Article

Material Technology and Science in Manuscripts of Persian Mystical Literature*

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Abstract

Mysticism has always been part and parcel of Persian art and literature. So far, however, the scientific aspects of it have been overlooked by art historians and scholars. The aim of this study is to investigate how researchers can uncover the reasons for the choice of substances used to produce such works from the huge amount of information found in historical sources and to present some case studies to show how science should look at this kind of literature. The research presented here focuses on introducing a theoretical and methodological approach and is illustrated by three examples that reveal the reasons behind the use of certain ingredients in the Persian art of book-making, namely saffron, henna and cucumber-seed mucilage to make verdigris pigment and paper dye and influence the sizing process. Examples of poetic treatises from the thirteenth to the nineteenth century are presented that were written by master calligraphers. The scientific laboratory investigation that was carried out on the works will be reported as evidence revealing the premodern scientific knowledge behind their mystic recipes.

Introduction

Traditional Persian arts and crafts are not only considered to be simple works of handicraft but are committed to an aesthetic standard that encompasses pure manual perfection. When the artist strives for a state of perfection his or her striving has a religious meaning as well. Hence perfection is a mystical quality that in its absolute sense refers to the divine sphere.[1]

The following poem by Solṭān ʿAli Mašhadi (841–926 Hijra/1437/1438–1519/1520 CE) found in a chapter about calligraphers included in his treatise *Ṣerāt al-Soṭur* is a fine example that links reaching a state of perfection in calligraphy to self-purification:

در باب خوشنویسان

ای که خواهی که خوشنویس شوی — خلق را مونس وانیس شوی
خطهٔ خط مقام خود سازی — عالمی پر زنام خود سازی
ترک آرام وخواب باید کرد — وین زعهد شباب باید کرد
سر به کاغذ چو خامه فرسودن — زین طلب روز وشب نیاسودن
زآرزوهای خویش بگذشتن — وز ره حرص وآز برگشتن
نیز با نفس بد جدل کردن — نفس بد کیش را زدن گردن
تا بدانی جهاد اصغر چیست — باز گشتن به سوی اکبر چیست
آنچه با خود روا نمی داری — هیچ کس را بدان نیازاری
دل میازار، گفتمت زنهار — کز دلازار حق بود بیزار
همه وقت اجتناب واجب دان — از دروغ وزغیبت وبهتان
ورد خود کن قناعت وطاعت — بی طهارت مباش یک ساعت
حیله ومکر را شعار نکن — صفت ناخوش اختیار مکن
هر که از مکر وحیله و تلبیس — پاک گردید، گشت پاک نویس
داند آنکس که آشنای دلست — که صفای خط از صفای دلست
خط نوشتن شعار پاکانست — هرزه گشتن شعار نادانست

About Calligraphers

If you wish to become a calligrapher and to love and be loved by people,

If you want to be a resident of the land of script and make your name known all over the world,

You must renounce sleep and rest, you should start doing this when you are young.

You should bend your head down at all times like the nib of the reed pen,

You must not let this wish fade at all day or night,

You have to renounce all your desire, and avoid greed and envy,

* I am grateful to Professor Amir Hossein Zekrgoo for his kind assistance in translating some of the Persian poems quoted in this paper into English. I would also like to thank the anonymous reviewers and the editorial team of the Centre for the Study of Manuscript Cultures

[1] See Zekrgoo 2008, 181, Barkeshli 2002, 56.

You have to constantly fight with your ego until you slaughter it so that you learn what the lesser *jehād* (*jehād-e aṣġar*)[2] is and what it means to set out towards God (*akbar*).

Don't do anything to others that you wouldn't do to yourself.

Never hurt the heart, because God dislikes heart-hurters avoid lying, back-biting and making false accusations at all times.

Always be in a state of contentment and thankfulness [to thy Lord] and observe [ritual] purity and cleanliness constantly.

Avoid tricks and fraud and do not let bad attitudes affect you.

Whoever is able to cleanse himself from machinations, deception and pretence will become a fine writer.

Those who are aware of manners of the heart know that fine handwriting emanates from a pure heart,

Fine handwriting comes from those who are pure, sitting idle is what the ignorant do.

To achieve this task, in bygone days, the Iranian artist always took care not only to purify him- or herself through this journey, but also to try and create a piece of art in a perfect manner, symbolising the balance, harmony and organic relations that rule in the universe by using only the best materials and the most advanced techniques in his work. He or she also took care to ensure the artwork created was not faulty in any way, but was capable of lasting a long time and that the ageing process of the artefact could be minimised. For this very reason, the artists had to equip themselves with the scientific knowledge in order to understand the nature of the materials used and to apply techniques that could reduce any damage due to physical, chemical or biological deterioration over time.

Objectives of the research

This study was conducted on a number of examples of historical poetic treatises written by Iranian master calligraphers in order to reveal the empirical knowledge underlying their work. In these selected exemplars of Persian literature, they discussed the art of book-making and miniature-painting, revealing their expertise in the art of calligraphy, ink-making and the preparation of sizing materials to apply on paper to prepare a suitable basis for calligraphy. Besides finding recipes on the art of calligraphy, one can discover a great amount of knowledge on the art of making dyes and pigments used by artists to create Persian miniatures and illuminate manuscripts. In many cases, the recipes contain elements that the masters advised readers to add or avoid. On account of the research I conducted, I found that this advice was based on reasons that can be identified as underlying stipulations to prevent the works of art from getting damaged or deteriorating. One can discover the reason for the stability of Persian manuscripts and miniature paintings by studying Persian literature. The scientific laboratory investigations that were carried out for the study are presented here as supporting evidence for my claims.

Methodology of the research

The methodology used in the present study is based on historical and scientific analyses. In the first phase, a historical analysis based on 24 treatises belonging to the Timurid (eighth–ninth century Hijra/fourteenth–fifteenth century CE), Safawid (tenth–twelfth century Hijra/sixteenth–eighteenth century CE) and Qajar periods (1193–1344 Hijra/1779–1925 CE) was carried out to identify ingredients that were advised by painters and calligraphers during these eras. In this research, all the identified treatises were examined thoroughly, but only a few examples of them can be presented here (see appendix A).

