	Turkish	Japanese
Recipe of Madder	Madder (owf)=400%				
Recipe of Mordant	Alums (owf)=15%		Alums (owf)=20% Potassium acid Tartrate (owf)=6%	Club moss (owf)=100%	Burnt alum (owf)=15%
Implementation of Dyeing	Refer to Figure 1	Refer to Figure 2	Refer to Figure 3	Refer to Figure 4	Refer to Figure 5
owf: on weight of fabrics					

Table 3. Recipes of dyeing procedure of fabrics

Type of Method / Type of Textile	Chinese (I)	Chinese (II)	European	Turkish	Japanese
Cotton fabrics					
Cotton fabrics pre-treated with chebule					
Cotton fabrics pre-treated with chebule & milk					
Cotton fabrics pre-treated with milk					
Cotton fabrics pre-treated with gallnut					
Linen fabrics					
Raw silk					
Boiled-off silk					
Wool					

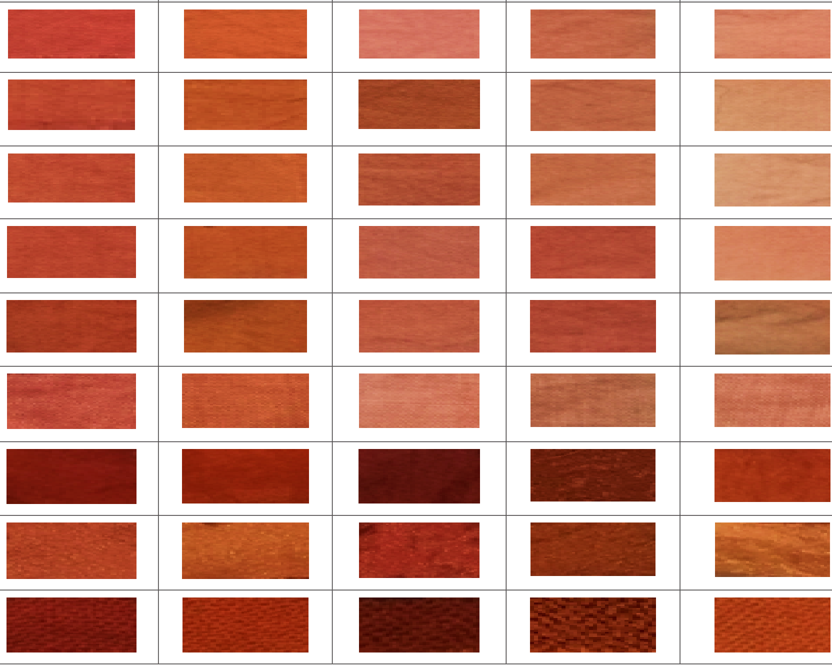


Table 4. Colors of different traditional dying techniques on different fabrics

5.4. Results of madder dyeing

The five methods discussed in Section 2 were applied to the nine types of textiles in this part. As a result, diverse color effects were obtained and are presented in Table 4.

An overview of five madder dyeing techniques from specific countries and regions was obtained, representing a historical snapshot of the development of traditional plant dyeing. However, it is important to recognize that the evolution of these techniques is complex and dynamic, and includes processes such as re-dyeing, overdyeing, and mordant dyeing, which vary depending on the sequence of the entire dyeing process. For instance, re-dyeing can occur at different stages, overdyeing may involve different dyeing materials or variations in the sequence of mordant addition, and mordant dyeing can involve changes in the type and concentration of mordant. Moreover, a range of textile colors can be achieved by adjusting dyeing conditions such as the bath ratio, dye concentration, time, temperature, acidity, and process sequence, as well as by using different dye raw materials.

