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DIGITIZING AND RECOVERING THE KNOWLEDGE OF TRADITIONAL CHINESE COLOUR OF THE NANJING BROCADE

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Abstract

Colour knowledge of Nanjing Brocade has not been systematically and precisely documented due to many difficulties. This paper presents a comprehensive research on literature, artifacts and expert experience to demonstrate the colour range of Nanjing brocade from the conceptual and visual perspectives. By text mining, the commonly used colours of Nanjing brocade have been collected. Then, a combined research of chemical experiments of natural dyes in textile fragments and traditional dyeing experiments finds out the specific materials used in the ancient China and what kind of colours are dyed by these materials. Finally, a perceptual evaluation by experts helped match the colour samples to terms and a colour specification in line with Chinese aesthetics has been developed. With internationally accepted LCh value, the specification will facilitate colour identification and application for researchers, producers, and designers.

Keywords

Chinese colour, textile colour, text mining, natural dyeing, HPLC, perceptual evaluation

1. *Introduction*

Chinese silk production has a great impact in the world through Silk Road for hundred years. The important imperial robe materials produced in Nanjing (southwestern Jiangsu, China) during the Yuan, Ming and Qing dynasties (13th–20th century AD) represent the topmost craftsmanship of silk dyeing and weaving in China. These materials were later collectively known as Nanjing brocade (*yunjin* 云锦, lit. "cloud brocade"), famous for their colours that were as gorgeous as rosy clouds. (Huang, Wang & Xiao, 2003). Nanjing brocade is operated on the large loom and based on weft-weaving techniques. The superiority of its colours lies in several aspects: First, Nanjing brocade includes several types of polychrome and gilded weaves as shown in Fig.1, among which the most representative type known as *zhuanghua* uses at least five and as many as twenty or more colours in one piece (Xu, 2002; Vainker, 2004). Second, Nanjing brocade uses fine mulberry silk which can get bright colours and high colour fastness, and it benefited from the development of silk refining and over-dyeing[1] techniques in the Ming dynasty which greatly enriched the colour range of dyeing and weaving. Meanwhile, in order to describe the ever-increasing range of hues, the ancients coined hundreds of new colour terms[2] that not only reflected but facilitate their perception and recognition of colours. For example, *dahong* 大红 (lit. "great red", scarlet) was a new colour term created out of the pre-existing term *Hong* 红 (red), to describe the saturated pure red derived from repeated dyeing, while *taohong* 桃红 (lit. "peach red") was used to describe a lighter red, similar to the colour of peach blossoms. Moreover, as produced for officials and official gifts, Nanjing brocade's colours were strictly selected and controlled by the weaving and dyeing bureau set in Nanjing, which ensured the

[1] Over-dyeing is to immerse fabric in two or more different dyeing solutions to obtain intermediate colours.

[2] A colour term (or colour name) is a word or phrase that refers to a specific colour. The colour term may refer to human perception of that colour (which is affected by visual context).

Fig. 1: Four types of Nanjing brocade: (a) *kuduan* 库缎 (lit. "storehouse satin", mainly monochrome or bichrome satin). (b) *zhijin* 织金 (lit. "weave gold", gold woven fabric). (c) *kujin* 库锦 (lit. "storehouse brocade", polychrome brocade with wefts passed throughout the whole width). (d) *zhuanghua* 妆花 (lit. "decorative pattern", polychrome brocade with wefts weaved in sections and colours changed freely. (Huang, Wang & Xiao, 2003)

standardisation of commonly used colours, so that Nanjing brocade can better represent the aesthetics and etiquette in ancient China.

Although Nanjing brocade is a wealth of traditional knowledge of Chinese colour, the inheritance has been facing huge challenges. To the best of our knowledge, there was no systematic documentation of Nanjing brocade colour throughout history, and only a few of scattered colour terms and natural dyeing methods appear in the literature. Precious experience of colour cognition or dyeing technique was mainly kept in the human hand and mind as tacit knowledge and passed on from master to apprentice privately for guarding trade secrets. Hence, Chinese colour knowledge has been forgotten slowly, especially after the popularity of synthetic dyes and western colour specifications during the 19th century. The ancient brocade fabrics, meanwhile, are irreversibly fading. It's difficult to tell what colours they once were, and how to reoccur them. Institutions like Nanjing Yunjin Brocade Research Institute have been trying to recover the ancient textile, but mainly on weaving technique. As for colour, they usually use synthetic dyes and choose faded fabric surfaces as the reference samples for colour restoration, which cannot reproduce the original colour of these luxury fabrics (Zeng, 2019).

In 2009, Nanjing brocade was selected into the representative list of oral and intangible heritage of humanity of UNESCO[3]. There has been a resurgence of the appreciation on and academic interest in its colour. Some experts have summarized typical colours of Nanjing brocade and analysed the aesthetic and culture of it, mainly basing on their own experience (Xu, et al., 2002; Dai, 2009). Several scholars searched literature and collected colour terms related to textiles in the Ming and Qing dynasty (Cao, 2012; Fan, 2016). Others traced the traditional dyeing methods in literature and tried to recover the colour with natural dyes (Kim, 2006; Zhang, 2014; Liu, Wang, et al., 2020). In general, researches on separate fields of literature, artifacts, and expert experience have been conducted, while a comprehensive study on Nanjing Brocade colour combining all the fields is in lack. In most cases, the knowledge production remained in traditional way of literature interpretation and experience induction.

[3] See "Craftsmanship of Nanjing Yunjin brocade" on the list of UNESCO Intangible Cultural Heritage.

The former method leads to an in-depth study of individual classic texts but ignores a large number of other texts. The latter leads to perceptual and subjective description instead of convincing data, which is unclear and inconvenient for the reproduction of knowledge. For now, the colour knowledge of Nanjing brocade is still scattered, blurry, and personal, incapable of forming a knowledge system.

As a result, the designers and producers of Nanjing brocade are in lack of an acknowledged brocade colour specification, which associates the colour terms, dyeing techniques, and expert experience together, and gives accurate standard of Nanjing brocade colour. Although some producers currently use the Nanjing Brocade Silk Colour Swatches (Fig. 2), three drawbacks of it are troubling. First, its colour samples were dyed with synthetic colourants which cover a different perception from natural colourants. Second, the swatch of certain colour was selected by just one expert, so its subjective and unilateral. Third, it has not been digitized and lacks colour value, causing inconvenience for preservation, propagation and communication of colour. Today's textile production in China prefers Pantone colour system for its precise colour guidance, and there hasn't been a practical colour system that roots in Chinese traditional aesthetic and cognition yet.

By reviewing the difficulties in inheritance and recovery of the Chinese colour knowledge of Nanjing brocade, it can be found that the core problem lies in the traditional mode of knowledge production. How to turn the traditional scattered, blurry, and personal colour knowledge into scientific knowledge which is systematic, accurate, and standard, is the primary problem to solve.

2. *Theoretical model*

In this digital age, significant changes have taken place in the way knowledge exists and is organized. Advanced technology has brought solutions to some previously intractable problems in the humanities, including the preservation and restoration of cultural heritage.