In the second phase, a number of case studies were undertaken by the author based on laboratory work on original historical samples of illuminated Persian manuscripts and miniature-painting; these complement the objectives of this research. In this scientific analysis, the use of certain ingredients recommended or emphasised by the master calligraphers was studied to discover the reasons for them picking the elements described in the recipes. All the recommended elements were found to be science-based and were used as a preventive measure in historical illuminated Persian manuscripts, miniature-paintings, paintboxes, and palettes.

Scientific analyses have tried to identify the elements in the Persian historical treatises that were particularly recommended – the masters made a point of stressing certain elements to add or avoid.[3] With this in mind, saffron was studied as a

[2] Especially in Shiite tradition 'greater *jehād*' refers to the 'spiritual *jehād*' (the mortification of the self in order to draw closer to God) and 'lesser *jehād*' refers to the 'striving for the cause of Islam'.

[3] These scientific analyses were carried out in several phases by the author and co-authors in order to identify the use of certain ingredients recommended or emphasised by the master calligraphers and collected from historical analysis data. The results of these analyses have been reported in detail in various publications (Barkeshli 1999, 2002, 2003, 2008a, 2008b, 2009, 2011, 2014).

corrosion inhibitor, henna as a fungicide and cucumber-seed mucilage as a suitable sizing material. To this end, original samples taken from fifteen Timurid- to Qajar-period miniature Persian paintings, illuminated manuscripts and paintboxes from museums and private collections were gathered for analysis. The samples were analysed in a laboratory to identify pigments using Spot Test, X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and Polarised Light Microscopy (PLM). In many cases, a number of ingredients were prepared based on the historical recipes found in the Persian literature and they were used as controls for FTIR analysis of their spectra, in order to identify sizing materials and saffron in green verdigris pigment as an inhibitor. To identify the property of some of the elements, analytical procedures were carried out using fungus cultures in the case of henna and standard procedures were followed to identify the buffering property of an element in the case of saffron.

Case study I: the mysterious presence of saffron in Persian green

The first case study was intended to unravel the mystery of why saffron dye was used to prevent the corrosive effect of green verdigris (*zangār*)[4]. Before the rise of the chemical industry at the beginning of the twentieth century, verdigris pigment was commonly used as a green paint in Persian miniature paintings and for colouring the borders (*ḥāšiyeh*) of illuminated manuscripts. Basic verdigris is the only green pigment which appears in the preparation of *zangār* in mediaeval Persian texts, i.e. writings from the Timurid to the Qajar periods. Three different techniques are described in the historical literature:

Persian recipes

The first technique for making *zangār* is described in quite a similar manner by at least four authors, viz. by Solṭān Aḥmad Majnun Rafiqi Heravi, Mir ʿAli Heravi, Hossein Aqili Rostamdari and Alkašfi. In his treatise *Savād al-ḵaṭṭ*, Solṭān Aḥmad Majnun Rafiqi Heravi described the technique as follows:

یک رطل نوشادر ونیم رطل خرده مس در کاسه کن، وآب سرکه انگوری در وی چکان، وچوبی که سر آن چون سم شتر بوده باشد در آن کاسه صلایه می کن تا آنگاه که زنگار گردد.

Mix one *raṭl*[5] of sal-ammoniac *(nošādor)* and half a *raṭl* of copper pieces in a bowl. Add some very strong grape vinegar. Pound the pieces with the help of a camel-hoof-shaped wooden stick. Continue the process until all the copper pieces have turned into green verdigris *(zangār)*.

Various writers described a second technique for making *zangār*: Solṭān Aḥmad Majnun Rafiqi Heravi, Seyrafi, Sadeq Bek Afšar, Ali Hosseini, Alkašfi and two anonymous artists in *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* and *Resāleh dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. In his book *Morakkab Sāzi va Jeld Sāzi* Ali Hosseini explained the process as follows:

نوع دیگر چنان است که خرده مس وسرکه انگور کهنه برابر به یکدیگر بهم آمیخته در چاه آویزند تا چهل روز، چون بیرون آرند زنگاری باشد در نهایت خوبی.

The other type is to mix copper pieces and strong old grape vinegar in equal proportions. Keep this in a vessel and hang it in a well for forty days. When you take it out, the copper will have changed to verdigris of extremely good quality.

Ṣādeq Bek Afšār describes another method in greater detail in *Qānun al-Ṣovar*:

بکن چاهی دو گز در جای نمناک — صفایح کن تنک، لیک از مس پاک
بریز از سرکهٔ ناصاف چندان — که گردد سرکه ها در خاک پنهان
در آن جایی بنه یک مه کم وبیش — بپوشان از کم وبیشش میندیش
پس از یک ماه بنگرکان تمامی — شود زنگار خاطرخواه نامی

Dig a well two *gaz*[6] deep in a moist place, [hang] thin blades made of clean copper into it.

Pour down as much unfiltered vinegar as the soil can absorb, cover [the well].

Leave it there for almost a month – don't worry if it is a couple of days more or less [than that].

After a month, you will see that the entire [copper] has turned into an attractive verdigris.

[4] Verdigris is not a unique chemical substance but is a collective name for various copper acetates. Their colour varies from blue to green. Basic verdigris can contain several forms of copper acetates, the following copper acetate shows green colour: Cu(CH3COO)2·[Cu(OH)2]3·2 H2O; Kühn 1993.

[5] A *raṭl* is half a *mann*, which is equivalent to c. 1.5 kg. A *mann* is another traditional measurement, used for dry goods – its weight varies, in Iran it has a weight of c. 3 kg or 40 *sir* (a *sir* is equivalent to 75 grams), see Hinz 1970, 16–23, 27–33.

[6] *Gaz* is an old Iranian measure for measuring cloth, a Persian ell; see Hinz 1970, 62.

Several writers explained a similar alternative procedure to that mentioned above, except that the use of yoghurt made from sheep's milk was recommended instead of vinegar: Mir ʿAli Heravi did this in *Medād al-Ḵoṭuṭ*, ʿAli Hosseini in *Morakkab Sāzi va Jeld Sāzi*, Alkašfi in *Bayān al-Ṣenāʿat* and an anonymous artist in *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*.

واگر به عوض سرکه آب ماست گوسفند کنند شاید، وچون خواهند که آن را حل کنند وبا آن کتابت کنند در کاسه چینی با صمغ وانزروت حل کرده بکار برند. وانزروت نام درختی است در پارس پوست بر پوست مانند پیاز، هرچه از آن درخت به شب درآید سفیدتر شود وهرچه به روز در آفتاب بماند سرخ شود. اما چون مدتی کاغذ را زنگاری که به آب ماست گرفته باشند سوراخ کند تدبیر آن است که اندک زعفران به آن ضم کند تا پایدار بماند.