It could be concluded that selecting the classical European technique or Turkish technique for madder dyeing can help save resources, shorten the process cycle, and have high adaptability and popularity. However, the classical European process uses more water and auxiliary dosage than the Turkish technique, making it less water-efficient but more efficient overall. All the traditional madder dyeing techniques explored in this article not only involved different pretreatment methods for cotton fabrics, but also employed diverse dyeing techniques to produce unique and innovative practices, resulting in a rich array of textile colors. The diversity of madder dyeing materials and techniques from different regions around the world has contributed significantly to the great prosperity of world culture, as the richness and diversity of cultures come from differences and variations. As we all know, the main reason for plant dyeing attracting people's attention again in the current era is that compared with synthetic dyes and chemical dyeing processes, the raw materials of plant dyeing are natural, safe, and the dyeing process is environmentally friendly, recyclable and sustainable. The biggest advantage of plant dyeing is the recycling of the dyeing process. On the one hand, the dyeing solution of the natural dyeing process can be used repeatedly more than once before it is treated as liquid waste and be thrown away, which could be verified by the records of plant dyeing in ancient books. On the other hand, the liquid waste of natural dyeing is more environmentally-friendly than that of chemical dyeing, which needs a quantity of water for the after-finish of textiles. Thus, as part of natural dyeing, those ancient madder dyeing techniques are much more water-saving and resource-conserving compared with chemical staining, which has positive impacts on the current dyeing status.

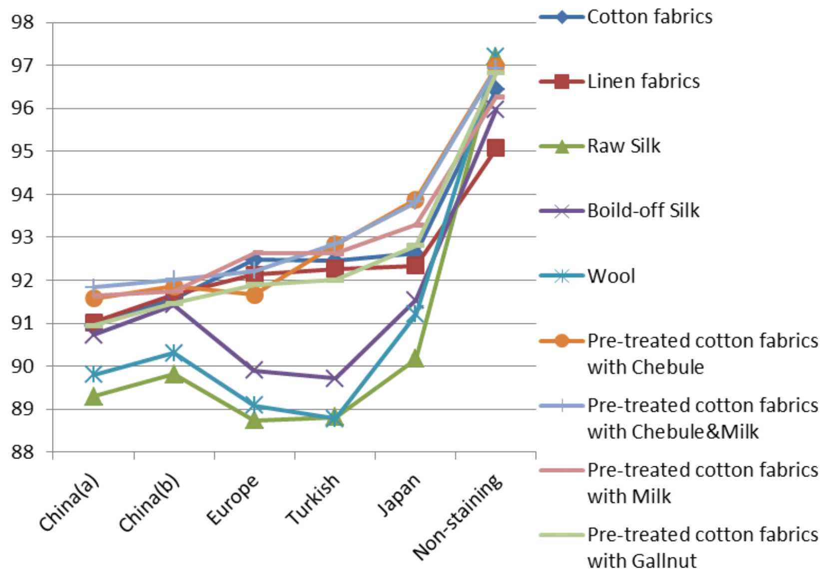


Fig. 6. Value L of different fabrics dyed with madder

6. Color characteristics testing and discussion

In this study, various madder dyeing techniques were explored from different countries and practised on different fabrics to obtain 45 samples of dyed fabrics with diverse colors and textures. To provide a scientific and objective basis for further color analysis, we measured the color characteristics of the dyed fabrics using a Hunterlab spectrophotometer. The values of L*, a*, and b* based on the CIELAB Color Space were used to describe the color characteristics, including the lightness value, hue, and color saturation.

All 45 dyed fabrics were tested with Hunterlab, and the corresponding color coordinates were obtained, presented in Table 5. The L-axis represents the lightness value (L) of the dyed textiles, with 0 indicating black and 100 indicating white. The a-axis (red-green) has positive values for red, negative values for green, and 0 for neutral, while the b-axis (yellow-blue) has positive values for yellow, negative values for blue, and 0 for neutral. Madder dyeing altered the lightness value of the textile (L-axis), as well as the hue and color saturation (a-axis and b-axis). By analyzing the position of the color coordinate point in the coordinate system in combination with color visual effects, we can clarify the color features of the textiles.

The madder dyeing process results in a change in the lightness value of the fabrics. Figure 3 displays the changes in the lightness value (L) of the dyed textiles for different dyeing techniques. Based on the test results in the chart, the lightness value of the fabric was higher before being dyed, and all five dyeing techniques were effective in reducing the lightness value of the fabric. The lightness value of the non-staining fabric is higher, which is close to 100. Once dyed, the lightness value of textiles decreases, and the textile color presents a muted visual effect, which adheres to the principles of color perception. Furthermore, according to the test results of the lightness value, different dyeing techniques have the same impact on the lightness value of silk and wool. The classical European process and Turkish technique have a greater effect on the lightness value of silk (including raw silk and boiled-off silk) and wool, compared to non-staining fabrics. Overall, the lightness value of silk and wool fabrics obtained through madder dyeing is lower than that of cotton and linen fabrics. This is because silk and wool are both protein fibers, and the way they interact with dyes differs from that of cotton and linen fabrics.