Nowadays, scholars from different fields have conducted comprehensive studies and used digital technology to construct a knowledge system of traditional Chinese colour. Li (2019) explored the colour of ancient buildings basing on the analyses of literature, cultural relics, and techniques, with the experiments of pigments remaking. Cui (2019) proposed a similar triple-evidence methodology of colour researching, that is "documents to consult, artifacts to test, and experts to ask", and built a database of hundreds of colours in Beijing City by measuring the colour data of traditional buildings, craft arts, costumes, and foods. Their approaches are also applicable to the study of textile colour. Whereas, these researches used digital technology mainly to collect and store colour information

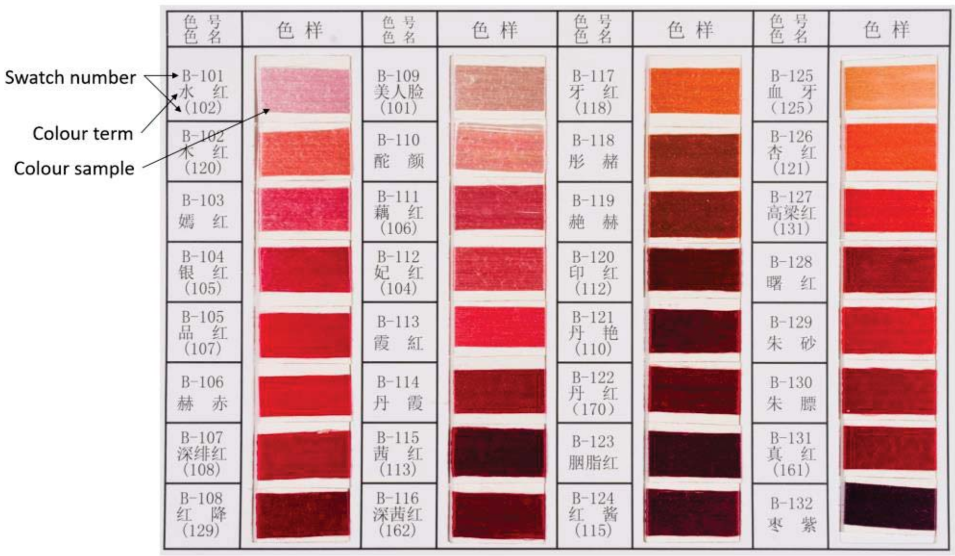


Fig. 2: The Nanjing Brocade Silk Colour Swatches made by Jisheng Wang after 2010.

from objects, and there are much more to be done with the literature and expert experience.

For explicit knowledge of literature, an increasing number of historical documents are digitally available online. Through database technology, different information resources can be organized together for search or analysis. The sophisticated process of text mining helps extracting interesting and non-trivial patterns or knowledge from unstructured text documents (Tan, 1999), including implicit associations between different information. Text mining has proven useful for collecting highly dispersed colour information (Wong, Zhou & Xu, 2016; Zhou, 2020).

The tacit knowledge condensed in human cognition and experience can also be transformed into explicit knowledge through recording and measurement. Scientific experiment leveraging advanced instruments and technologies is a crucial way to resolve the ambiguity of experience, and produce precise and reliable knowledge (Kuhn, 1996). Questionnaire survey is an important method to collect and transform the tacit information, for answers from different people can be quantified and compared (Burke, 2012).

On the basis of former studies, this research aims to explore a new methodology for knowledge production on Nanjing brocade colour, to turn scattered, blurry, and individual knowledge into systematic, accurate, and standardized scientific knowledge. The three major resources—literature, artifacts, and expert experience—are all investigated for the reproduction of colour knowledge. Besides, digital methods are not only applied to colour measurement or restoration of objects, but also to the analyses of literature and expert experience. When every process in knowledge production has a reliable output, it should be possible to bridge the gap between knowledge from diffenrent sources. One of the specific objectives of this research is to set up an acknowledged colour specification that will better guide the heritage conservation and handicraft production of Nanjing brocade. The specification should list the colour samples with related colour terms, and preferably introduce their dyeing materials and methods. In addition, it is common international practice to give the colour value of each sample to facilitate and standardize the colour usage.

3. *Materials and methods*

The main process of knowledge production on Nanjing brocade colour in this research is shown in Fig. 3.

3.1 Text mining

Over 19 related historical texts (Tab. 1) were collected for the text mining, including official documents, literary works, or folk records in the Yuan, Ming, and Qing dynasties. They provide information about colour terms, natural dyes, and dyeing methods related to Nanjing brocade. Catalogues of ancient textiles from 13 museums[4] were also included as the corpus for brocade colour terms.

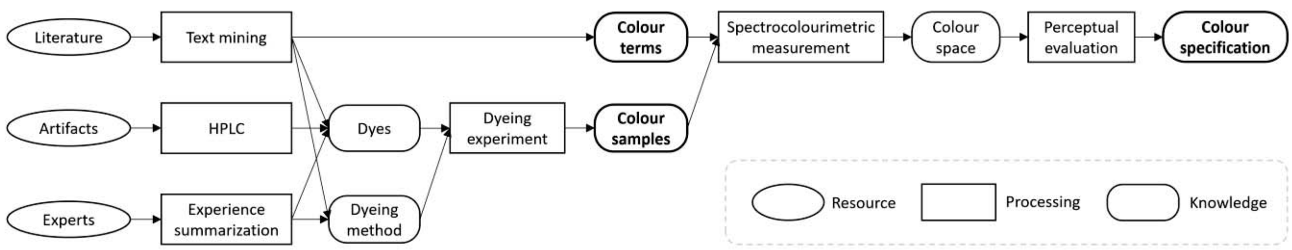


Fig. 3: The knowledge production process of Nanjing brocade colour

[4] Including the Palace Museum, the Nanjing Museum, the Nanjing Museum Administration, the Nanjing Brocade Research Institute, the Ming Tombs Museum, the Capital Museum, the National Museum of China, the China National Silk Museum, the Suzhou Silk Museum, the Ethnic Costume Museum, the Chengde Mountain Resort Museum, the Potala Palace, and the Academy of Arts & Design of Tsinghua University.