[…] and if sheep-milk yoghurt is used instead of vinegar, that can also work. If you want to dissolve it so that it can be used for calligraphy, place it in a porcelain container and dissolve it with gum arabic and *anzarut*[7] gum. *Anzarut* is the name of a Persian tree that has a number of layers of skin (bark) similar to an onion. What is taken from this tree at night will get whiter and what is taken in sunlight will get redder […]

The introduction of saffron as an inhibitor

It seems artists soon recognised the instability and destructive nature of some pigments. Cennini (1954), for example, mentioned that verdigris is beautiful for painting eyes, but does not last. Theophilus warned against using 'green salt' for book illumination as 'it is not good for books'.[8] This phenomenon was not unknown to Iranian artists. For example, in *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* cautious use of verdigris was recommended after describing the techniques of making it: '... *zangār* is not stable and will char the paper'.

What is noteworthy, however, is that some of the old Persian recipes describe the addition of saffron to verdigris as one of the measures to counter its destructive effect. Mir ʿAli Heravi mentioned this in *Medād al-Ḵoṭuṭ*, ʿAli Hosseini in *Morakkab Sāzi va Jeld Sāzi* and Alkašfi in *Bayān al-Ṣenāʿat* mentioned the destructive effect of *zangār* made from yoghurt and recommended saffron to be mixed with *zangār* to prevent its charring effect on paper in the last part of their recipes. According to Mir ʿAli Heravi in *Medād al-Ḵoṭuṭ*:

اما چون مدتي كاغذ را از زنگاري كه به آب ماست گرفته باشند سوراخ كنند تدبير آن است كه اندك زعفران به آن ضم كند تا پايدار بماند.

The verdigris, which is made out of yoghurt, chars paper. The answer is to add a small amount of saffron (*zaʿfarān*) so [it] becomes stable.

Besides being used as a preventive measure against the destructive effects of *zangār*, saffron was also recommended for obtaining different shades of green. For example, Ali Seyrafi poetically states in *Golzār-e Ṣafā*:

ور چو خط لب خود اي جانان فستقي ميل كن بشنو از آن
زعفران داخل زنگار نما پس بدان رنگ كتابت فرما

The smiling green pistachio that resembles your beautiful lips whispers tenderly.[9]

Mix saffron with *zangār* and move your pen with it gracefully.

As one can see from mediaeval Persian texts, mixing saffron with verdigris was a common practice among Iranian artists. It was used either as a preventive measure recommended by their masters or for obtaining a popular green pistachio colour, as recommended in old recipes.

Scientific analysis

An examination was carried out in two stages to investigate whether saffron has any chemical properties that prevent the destructive action of verdigris and whether traces of saffron can be found in original samples of mediaeval writing which have prevented the charring effect of verdigris.

The first step was conducted to ascertain the presence of saffron as an inhibitor in verdigris pigment. Original samples were selected from the Iran Bastan Museum as well as from private collections, and their green pigments were analysed in a laboratory.[10]

A second examination was carried out to investigate the possible buffering properties of saffron, since the change of

[7] *Anzarut*: sarcocolla, flesh-glue.

[8] Ed. Hawthorne and Smith 1961: Theophilus, *De diversibus artibus*, book I, chap. 31.

[9] Literal translation: 'If like calligraphy your lip, my beloved, wants pistachio, listen to it.' The poet uses a double understanding of *mayl kardan*, 'eat' and 'want'. The lip of the beloved eats pistachio whereas calligraphy needs it. The double understanding is further stressed in the end of the first verse: *bi-shinaw az ān*, listen to it, and 'it' can be the lip (a lip can eat pistachio and want it) and calligraphy as well.

[10] Barkeshli 1999, 2008b, 2013.

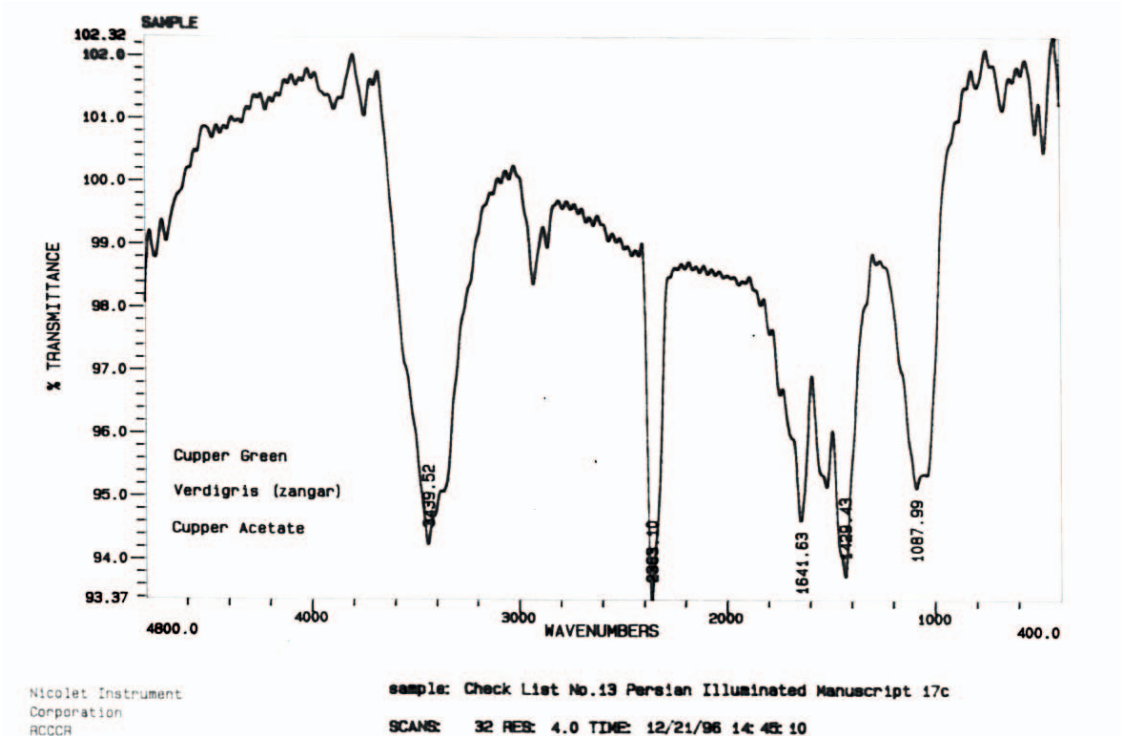


Fig. 1: The spectra of pure green verdigris (copper acetate) used in an illuminated Persian manuscript, Atiqi Collection, Tehran, Iran (appendix B, table 2, checklist no. 13).