Based on the data in Table 5, it can be observed that the chroma value coordinates a* of cotton fabrics pretreated with milk was higher than that of other fabrics, suggesting that this fabric type has better pigment compatibility with madder. Irrespective of the fabric type, the a* value of textiles dyed using the ancient Chinese technique (I) was higher than that of the other techniques, indicating that this technique can release and combine more pigments with textiles, leading to an excellent dyeing rate. Moreover, the b* value of fabrics dyed using the ancient Chinese technique (II) was positive, indicating that the color obtained using this technique is reddish-yellow. Conversely, the coordinate points of fabrics dyed using the classical European process were on the b-axis or in the negative area of the b-axis, indicating that the fabric color obtained is bluish-pink, i.e., color fuchsia, which lies between red and blue. Furthermore, the b* value of wool and raw silk fabrics was mainly distributed in the positive axis, presenting a visual effect of orange, which was especially evident with the ancient Japanese and Chinese technique (II).

Modification has been made to cotton fabric in order to increase its dyeing property, and it is easy to be seen from Table 6 that the textile color of

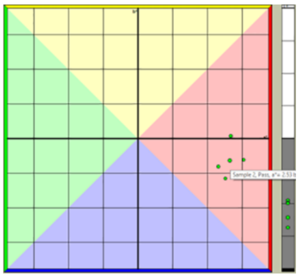
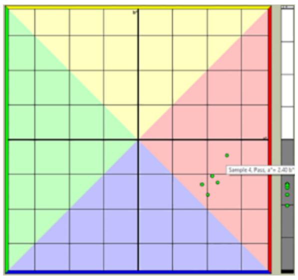
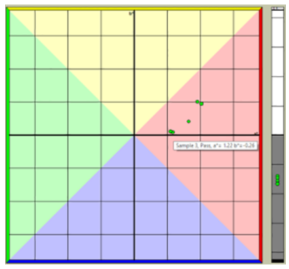
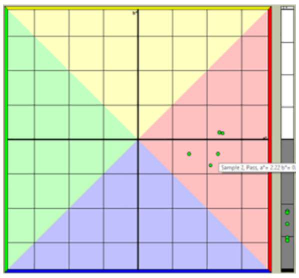
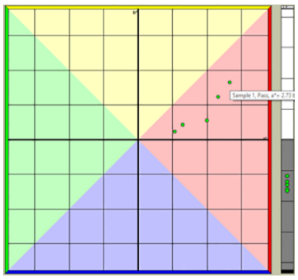
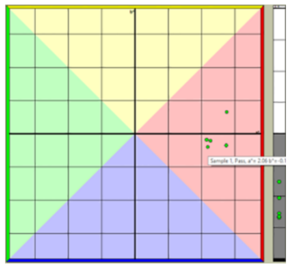
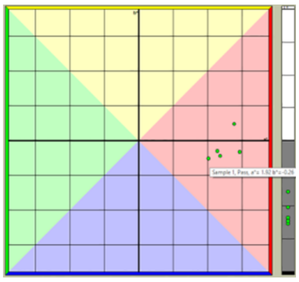
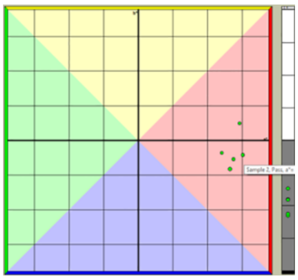
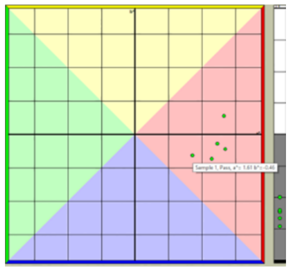
Type of fabric	Cotton fabrics	Linen fabrics	Raw silk
• Chroma value coordinates			
Type of fabric	Boiled-off silk	Wool	Cotton fabrics pre-treated with chebule
• Chroma value coordinates			
Type of fabric	Cotton fabrics pre-treated with chebule & milk	Cotton fabrics pre-treated with milk	Cotton fabrics pre-treated with gallnut
• Chroma value coordinates			

Table 5. Color coordinates of different fabrics dyed with madder

Type of dyeing method	Color effects of cotton fabrics
Chinese(I)	
Chinese(II)	
European	
Turkish	
Japanese	

The color shown from left to right: cotton fabric, cotton fabric pre-treated with chebule, cotton fabric pre-treated with chebule & milk, cotton fabric pre-treated with milk, cotton fabric pre-treated with gallnut.