Tab. 1: Literature collected for text mining

Title	Date	Main information
Neiwufu quanzong dang'an, Zhiranju buce 内务府全宗档案，织染局簿册 (Complete File of the Imperial Household, Volume of the Weaving and Dyeing Bureau)	Qing dynasty	Official record of weaving and dyeing
Suzhou zhizaoju zhi 苏州织造局志 (The Chorography of Suzhou Weaving Bureau)	Qing dynasty	Official record of weaving and dyeing
Songjiangfu zhi 松江府志 (The Chorography of Songjiang Prefecture)	Qing dynasty	Official record of weaving and dyeing
Yuan shi, Yu fu zhi 元史，舆服制 (Record of Proper Carriage and Attire, History of Yuan)	Ming dynasty	Official record of clothing system
Ming shi, Yu fu zhi 明史，舆服制 (Record of Proper Carriage and Attire, History of Ming)	Qing dynasty	Official record of clothing system
Daming huidian 大明会典 (Collected Statutes of the Ming Dynasty)	Ming dynasty	Official record of clothing system and dyeing
Qing shi gao, Yu fu zhi 清史稿，舆服制 (Record of Proper Carriage and Attire, Draft History of Ming)	Early Republic of China	Official record of clothing system
Tianshui bingshan lu 天水冰山录 (Record of Heavenly Waters Melting the Iceberg)	Ming dynasty	Record of Nanjing brocade fabrics
Jinping mei 金瓶梅 (The Plum in the Golden Vase)	Ming dynasty	Novel mentioned Nanjing brocade fabrics
Honglou meng 红楼梦 (A Dream of Red Mansions)	Qing dynasty	Novel mentioned Nanjing brocade fabrics
Duoneng bishi 多能鄙事 (Various Arts in Everyday Life)	Early Ming dynasty	Record of dyeing methods
Tiangong kaiwu 天工开物 (The Exploitation of the Works of Nature)	Ming dynasty	Record of dyeing methods
Wuli xiaoshi 物理小识 (General Knowledge of Matters)	Ming dynasty	Record of dyeing methods
Bencao gangmu 本草纲目 (Compendium of Materia Medica)	Ming dynasty	Record of dyes
Cansang cuibian 蚕桑萃编 (Collection of Important Essays on Sericulture)	Qing dynasty	Record of dyeing methods
Bu jing 布经 (The Cloth Classic)	Qing dynasty	Record of dyeing methods
Suijin 碎金 (Golden Bits)	Late Yuan dynasty	Record of common colours
Xue Yi xiupu 雪宧绣谱 (Principles and Stitching of Chinese Embroidery)	Qing dynasty	Record of common colours
Yangzhou huafang lu 扬州画舫录 (Record of the Pleasure Boats of Yangzhou)	Qing dynasty	Record of common colours

After scanning, recognizing and proofreading all the texts, MARKUS[5], a text analysis and reading platform, was used to label the colour terms of Nanjing brocade and other entities such as its pattern, date and wearer's identity. Then, with the help of a text database built on DocuSky collaboration platform[6], a list of colour terms or other entities were generated. Further statistics and analyses focused on the frequency and categories of colour terms, revealing the conceptual colour range of Nanjing brocade. The correlations between colour and hierarchy, gender, pattern, etc. were also explored through co-occurrence analysis. MARKUS and DocuSky are two existing text mining tools, while back-end data processing scripts and machine learning

[5] Ho, Hou Ieong Brent, and Hilde De Weerdt. MARKUS. Text Analysis and Reading Platform. Funded by the European Research Council and the Digging into Data Challenge.

[6] DocuSky Collaboration Platform. Planned by the National Taiwan University Digital Humanities Research Center, Information Engineering Coefficient Collection and Automatic Inference Laboratory, chaired by Professor Xiang Jie, and designed and developed by Dr. Du Xiechang.

algorithms are now better options due to their flexibility, which is what we are exploring.

3.2 HPLC

The technology of high performance liquid chromatography (HPLC) has shown great potential when dealing with the analysis of organic materials in textiles (Pauk, Barták & Lemr, 2014), and it helps to identify specific dyes in historical artifacts. Analyses of this research were carried out using a Shimadzu Prominence UFLC, coupled with an ACE Excel 5 C18 column. The relic samples included 14 textile fragments of a red dragon robe of the Ming dynasty ("M" for short) from the Confucius Museum in Qufu, and 15 fragments of an official robe of the Qing ("Q" for short) from a private collection (Fig. 4–a). All samples were collected from different parts of the garments, and each piece did not exceed 6 mg. They vary in shades and can be roughly divided into yellow, red, blue and green, some of which are quite faded. The reference samples were silk yarns dyed with natural dyes, including 26 specimens of Chinese plant and one specimen of sticklac (Fig. 4–b). Identification of natural dyes based on the comparison of HPLC chromatograms of textile fragments with reference dyed samples (Fig. 4–c). The relic is probably dyed with that colourant if the retention times of two samples match each other. With the knowledge of natural dyes actually used in ancient days, the restoration of Nanjing brocade colours will be more reliable.

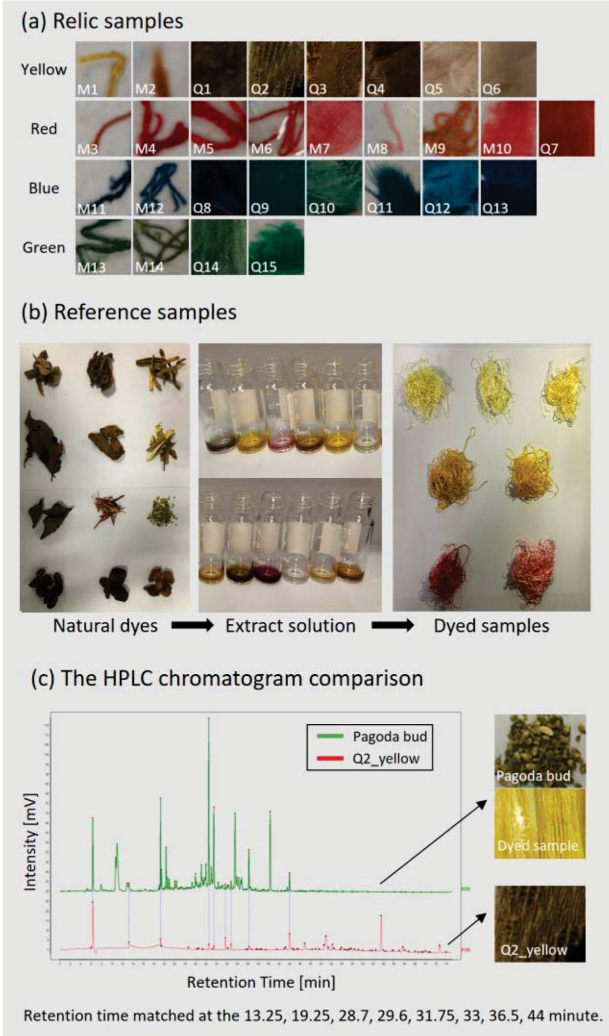


Fig. 4: Materials and results of HPLC: (a) The samples of fabric relics. (b) The natural dyes, their extracting solution and dyed threads. (c) The HPLC chromatogram comparison of Q2_yellow (red line) with silk sample dyed with pagoda bud (green line).

3.3 Dyeing experiment

Combining the information obtained from text mining, HPLC analysis, and the experience summarized from professional dyers, dyeing experiments were designed to explore the ancient dyeing techniques and the colour range of natural dyes. Two experts participated in and conducted more than 35 experiments with 21 natural dyes, including over-dyeing of two different dyes.