pH from a low level to a high one plays an important role in the destructive mechanisms of copper-based pigments.[11]

Materials and techniques

In the first phase, the presence of saffron in verdigris pigment was investigated, as advised by masters in order to prevent the destructive effect of verdigris, and the green pigments of twelve miniature Persian and Indian paintings, illuminated manuscripts and paintboxes from the Safawid to Qajar periods were analysed along with the paint palettes of two traditional Persian artists of the time. To identify the chemical composition of green pigments used in the sample collection, different techniques were employed, including microscopic analysis, micro-chemical analysis, FTIR and XRD methods.

The optical appearance of the pigment mounted in Canada balsam (N = 1.53) on a microscopic slide was observed in reflected and then in transmitted plain polarised light. The identification of some pigments was confirmed by determining the presence of copper in the case of copper green pigment and iron in the case of green *terre-verte* by a positive test for copper or iron with potassium ferrocyanide using chemical microscopy. The different copper-based pigments such as verdigris, malachite, atachamite and langite were identified using FTIR by confirming the presence of acetate, carbonate, chloride and sulphate. Sample preparation was done by mixing potassium bromide (KBr) with the unprepared sample (100:1). The materials present in the samples were identified by comparing the infrared spectrum with the reference spectra via recognition of specific bands. X-ray powder diffraction supplied evidence of specific minerals when a large enough sample was available. Green pigments collected from original samples were present in extremely small amounts except in one case, which belonged to a paint palette collected from traditional artists.[12]

A complete record of the pigments found in samples from private collections and selected paintings from Iran Bastan Museum is shown in table 2 (appendix B) along with an indication of the corresponding identification methods. Of the twenty green pigments analysed, nine were identified as being green, copper-based pigments and the rest were found to be mixtures of yellow and blue, whereas no *terre-verte* was identified. Of the nine green, copper-based pigments examined, five were identified as green copper acetate, whereas two were found to be pure verdigris and three were identified as verdigris mixed with saffron.

Figure 1 shows the spectra of pure verdigris used in illuminated Persian manuscripts (appendix B, table 2,

[11] Barkeshli and Ataie 2002.

[12] Paintboxes collected from A. Tavoosi belonging to the sixteenth century and from M. Bekhradi belonging to the nineteenth century from Isfahan, Iran.

Fig. 2a: A seventeenth-century illuminated Persian manuscript with green verdigris in its pure form, Atiqi Collection, Tehran, Iran (appendix B, table 2, checklist no. 13).

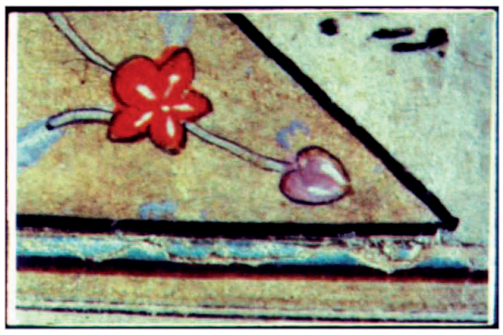
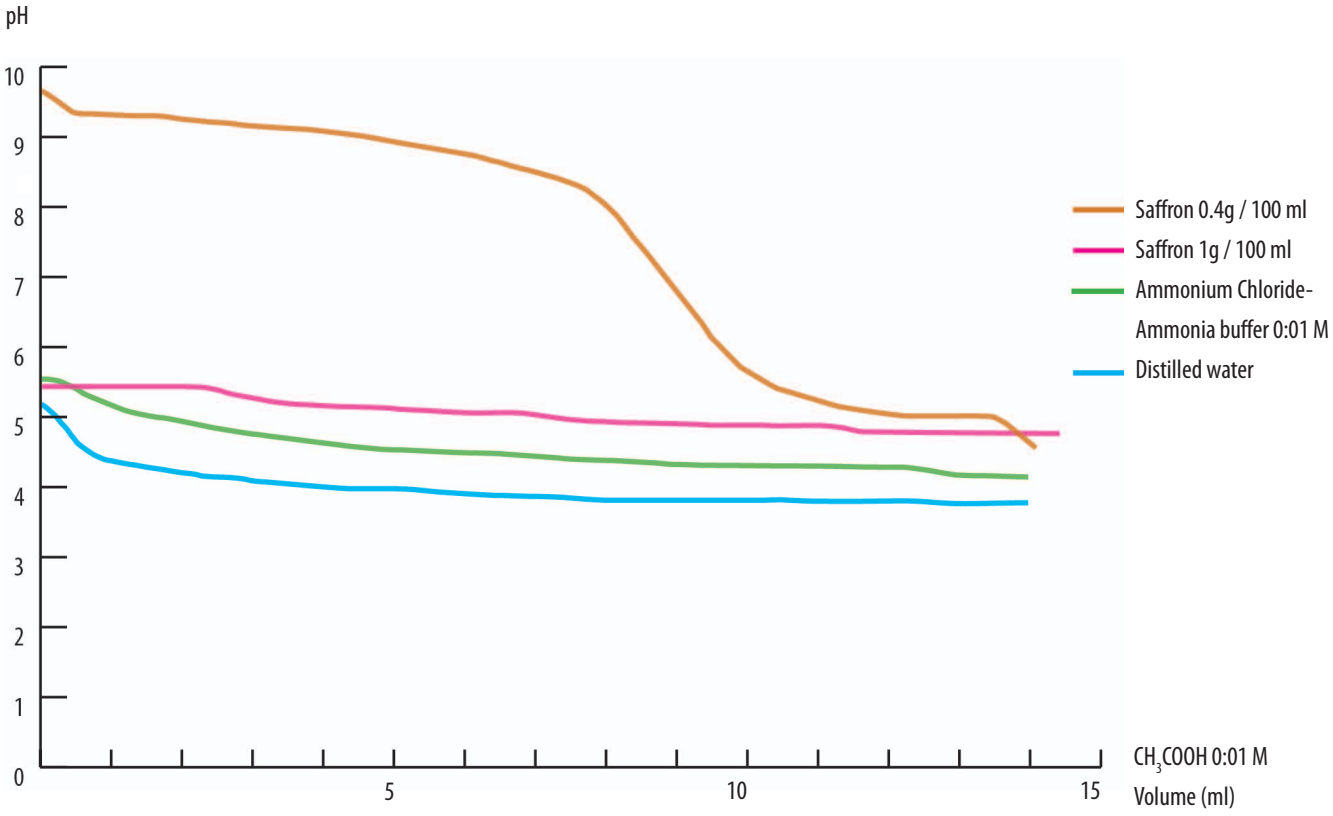