Table 6. Comparison of the dyeing effect between cotton fabric and pre-treated cotton fabric

cotton fabric and pre-treated cotton fabric showed a difference. The cotton fabric pre-treated with gallnut could get the best dyeing depth with ancient Chinese technique (I), ancient Chinese technique (II), and the ancient Japanese technique, while cotton pretreated with chebule could get the best dyeing depth with the classical European method, and cotton fabric pretreated with milk could obtain the deepest color with the Turkish technique. Therefore, from the perspective of dyeing depth, there is an optimal match between cotton fabric pre-treated with gallnut and the ancient Chinese and Japanese dyeing techniques, and cotton fabric pre-treated with chebule matches the classical European method the best. While cotton fabric pretreated with milk matches the Turkish dyeing technique the best.

Thus, based on the objective and scientific test results combined with the visual perception of fabric color, it can be concluded that the different fabrics show characteristic differences and commonalities in their dyeing effects with various dyeing techniques. The madder dyeing process involves several physical and chemical reactions, making it an interactive process. Any variation in any factor during the complex reaction will affect the final dyeing effect. The quantitative analysis of the visual effects presented by the dyed fabrics using scientific and accurate data is a verification of the authenticity of people's subjective visual perceptions.

7. Application: visual art of the color of textiles dyed with madder

In addition to the use of professional color measuring instruments for color value testing, the study of textile color art generally needs to rely on a professional color research system, like NCS from Germany, the Munsell Color System from America, and PCCS from Japan. PCCS is the abbreviation of the Practical Color-ordinate System, which was invented in Japan in the year 1964. It can be easily seen form its name that PCCS focuses on how to get and use harmony and attractive colors to achieve the best visual effect and commercial value. PCCS divides colors into 12 different regions, which can be seen in Figure 10. Color can be freely used and enjoyed in our daily life, which is associated with people's perception and impression. There is a commonality in humans' impression of specific colors. Experiments in color psychology help humans to scientifically grasp the correlation between color and human emotion. This correlation can be used as an objective basis for selecting color and applied to a design requiring a marketing function and publicity. In order to explore the aesthetic value and commercial value of madder dyed textile color, all those colors obtained were put in PCCS to find out the color characteristics and color styles.