Raw or refined silk yarns purchased from a local silk factory were used for dyeing, and were soaked in water for better penetration of the dyes before experiments. Dried or processed dyes were collected from different places of China. Dye colourants were extracted with water or alcohol, then fixed with silk fibers at the appropriate pH and temperature, according to their chemical properties. Reagents like sodium carbonate Na_2CO_3, alum $KAl(SO_4)_2{\cdot}12H_2O$, and melanterite $FeSO_4{\cdot}7H_2O$ were used as mordants. Natural straw ash and prunus mume were also used to make acid and lye. The silk yarns were soaked in solution of different concentrations or for different times to obtain colour gradients. After dyeing, the silk was washed in water and dried in the shade. Fig.5 shows the process of indigo dyeing.

Although dealing with ancient techniques, the whole dyeing process followed the requirements of scientific experimentation. The weather, environment, materials, tools, procedures and results of the dyeing process were recorded in detail, as well as measurement data of time, amount, temperature, pH, and other dyeing conditions. Pictures and videos were also captured by digital cameras throughout the experiments.

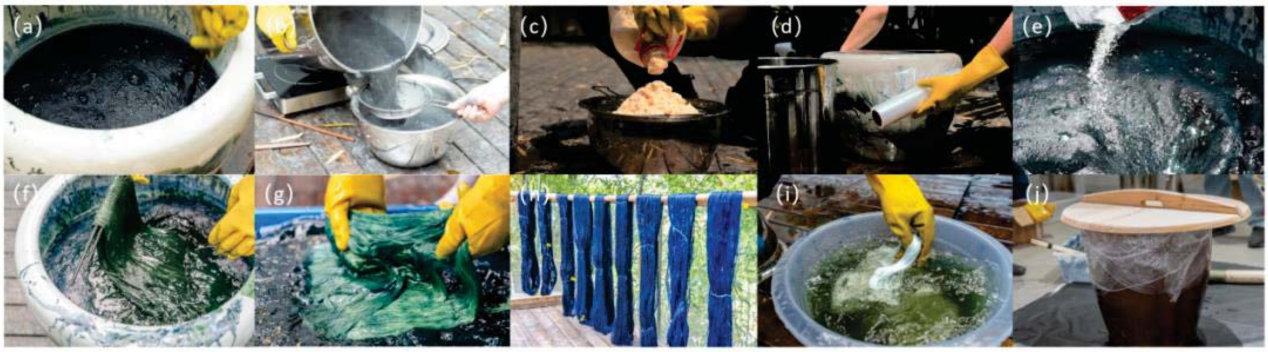


Fig. 5: The image record of indigo dyeing by the professional dyer Jisheng Wang: (a) Dissolve indigo mud in the vat. (b) Add alkaline straw ash filtrate to the indigo solution. (c) Add sweet fermented-rice filtrate to aid fermentation. (d) Seal the vat to create a suitable environment for fermentation. (e) Check the condition of the dye solution after several days. (f) Dip silk yarns in the vat for dyeing. (g) Rinse the silk with water. (h) Hanging the silk to reveal the blue colour by oxidation. (i) Dye other silk yarns for different time or in different concentration. (j) Add some materials, reseal the vat, and continue fermentation for the next dyeing.

3.4 Perceptual evaluation

A numerical system of colour specification including colour samples with related colour terms, referred to as colour space, is an ideal tool for understanding the colour characteristics of Nanjing brocade. The spectrocolourimetric measurement provides accurate L*, C*, h° values of dyed samples for building colour space based on the CIE system. An X-Rite Ci64 Handheld Portable Spectrophotometer was used to measure the colourimetirc values in this research.

Basing on the colour space, the evaluation of colour perception by experts in this research is a new attempt to formulate colour specification. 10 experts participated in the evaluation. They are from different research institutes of Nanjing brocade or dyeing factories.

The questionnaire consisted of 3 main questions: 1) What are the commonly used colour terms for Nanjing brocade? 2) What is the typical colour of each term and its LCh values? 3) Among all the samples we have dyed with natural materials, what is the most visually ideal sample for each colour?

Experts were asked to point out the focal point of each colour in the LCh colour space, with reference to both the artifacts and our dyed samples.

Thus, the subjective and blurry perception of human towards colours changed into quantitative data, which allowed for further comparisons and calculations.

4. Results and discussion

The significant knowledge produced in this research are the Nanjing brocade's colour terms, colour samples, and a colour specification.

4.1 Colour terms

A thorough exploration of colour terms in the literature reveals the significant position of colour in Nanjing brocade. The Chinese name of a Nanjing brocade fabric usually starts with a colour term to describe its ground colour, and the record format is: *colour_technique_pattern_texture_garment type.* For example, the *Dahong zhijin mang duan nüpao* 大红织金蟒缎女袍 (lit. "scarlet gold-woven boa-patterned satin female robe") begins with the colour term *dahong* 大红 (scarlet), suggesting that all patterns are woven on a red ground, and the fabric is generally considered as a red robe. The naming rule embodies the traditional wisdom that colour is always the first and foremost impression when appreciating Nanjing brocade, because one can only see the patterns up close but colours from a distance.

There are 73 different colour terms in the entire corpus of Nanjing brocade texts, occurring nearly 1000 times in total, of which more than a quarter are *dahong* 大红 (scarlet) and a fifth are *Qing* 青 (cyan). *Qing* 青 (cyan) is a one-character word as a "basic colour term" that refers to an abstract hue category (Hemming, 2017), covering shades of green and blue, and even black. By contrast, *dahong* 大红 (scarlet) is a two-character word as a "hyponym" of the basic colour term

Hong 红 (red), describing a highly saturated and pure red. Among the top 10 high-frequency terms, there are six basic colour terms: *Qing* 青 (cyan), *Lan* 蓝 (blue), *Lü* 绿 (green), *Hong* 红 (red), *Huang* 黄 (yellow), and *Zi* 紫 (purple), all of which are one-character words. The other four terms are two-character words: *dahong* 大红 (scarlet), *minghuang* 明黄 (bright yellow), *chenxiang* 沉香 (agilawood brown) and *shiqing* 石青 (mineral blue), and they are probably the most commonly used specific colours for Nanjing brocade. The remaining terms, in smaller proportions, are *xiangse* 香色 (joss stick colour), *youlü* 油绿 (glossy green), *yuebai* 月白 (lit. "moon white", bluish white), *xuan* 玄(reddish black), *xinghuang* 杏黄 (apricot yellow), *molü* 墨绿 (lit. "ink green", blackish green), and so on. The word cloud of Fig. 6 shows all the colour terms that occur more than once. These terms are usually used to describe the ground colour of a Nanjing brocade.

Fig. 6: Word cloud by the frequency of individual colour terms of Nanjing brocade. (Colours in the chart are justindicative.)