Fig. 2b: Microscopic examination of the destructive effects of green verdigris (fig. 1), detail, Atiqi Collection, Tehran, Iran (appendix B, table 2, checklist no. 13).

checklist no. 13, fig. 2a and fig. 2b); bands 1400, 1500 and 1600 indicate the presence of acetate. Confirmation was provided by determining the presence of copper by microchemical analysis and by its microscopical appearance. Fig. 3 shows the presence of saffron mixed with verdigris found in a sixteenth century miniature Persian painting (appendix B, table 2, checklist no. 18; fig. 4); bands 1400, 1500 and 1600 show the presence of acetate. In this sample, it can also be clearly seen that the spectra exactly matched the fingerprints of saffron spectra which were used as a reference. The noticeable distinction when comparing the bands on 3439 is related to the possible effect of the local formation of alkali hydroxide on the trend of the destruction of the verdigris in pure form and verdigris mixed with saffron.

In the second stage for comparing the pH resistance of saffron with buffers and water, the pH profiles were



Graph 1 : pH variation of different solutions due to incremental addition of acetic acid 0:01 M.

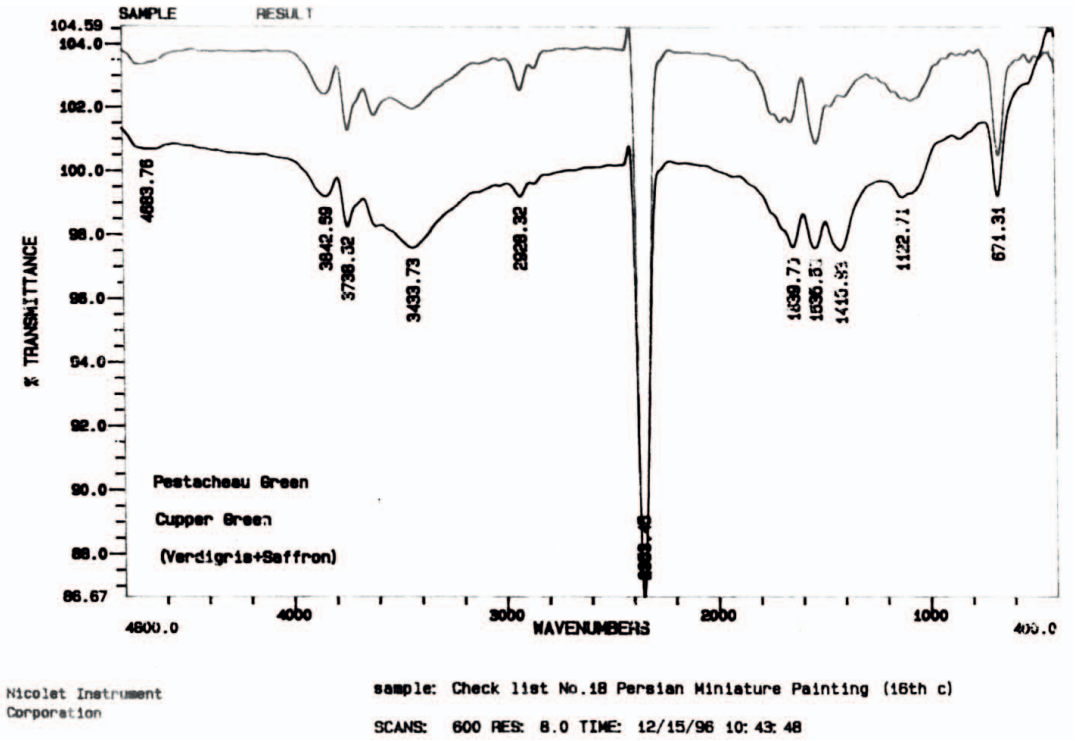


Fig. 3: The spectra of green verdigris mixed with saffron in a Persian miniature painting (appendix B, table 2, checklist no. 18). The red line is the reference and the blue line is the green verdigris sample from the manuscript.

determined over a range of pH 0–14. Five solutions were prepared: 20 ml of distilled water, two different saffron solutions of different concentrations; 20 ml of a 0.4% saffron solution (0.4 grams of saffron in 100 ml of distilled water) and 20 ml of a 1% saffron solution (1 gram of saffron in 100 ml of distilled water), 20 ml sodium acetate-acetic acid (acidic) buffer 0.01 M and 20 ml ammonium chloride-ammonium (basic) buffer 0.01 M. Distilled water and saffron solutions were divided into two portions. 0.01 M of acid (CH_3COOH) was gradually added to one portion and a 0.01 M base (NaOH) to the other. As for the buffers, acetic acid was added to the basic buffer and sodium hydroxide to the acidic buffer. Then the pH of all the solutions was measured and compared. The pH variations of different solutions due to the incremental addition of acetic acid are summarised in graph 1: One can see that the pH of 1% solution of saffron is maintained at 5.5 when gradually adding up to 2 ml of acetic acid to the solution, while the acetic acid solution alone indicated a gradual decrease of pH; 2 ml resulted in pH 4.3. Experimentation with a 0.4% saffron solution also showed a similar though less significant trend. In this case, the pH starting from 5.6 was lowered to 5 on the addition of 2 m of acetic acid, which was almost equivalent to the solution without acetic acid. It is evident that the pH variations in the saffron solutions are lower than the variations in water and that the buffering property of saffron is strengthened by increasing the concentration. The graph shows the behaviour of saffron solutions in comparison with a basic buffer, i.e. ammonium chloride-ammonium acidic solution.