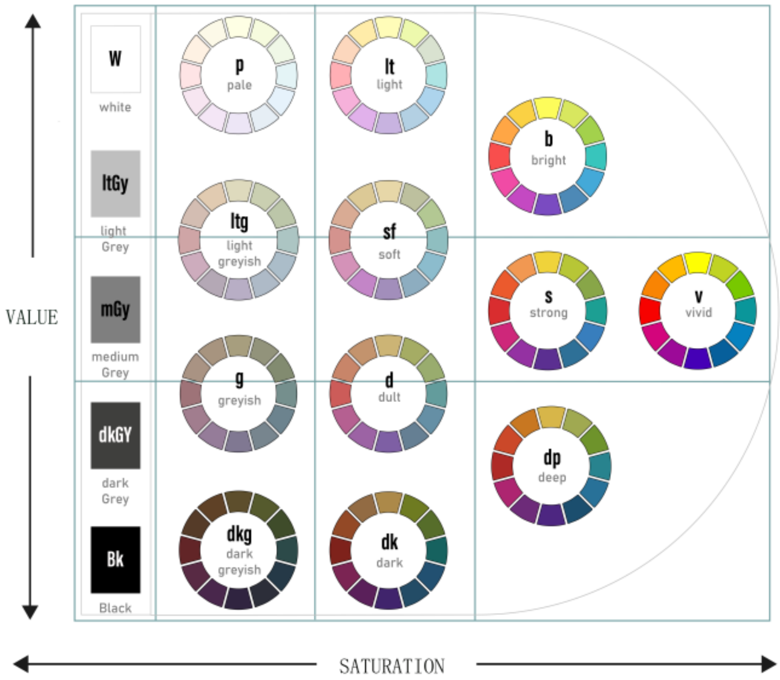


Fig. 7. Tonality distribution diagram of PCCS

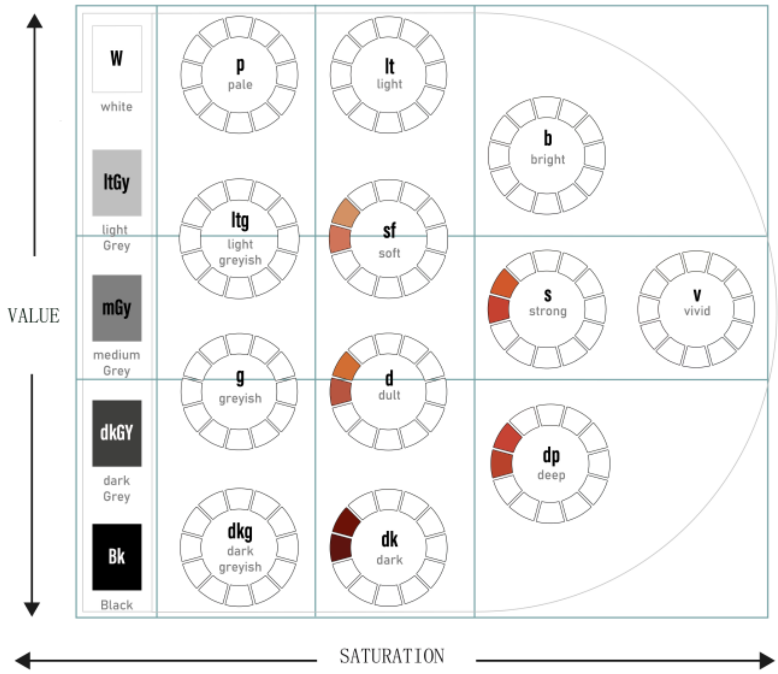


Fig. 8. Color distribution of madder dyed textiles

It can be clearly seen that the colors of textiles dyed with madder are located in 5 different color tone regions, which are soft tone, strong tone, dull tone, deep tone and dark tone, respectively. Colors in the soft tone have higher lightness and middling saturation, giving people an impression of softness, placidity and quietude, while colors in the strong tone have higher saturation and middling lightness, which makes people feel forceful, dynamic and enthusiastic. Colors located in the dull tone represent filminess, funkiness and steadiness, while colors distributed in the deep tone give people a visual traditional, archaistic and disimpassioned impression. Whereas the colors in the dark tone represent sedateness, maturity and stoutheartedness. Thus, textile colors obtained by traditional madder dyeing techniques present a rich variety of styles, and designers can match different color styles with different fashion ones to create innovative clothing products.

Dyeing technique is an important approach for getting textile color. The brightness and saturation of textile colors dyed with madder are unique and various. Those colors include scarlet with low saturation and moderate brightness, as well as magenta, reddish purple with high saturation and low brightness. As is known, besides alizarin, yellow pigments are contained in madder as well. If yellow pigments were not effectively removed from madder during the dyeing process, the textile color would be yellowish orange or poppy. Therefore, various textile colors could be gotten while overall color saturation and brightness are low. The dyeing effect of madder on cotton fabric creates an elegant and soft visual sense for people, while that on silk and wool brings a quiet and low-key visual sense.

According to color psychology, colors can evoke warm or cold feelings in people during visual contact [13]. These feelings are a visual phenomenon that arises from long-term human experience and conditioned reflexes. Fig. 8 illustrates the distribution of cool and warm colors, with warm colors such as red, orange, and yellow giving people a sense of warmth. In addition to the influence of the hue, the brightness and saturation of a color can also affect its perceived warmth or coolness. The ancient Chinese technique (II) produces colors that are predominantly orange-red, giving a stronger sense of warmth than other colors. When comparing the textile color obtained from the ancient Chinese technique (I) with that of the ancient Japanese technique, it can be observed that the former has higher saturation and warmth of color. On the other hand, dyed silk and wool convey a visual effect of orange, which brings about a stronger feeling of warmth.

Madder dyed textile color generally appears red or close to red in hue. However, the chroma value coordinates obtained through color testing indicate that the lightness and color saturation of the dyed color are low, resulting in a sense of weight. Psychologically, madder dyed textile color gives people a feeling of calm and softness. Ancient Chinese poems describe madder dyed clothes, which were mostly used to make women's clothing, such as the costume shown in Fig.9. The Chinese pronunciation of madder is 'Qian', which ancient people also used to describe the beauty and elegance of ladies in their poems. Women were often named with the word "Qian," reflecting the ancient people's taste in color aesthetics. The low brightness and saturation of madder dyed textiles create a quaint color visual effect.