Dividing all the colour terms into 10 hue categories (Fig. 7), it's clear to see the distribution of Nanjing brocade colour. It reveals that Nanjing brocade is a kind of colourful textile, as the neutral colours (black, white and grey) account for only 3%. Red and cyan are the dominant hues of Nanjing brocade. Positioned as the national colour by the Ming emperor, red was highly popular among the royals and nobles, and still has a great impact on Chinese aesthetics nowadays. Cyan covers a large range of cool shades that well complement and match the warm red and yellow, and was often used for official robes in China. Blue and green play a similar role to cyan and can both be included in the cyan hue. Yellow is an important colour as it had been reserved for use only by members of the royal court since the Tang dynasty (618–907 CE). Furthermore, considering the identity of the wearer, the colour diversity of men's clothing of Nanjing brocade was much lower than that of women's clothing, and concentrated more on red and cyan (Fig. 8). In ancient days, only men served as officials outside, so there were etiquette restrictions on the colour of clothes, but less aesthetic requirements.

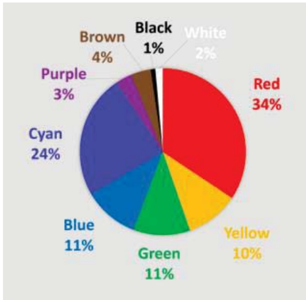


Fig. 7: Hue categories proportion of all colour terms of Nanjing brocade. (Colours in the chart are just indicative.)

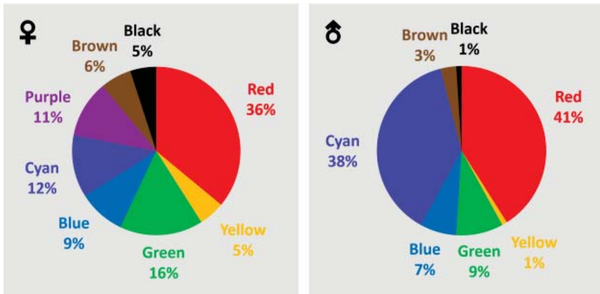


Fig. 8: Hue categories proportion of colour terms related to women's clothing (left) and men's clothing (right). (Colours in the chart are just indicative.)

4.2 Colour samples

In HPLC, nine natural dyes in textile fragments have been successfully detected, five found in the Ming robe and seven in the Qing robe (Tab.2). The cyan fragments were all dyed with indigo. In contrast, the yellow pieces were dyed with various materials, including gardenia fruit, pagoda bud, berberis, goldthread and curcuma aromatica. Two kinds of classic red dyes, madder and polygonum cuspidatum, were identified in the red fragments, while the yellow dye, gardenia fruit, was also in the formula. Besides, all green fragments were over-dyed with indigo and one of the yellow dyes (including granatum which didn't be found in yellow fragments). Fig. 9 shows three examples of analysis chromatograms, including a green fragment that matches both a yellow dye and blue

Tab. 2: Natural Dyes identified in relic samples by HPLC

Object	Colour	Results	Object	Colour	Results
M1	yellow	Pagoda bud	Q1	yellow	Berberis
M2	yellow	Gardenia fruit	Q2	yellow	Pagoda bud
M3	red	Unidentified red and gardenia fruit	Q3	yellow	Gurcuma aromatica
M4	red	Polygonum cuspidatum	Q4	yellow	Gurcuma aromatica
M5	red	Polygonum cuspidatum	Q5	yellow	Goldthread
M6	red	Polygonum cuspidatum	Q6	yellow	Gardenia fruit
M7	red	Polygonum cuspidatum	Q7	red	Unidentified
M8	red	madder	Q8	blue	Indigo
M9	red	madder	Q9	blue	Indigo
M10	red	Unidentified	Q10	blue	Indigo
M11	blue	Indigo	Q11	blue	Indigo
M12	blue	Indigo	Q12	blue	Indigo
M13	green	Gardenia fruit and indigo	Q13	blue	Indigo
M14	green	Unidentified	Q14	green	Gurcuma aromatica and indigo
			Q15	green	Granatum and indigo

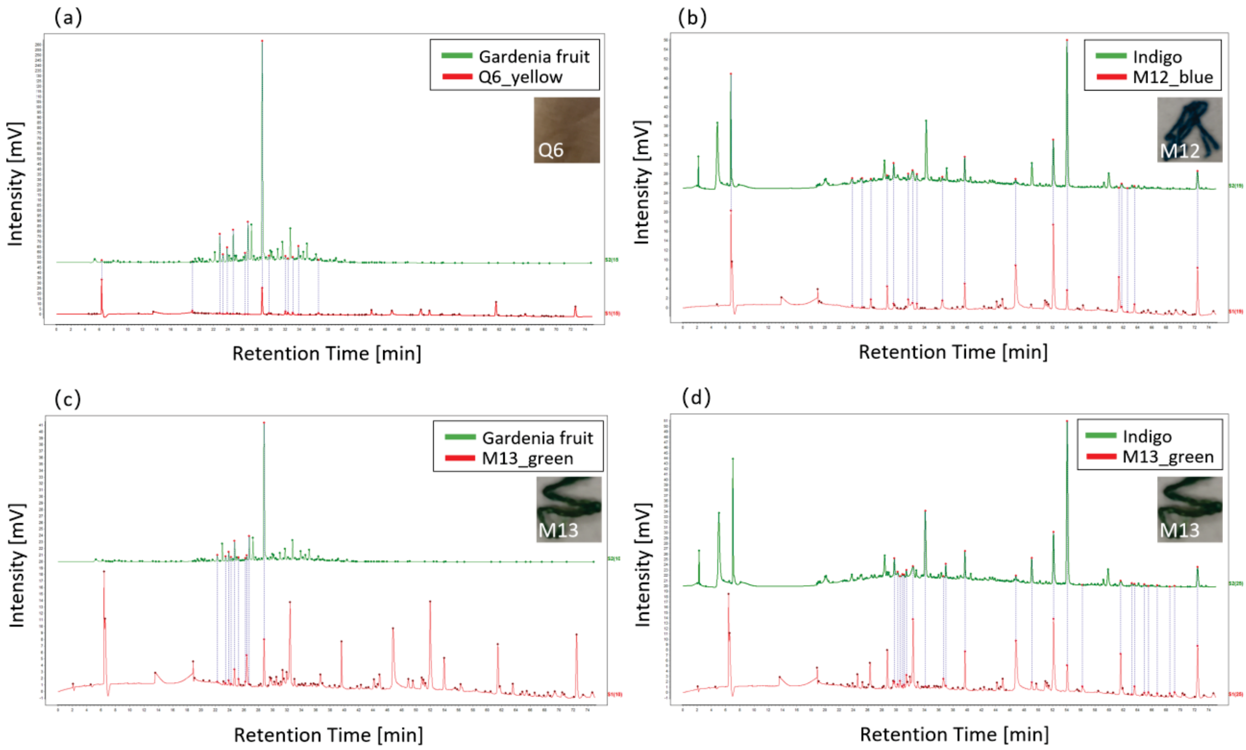
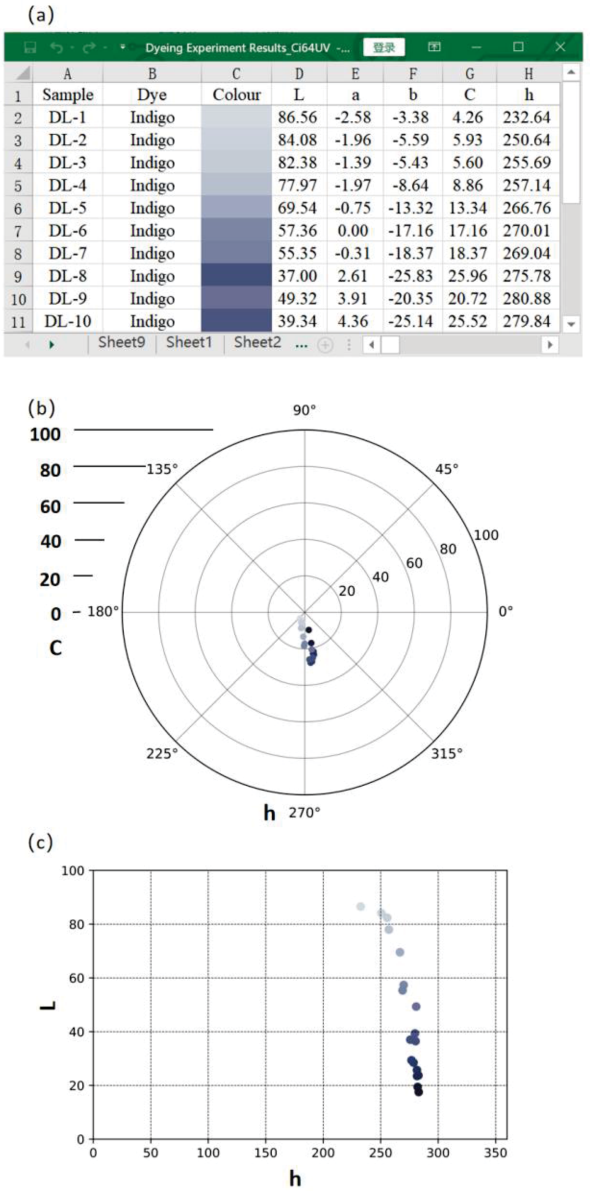