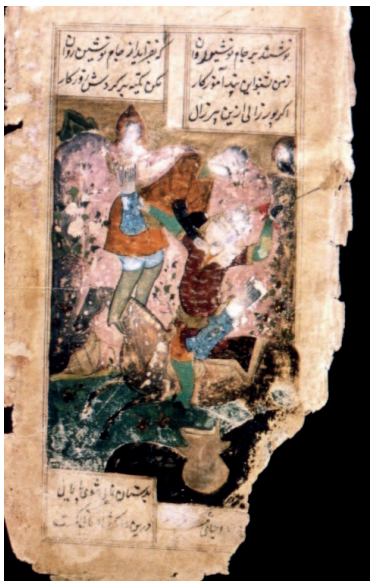


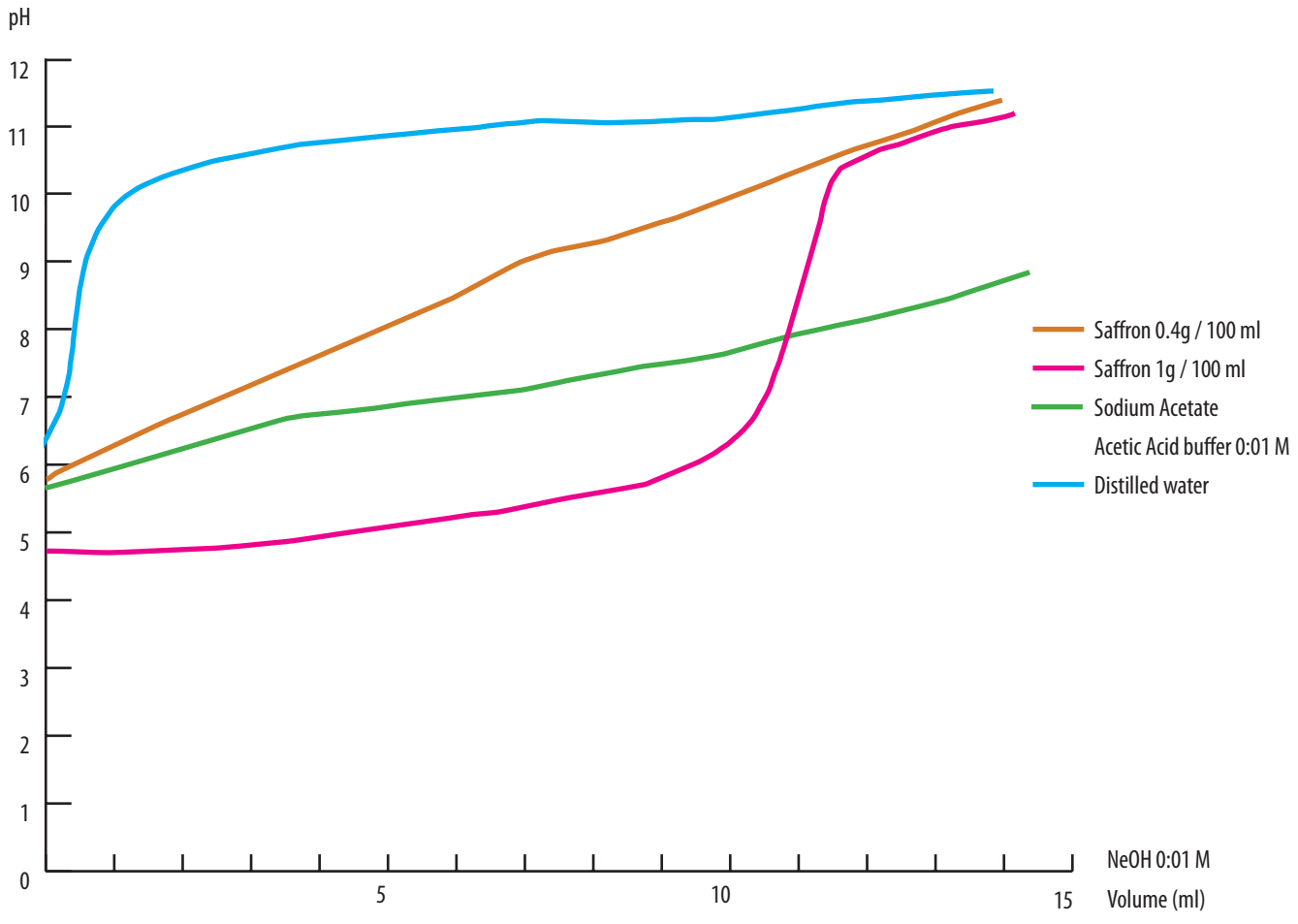
Fig. 4: A sixteenth-century Persian miniature painting with its green verdigris mixed with saffron, Atiqi Collection, Tehran, Iran (appendix B, table 2, checklist no. 18).

Graph 2 shows the buffering behaviour of the saffron solutions in a basic medium. The corresponding behaviour of distilled water and sodium acetate-acetic acid, which is an acidic buffer, is also shown as a reference. It is clear that the saffron solution is a stronger buffer than the acidic buffer under study and its buffering effect increases with an increase in the concentration. As the concentration of NaOH was gradually increased from 0.2 ml to 2 ml, the pH only increased to 6.3, while the pH of the NaOH solution with a 2 ml concentration was 10.4. Even the 0.4% solution of saffron had a sufficiently strong buffering characteristic. In this case, the addition of 2 ml of NaOH resulted in a pH of 6.8, which is higher than that obtained by a 1% solution of saffron and 2 ml of NaOH.

Results and summary

Right from the very first phase of the investigation, the study lent support to the idea of saffron having a preventive quality: the research showed verdigris which was mixed with saffron did not char the paper, whereas the verdigris which was used in pure form charred the paper extensively. Figures 2a and 2b and figure 4 show the condition of green pigment in miniature Persian paintings and illuminated Persian manuscripts when verdigris was used in its pure form and mixed with saffron. During the investigation, saffron mixed with green verdigris was found in a sixteenth century paintbox from the Safawid period (see fig. 5). This proves the use of saffron mixed with verdigris in Persian paint palettes to obtain pistachio green, as recommended by the masters.

By comparing graphs 1 and 2 from the second stage, it can be observed that the pH variations of the 1% saffron solution, ranging from 5.5 to 8.5, are quite minimal compared with the variation of pH in the acidic buffer, which ranges from 5 to 11, and that of the basic buffer ranging from 4.8 to 9.2 in an identical condition. The results of a previous[13] investigation show that saffron can resist a wide range of pH variations and that the existence of unsaturated dicarboxylic acid and its esters (crocin, carotenoid esters and crocetin) and nitrogen compounds in the chemical composition of saffron could be responsible for its high resistance. It therefore proves that the saffron solution,



Graph 2 : pH variation of different solutions due to incremental addition of sodium hydroxide 0:01 M.