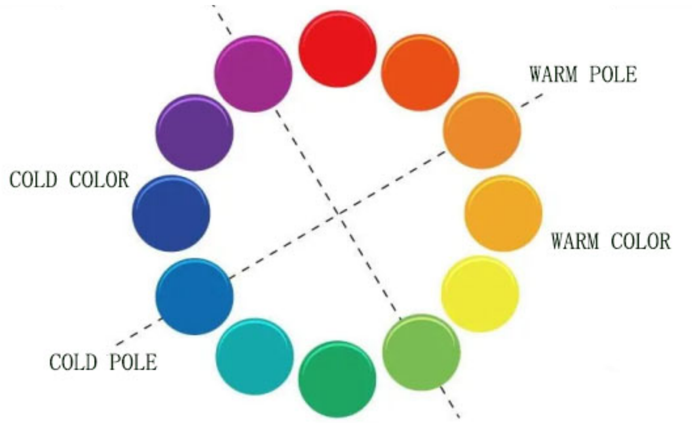


Fig. 9. Cool or warm colors in hue circle

Fig. 10. Traditional costume with madder

The public's perception and concept of color varied depending on the social trends of thought, philosophical culture, and development levels of dyeing materials and techniques in different regions and time periods, affecting the richness of dyeing colors. Ancient people sought a purer and brighter red due to the limitations of dyeing techniques. Nowadays, people's aesthetic appreciation of color has become more diversified and personalized. The revival of traditional color culture has led people to pursue natural colors. The elegant and low-key red color acquired through madder, with low saturation and brightness, is particularly attractive to people. Thus, textile colors obtained by madder have their own particular artistic style, giving people unique aesthetic experience, as well as a high aesthetic value.

8. Conclusion

1. As an important red dye in ancient times, madder was used in different regions over the world for dyeing red color, which has been a vital color to human-beings throughout history. Five ancient dyeing techniques and the detailed process of these techniques were explored and presented by researching ancient books, academic studies and existing historical records, which is a supplement of modern research of madder dyeing. It was found that the formations of different ancient dyeing techniques were closely related to different regional cultures.
2. Both the technique of dyeing in the field of science and technology and color aesthetics at the level of visual art rely on certain materials for expression. The type of textiles and the different fabric types determine the combination of dyes and fabrics in different ways, which can obtain different fabric colors. Cotton fabric was pretreated by four traditional methods in order to improve its dyeing property, and it was found that pre-treating could definitely improve the dyeing property of cotton fabrics; but there is a certain match between different pre-treatment methods and different dyeing techniques.
3. Four pre-treated cotton fabrics and five different textiles including cotton fabric, linen fabric, raw silk, boiled-off silk, and wool were dyed according to five ancient madder dyeing techniques, obtaining various textile colors, and their color value was tested and analyzed according to the CIELAB color space. It was found that the color value of silk and wool fabrics obtained through madder dyeing is lower than that of cotton and linen fabrics. All types of textile obtained reddish-yellow with the ancient Chinese technique (II), while all types of textile obtained bluish-pink the classical European process. All colors with the ancient Chinese technique (I) were more reddish than those obtained by other dyeing methods.
4. After conducting a comparative analysis of the traditional madder dyeing techniques , it was found that differences in environmental protection, energy efficiency, and process efficiency existed. From an environmental and energy-saving perspective, the classical European process and Turkish technique were more cost-effective in terms of raw materials and auxiliaries used, while the ancient Chinese technique and ancient Japanese technique required a higher quantity and variety of raw materials. In terms of process efficiency, the ancient Chinese and Japanese techniques required longer dyeing cycles and involved more dyeing steps, while the classical European process and Turkish technique were simpler and had shorter dyeing cycles.
5. Madder dyed textile color art was studied and analyzed based on PCCS, which is a professional color research system. Different color styles were created by madder dyeing, including soft, placid dynamic, enthusiastic, filmy, archaistic and disimpassioned, mature etc. Artistic color features were also analyzed from the viewpoint of color psychology and social properties of textile color. It was found that the dyeing effect of madder on cotton fabric creates an elegant and soft visual sense for people, while that on silk and wool brings a quiet and low-key visual sense. Various styles of textile colors obtained not only provide design materials to designers, but also cater to the artistic aesthetic color taste of the public.

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