Fig. 9: The HPLC chromatogram comparison of 3 fabric relics: (a) Q6_yellow matches the gardenia fruit dyed sample. (b) M12_blue matches the indigo dyed sample. (c) (d) M13_green matches both the gardenia fruit dyed sample and the indigo dyed sample.

dye. These results well confirm and supplement the information from literature.

18 dyestuffs have been tried in the dyeing experiments, including eight detected by HPLC, 16 founded in the literature, and the other four recommended by experts. Finally, the experiment produced 434 different samples of dyed silk yarns, all of which were warped to swatches and measured the CIELCh value. Then, digital samples were drawn according to the values and positioned in the CIELCh colour space. An example of indigo dyeing results was shown in Fig. 10. Results of all dyes were shown in Tab. 3 and Fig. 11–a. Compared to the colour range of the Nanjing Brocade Silk Colour Swatches made with synthetic dyes (Fig. 11–b), the natural dyed samples also

cover the entire hue, but generally have lower saturation (saturation is indicated by the C value) except for yellow. Although the colour range will be expanded by conducting more experiments with more dyes, the difference between synthetic and natural colour is still notable, which strengthens our determination to build a natural colour specification.



Sample	Dye	Colour	L	a	b	C	h
DL-1	Indigo		86.56	-2.58	-3.38	4.26	232.64
DL-2	Indigo		84.08	-1.96	-5.59	5.93	250.64
DL-3	Indigo		82.38	-1.39	-5.43	5.60	255.69
DL-4	Indigo		77.97	-1.97	-8.64	8.86	257.14
DL-5	Indigo		69.54	-0.75	-13.32	13.34	266.76
DL-6	Indigo		57.36	0.00	-17.16	17.16	270.01
DL-7	Indigo		55.35	-0.31	-18.37	18.37	269.04
DL-8	Indigo		37.00	2.61	-25.83	25.96	275.78
DL-9	Indigo		49.32	3.91	-20.35	20.72	280.88
DL-10	Indigo		39.34	4.36	-25.14	25.52	279.84

Fig. 10: Dyeing results of indigo: (a) Part of the spectrocolourimetric measurement results. (b) The Ch dimension of CIELCh colour space. (c) The Lh dimension of CIELCh colour space.

4.3 Colour specification

Three questions got access to the solution through colour perceptual evaluation with experts:

First, among all the 73 colour terms found in ancient literature, over 60% of them are still in common use. 33 colour terms have been successfully matched with dyed samples by experts.

Second, except for the basic colour terms that represent a broad hue category, each specific colour term covers a certain shade in the colour space and usually has a focal point (the typical colour). However, this ideal point differs among experts. For example, a wide range of light blue can be considered *yuebai* 月白 (bluish white), yet the typical colour pointed out by experts are generally separated into three disconnected areas, as shown in Fig. 12. Considering the opinion of the majority, the ideal colour of *yuebai* was decided on L=92, C=12, h=235.

Third, there is not always an ideal natural dyed sample for each colour term, but currently the experts can select a closest one from experiment results. The recommended natural dyed sample for *yuebai* went to the lighted one tinged with indigo solution, which has a value of L=85, C=7, h=228 (see "*yuebai*" in Fig. 13). In further experiment, a sample with closer colour may be dyed and the current one will be replaced.

With all the data and samples obtained, a colour specification of Nanjing brocade has been created. Fig. 13–a shows a simplified specification of 10 typical colours with the natural dyed samples obtained through dyeing experiment. Fig. 13–b is the digital version in which the colour swatches were drawn with Adobe Photoshop CC.

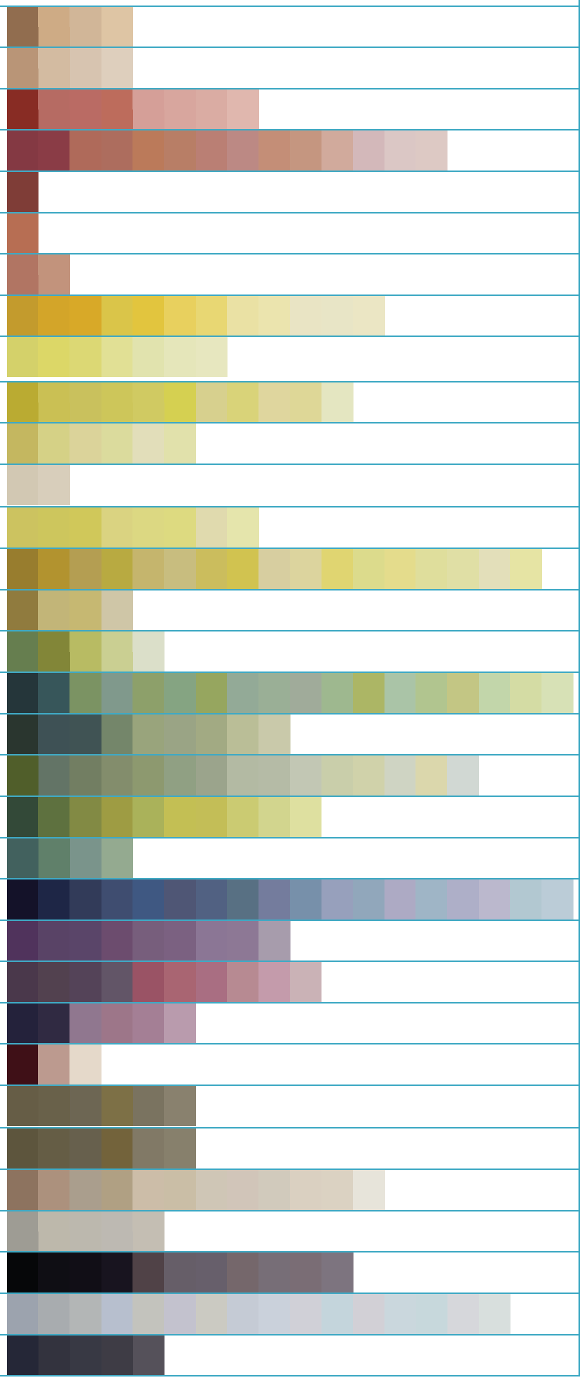
Those digital colours are more uniform and real, because they are not as affected by the shooting environment, especially the angle of light, as the silk sample.