[13] Barkeshli and Ataie 2002

Fig. 5: A sixteenth-century paintbox from Bekhradi Collection, Isfahan, Iran.

when added to the verdigris pigments, acts as a powerful buffering agent which prevents the charring of paper by maintaining a constant pH. This prevents the destructive mechanism of verdigris from unfolding by increasing the pH and the local formation of alkaline hydroxide, which is active in the final stage of the degradation process due to a Fehling reaction.

Case study II: the mystery of the henna dye recommended in Persian literature

The art of calligraphy and illumination which emerged during the Islamic period has great relevance for the history of the arts. Paper was first produced in Khorasan in the eastern part of the Islamic world by Chinese captives in the second century Hijra (around 750).[14] It spread to other Islamic territories and soon became a significant commodity in the Islamic world. Persia actually developed into one of the most important centres for papermaking and was a bridge that connected East and West in this art, which became so popular in Iran that there were some cities where the entire population engaged in it. During the period of Yāqut, for instance (sixth and seventh centuries Hijra), there was a city called 'Kāḡaz konān' (the 'city of paper producers'), located between Marāḡeh and Zanjān, which was famous for producing quality paper; almost everyone in that city engaged in paper production.[15] The growing demand for paper on the part of scribes and men of letters prompted papermakers in the Islamic Middle Ages and subsequently those in the Timurid and the Safawid eras to focus upon the aesthetic aspects of paper production and to produce a wide-ranging variety of paper.[16]

Persian recipes

A number of treatises relating to methods used in paper-dyeing during the periods under study have survived and are accessible to us today. Historical evidence from the Timurid and Safawid eras, including the Qajar period, has revealed that the paper used for producing books in these years was generally dyed. Experts on the field of papermaking recommended dyeing the paper in two respects: one was the aesthetic aspect and the other the effect of the paper's colour on the reader. According to them, white paper had a harmful visual effect on the reader, while dyed paper reduced the strain on the reader's eyes. In his famous treatise entitled *Golzār-e Ṣafā*, Seyrafi, a renowned expert from the Safawid period, says the following:

کاغذ ار رنگ کنی خوبتر است کز سفیدی به بصر صد ضرر است
ضرر چشم پسندیده مدان خامه بر کاغذ بی رنگ مران
رنگ کن کاغذ زیبا ز نخست تا بود خط تو وچشم درست
از تو چون زین هنری می جویم بهر تو مختصری می گویم

Paper once dyed is better, for white surely harms the eyesight one hundred times.

It is not favourable to hurt the eyes, it is wise to refrain from penning on uncoloured paper.

First, dye the paper to beauty, so that your hand and eyes remain fine.

Since I expect you to scale great heights in this art, I have helped you with this little part.

In some old treatises, references have also been made to the harmful effects of certain kinds of dyed paper on the eyesight with regard to the ink used for calligraphy and the dyes employed for colouring paper – Mohammad Boḵāri and Solṭān ʿAli Mašhadi discussed this matter in almost the same way in their respective works, *Favāyed al-ḵoṭuṭ* and *Ṣerāt al-Ṣoṭur*, for example. The latter mentions the following:

چشم را رنگ سرخ وزرد وسفید خیره سازد چو دیدن خورشید
بهر خط نیمرنگ می باید تا از او دیده ها بیاساید
رنگهایی که تیره رو باشد خط رنگین بر او نکو باشد
کاغذ سرخ را سفید نویس تا نماید خط تو خوب ونفیس
کاغذی کان کبود رنگ بود از سفیداب دلپسند بود

[14] Māyel Heravi 1993, 16.

[15] Māyel Heravi 1993, 17.

[16] Māyel Heravi 1993, 17.

Eyes get dazzled when they see red, yellow and white paper just as they do while looking at the sun.

For the purpose of calligraphy, temperate colours should be used as they relax the eyes.

The coloured lines are good on dark paper.

Write on red paper with white colour so that your handwriting (calligraphy) stays nice and elegant.

On blue paper, writing with white is pleasant.

However, in his treatise, *Favāyed al-ḵoṭuṭ*, Mohammad Boḵāri points out the following about other colours:

اما بعضی رنگهای دیگر هست نوشتن خطا است وبه خط سیاهی در او نوشتن سبب خیرگی چشم می شود ورنگ سرخ وسبز وسوسنی وماوی سیر وسفید تیره می سازد.

There are some more colours with which it would be a mistake to write, and writing on them with black ink will dazzle (blind) the eye. Red, green, dark blue (violet), full blue, and white make (the eye) dark.

چشم را رنگ سرخ وسبز وسفید خیره سازد چو دیدن خورشید
ماوی سیر وسوسنی با هم چشم را تیره سازد وپر نم

Red, green and white dazzle the eye (make it blind) like looking into the sun.

Full blue, dark blue and violet also make the eye dark and moist.

The most recommended dye for colouring paper: henna

One of the methods that have always attracted experts' attention is paper-dyeing with natural extracts of henna. This has been used in various ways throughout history.

Among the different coloured papers, henna is specifically recommended for making natural colour (*ḵodrang*) in historical documents either in its pure state or when mixed with saffron. For example, Bābā Shāh-e Isfahāni poetically says in his treatise *Ādāb al-Mašq* that:

هیچ رنگی به از حنایی نیست حاجت آنکه آزمایی نیست

There is no colour comparing to henna, there is no need for experiment.

In addition to this, Majnun Rafiq Heravi suggests in his *Ādāb al-Mašq* that:

ای طرفه پسر که عشق داری وز عشق هوای مشق داری
رو کاغذ طرفه ای بدست آر بریان ولطیف و صاف وهموار
رنگی که صفای خط در آن است از آب حنا وزعفرانست

Oh wonderful son who hath love in you, and with that love you desire to practise writing,

Go and gain the wonderful paper, paper that is crisp, delicate, pure and smooth.

The beautiful colour that adorns the calligraphy comes from henna dye and saffron.