This specification will solve the problems raised at the beginning of this article. It shows the colour terms and the relevant samples with documentation of the dyeing materials and methods.

It also gives the internationally-used CIE values of the colours and has a digital version, which enables users to identify and apply these colours quickly, accurately and widely. As a colour system of natural dyes, this specification covers a softer, more subdued shade than that made with synthetic dyes, allowing us to get closer to the traditional Chinese aesthetics.

Tab. 3: The identifying and dyeing results of natural dyes used in this experiment.

Hue	Natural dyes used	Found in literature	Found in HPLC	Digital experiment results drew by LCh value (partial)
Red	madder	Yes	Yes	
	Polygonum cuspidatum	Yes	Yes	
	Safflower	Yes		
	Sappanwood	Yes		
	Vermilion	Yes		
	Safflower and gardenia fruit			
	Sappanwood and amur-cork tree			
Yellow	Gardenia fruit	Yes	Yes	
	Pagoda bud	Yes	Yes	
	Amur-cork tree	Yes		
	Smoketree	Yes		
	Rehmannia	Yes		
	Berberis		Yes	
	Goldthread		Yes	
	Rhubarb			
Green	Pagoda bud and indigo	Yes		
	Amur-cork tree and indigo	Yes		
	Rhubarb and indigo	Yes		
	Gardenia fruit and indigo		Yes	
	Goldthread and indigo			
	Smoketree and indigo			
Blue	Indigo	Yes	Yes	
Purple	Gromwell	Yes		
	Sappanwood	Yes		
	Indigo and sappanwood	Yes		
Brown	Sappanwood	Yes		
	Smoketree	Yes		
	Goldthread		Yes	
	Cedar bark			
Black, white and grey	Acorn cup	Yes		
	Gallnut	Yes		
	Indigo	Yes	Yes	
	Indigo and Gallnut			



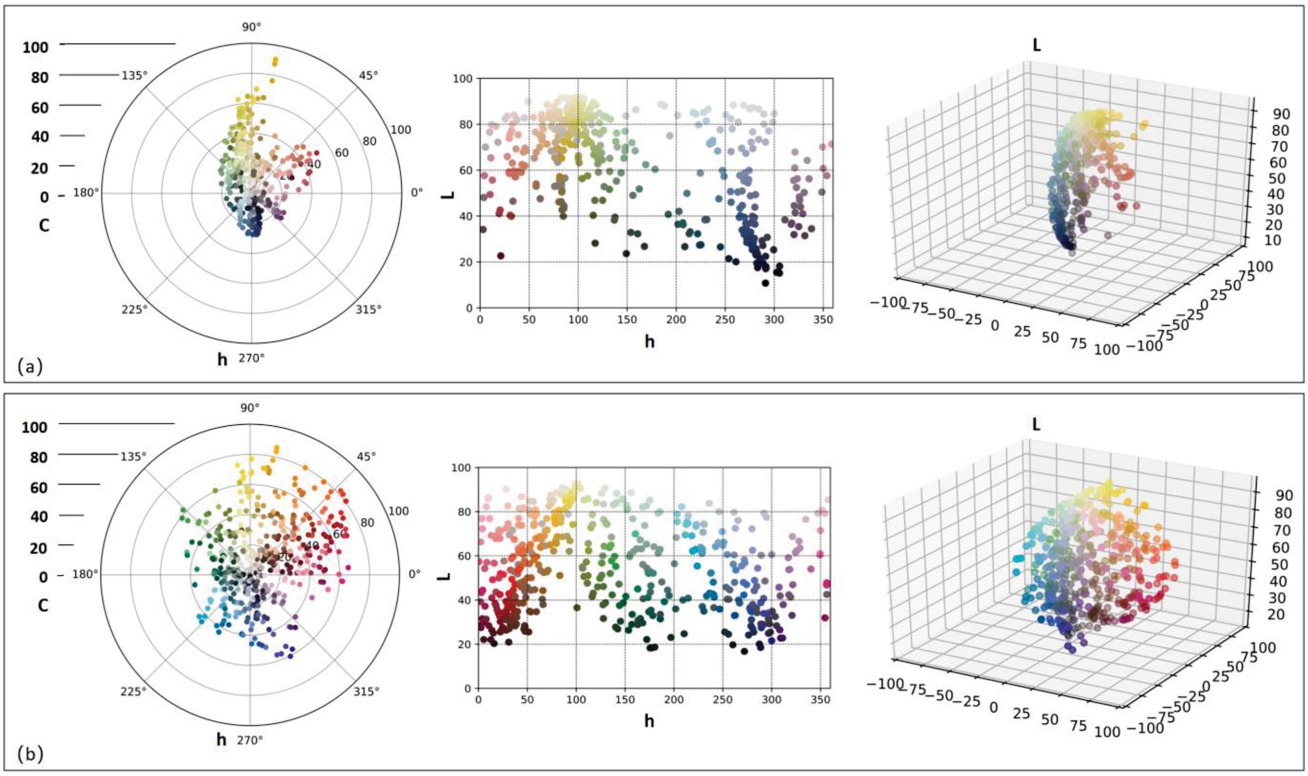


Fig. 11: (a) The CIELCh colour space of natural dyed samples. (b) The CIELCh colour space of the Nanjing Brocade Silk Colour Swatches made with synthetic dyes.

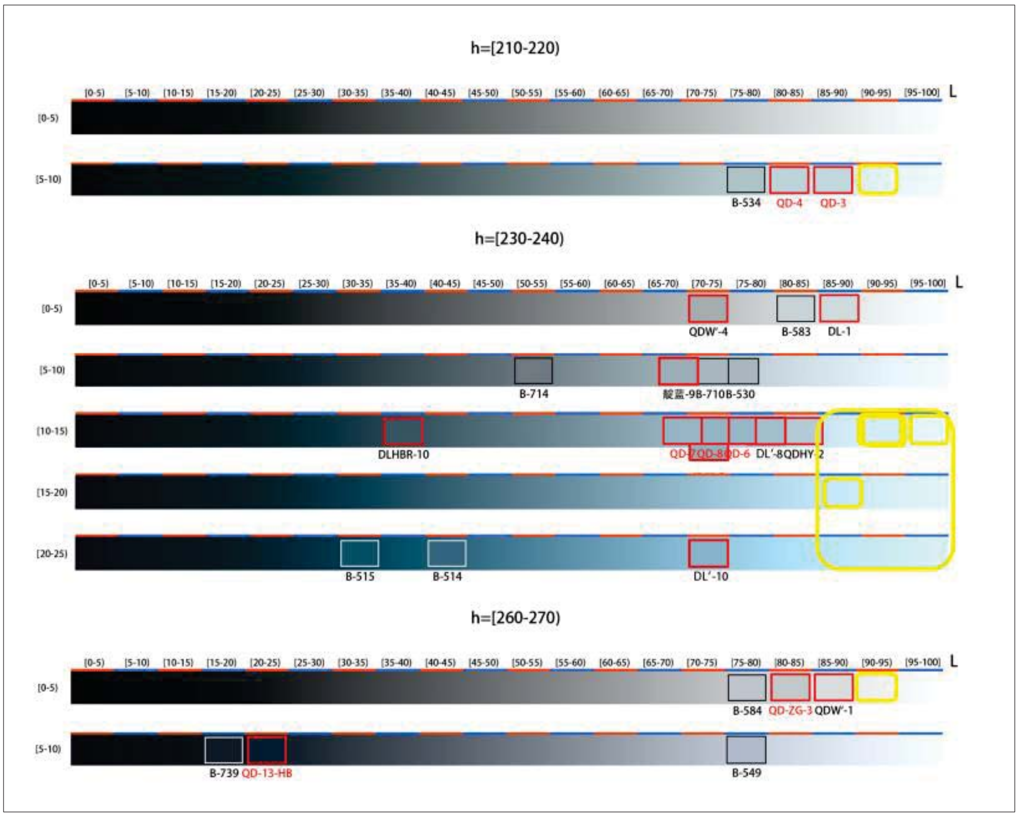


Fig. 12: The focal point of *yuebai* 月白 (bluish white) by experts (in yellow squares, other squares are reference samples).

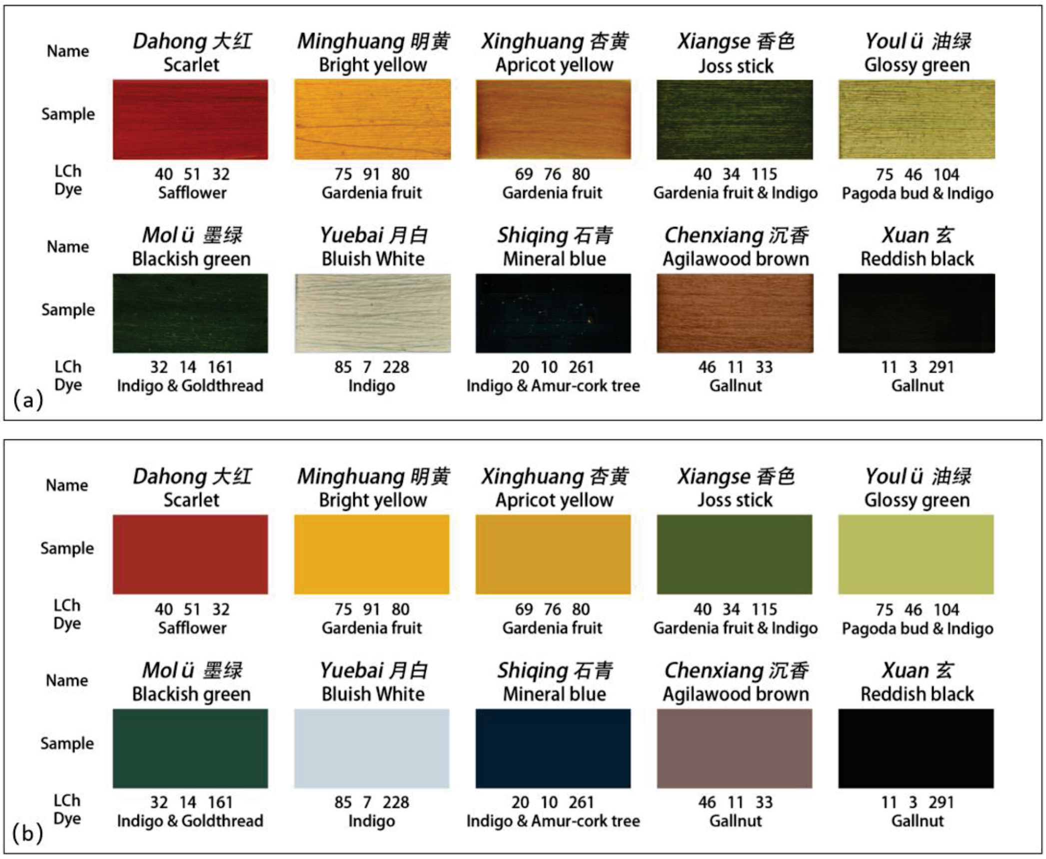


Fig. 13: The specification of 10 typical colours of Nanjing brocade: (a) With natural dyeing silk samples. (b) With digital samples.

5. *Conclusions*

This paper introduces a comprehensive research on the colour knowledge of Nanjing Brocade that leverages information from literature, artifacts, and expert experience. Based on the digital methodology of text mining, HPLC, dyeing experiment, and perceptual evaluation, the research explores a way of knowledge production that produces systematic, accurate, and standard scientific knowledge. The research results demonstrate the colour range of Nanjing brocade from both conceptual and visual perspectives.

The 73 colour terms collected by text mining show the large colour range covered by the ancient Nanjing brocade, where red and cyan are the dominant hues and *dahong* 大红 (scarlet) is the most typical ground colour of Nanjing brocade. Based on the dyes detected by high performance liquid chromatography (HPLC), and the dyeing methods found in the literature and memorized by experts, dyeing experiments were conducted to explore the colour range of traditional natural dyes and recover those typical colours in the literature. The 434 samples produced in natural dyeing experiments were measured for LCh value and established a colour space of natural dyes, proving that the colour saturation of traditional Nanjing brocade should be much lower than that of today's synthetic dyes. The perceptual evaluation converted the experts' blurry perception of colour into LCh values, and through further comparison and calculation of all experts' results, the ideal colour for each term was derived. The dyed sample with the LCh value closest to the ideal colour was then selected to create a colour specification.

Finally, Nanjing brocade specification was created, consisting of colour terms, colour samples (physical or digital), and LCh values. It will provide specific guidance for the heritage conservation and handicraft production of Nanjing brocade, as colour identification and communication will be faster and more accurate. Besides, it is a dynamic, inclusive colour specification that will expand and update as research progresses. The methodology presented in this work, along with our literature database and natural dyes database, also provides a reference for other researchers of textile colour.

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