However, several writers mention the need to add a few drops of black ink to the mixture of saffron and henna: Bābā Shah Isfahani in his treatise *Ādāb al-Mašq*, Majnun Rafiq Heravi in his treatise *Savād al-ḵaṭṭ* and Solṭān ʿAli Mašhadi in *Ṣerāt al-Ṣoṭur*. In *Ṣerāt al-Ṣoṭur*, for example, it says:

هیچ رنگی به از حنایی نیست با تو گویم که رنگ آن از چیست
زعفران وحنا وقطره ای چند از مداد است بیش ازین مپسند
خط بر او خوب وهم طلا خوب است زینت خط خوب مرغوب است

No colour is better than the colour of henna, I will tell you what the colour is made of.

Saffron and henna and a few drops of ink, do not allow any more [than that].

Both calligraphy and gold will go with it nicely, it is the ornament of fine, high-quality writing.

As mentioned earlier, henna dye was recommended by different masters based on their own experience. Perhaps that is why this colour was used so much in Persian paper manuscripts. Most historical treatises put more emphasis on the ratio of henna and water for obtaining the dye. This was also explained in various historical sources that were studied, including *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān, Golzār-e Ṣafā*, *Resāleh dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān* and *Resāleh dar Bayān-e Rang Kardan-e Kāḡaḏ*. In all these sources, the methods used for making henna are almost the same. In *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*,

for instance, the anonymous author describes the henna dye called *k̲odrang*[17] as follows:

> رنگ خودرنگ - قدری برگ حنای پاک، بی غبار وخاک را، که ناکوفته بود در آب گرم کند ویک روز یا یک شب بگذارد، بعد از آن بپالاید وصاف سازد وکاغذ بدان رنگ کند. وهر یک سیر حنا را ده سیر آب باید، واگر آب زیاده کند، رنگ مله شود. واکثر این رنگ اختیار کرده اند.
>
> Put a few clean, loose, unbeaten henna leaves into hot water for a while. Keep them for a whole day or a whole night and then filter them to get an extract of henna leaves. For every *sir*[18] of henna add 10 *sirs* of water. If more water is added, the colour will become dull and dusty (*mālle*). Most [experts] have chosen this colour.

On the other hand, in other treatises, the right ratio of water to henna is mentioned instead of any exact measurements. Ali Seyrafi says the following in *Golzār-e Ṣafā*, for example:

> کاغذ ای دوست چو خود رنگ کنی — خود به این رنگ هماهنگ کنی
> بستان برگ حنا را بسیار — پاک کن وانگهی از گرد وغبار
> آب کن گرم در آن رنگ نخست — پس حنا ریز در آن آب درست
> وزن آن آب حنا را دریاب — یکی از برگ حنا وده آب
> یک شبانروز به جایش بنه — صاف کن آب به آن رنگ بنه
> کاغذ از رنگ تو گیرد وایه — خشک سازش پس از آن در سایه
>
> Oh friend, if you want to dye paper in *k̲odrang*, harmonise yourself with this colour.
>
> First of all, heat some water and then add the henna leaves to it in the right proportion.
>
> Paper receives its joy from your dye. Afterwards, let it dry in the shade.
>
> Acquire large quantities of henna leaves and clean them by freeing them of dust.
>
> Be aware and conscious about the weight of the henna dye: it should be one portion of henna leaves and ten portions of water.
>
> Leave [the mixture] a day and a night, then filter the liquid and use it as a dye.

It should be mentioned here that a lower concentration of one *sir* of henna and half a *mann* of water was only recommended in one treatise, *Resāleh-ye Ṣaḥāfi*, whereas in the treatise *Resāleh dar Bayān-e Rang Kardan-e Kāg̲aḏ*, the ratio was not indicated at all; instead, the writer advised the reader to obtain the desired colour by trial and error.

Since all our sources strongly advised dyeing paper with henna, I studied the anti-fungal properties of henna and conducted a scientific examination in the second phase of the study.

Scientific analysis

In this analysis, the effects of henna extract were specifically examined to explore the reason for it being used for paper-colouring, as repeatedly advised by masters in Persian historical treatises, who recommended employing a ratio of one part henna to ten of water. The analysis was carried out in two stages.

Materials and techniques

In the first stage, the chemical composition of henna was reviewed and its colouring matter was investigated. It was found that the leaves of henna contain 7% tannin, 6% fat, 1.2% essences and 2–3% lawsone (2-hydroxy-1,4-naphthaquinone) responsible for the anti-microbial properties of henna[19] It was also found that henna has fungicidal properties, as previously reported by Soker.[20]

In the first stage, an examination was also carried out to investigate the relation of *aspergillus flavus* fungus growth on paper with the concentration of henna dye without taking into account the ratio that was advised by the masters. Three different samples of undyed and unsized historical handmade paper from the sixteenth to the nineteenth centuries – seemingly of different grammage and different fibres – were selected from the conservation laboratory of the Iranian Parliament's library in Tehran where papers were divided into three groups. In each of these, the papers were divided into four pieces of 2.5 x 2 cm in size for the sample experiments. To dye the samples of paper without any consideration of the ratio advised in the historical recipes, 1, 2 and 3 grams of powdered henna leaves (prepared from Yazd in central Iran) were soaked in 60 ml of distilled water (1.8–3.3 and 5% respectively) in three separate containers and kept under artificial light for four hours to see how the henna dye

[17] *K̲odrang* preserved the natural colour of the material, leaving it unchanged; at the same time it was a yellowish colour.

[18] *Sir* is a traditional Iranian measure equivalent to 75 grams.

[19] Malekzadeh 1968; Malekzadeh and Shabestari 1989.

[20] Soker 2000.

Fig. 6: Fungal growth of paper group samples dyed with henna extract solutions.

affected the paper in general. Each solution was filtered with a filter paper. The four paper samples collected from each group were soaked in solutions for 5, 15, 30 and 60 minutes. Each paper group was dyed simultaneously in the three different concentrations for the four different lengths of time to observe the effects of time and the concentration of dyes used in the colouring process on the growth of *aspergillus flavus* fungus on paper samples. A phosphate buffer was prepared (pH = 7.0) and the process was carried out in the Microbiological Laboratory of the Gamma Irradiation Centre, Tehran. In all the experiments, 10 ml of *aspergillus flavus* was prepared containing approximately 1×10^{-7} spores per ml. The concentration of the suspension was estimated by the pour plate method. Potato dextrose agar was applied to each sample to accelerate the growth of fungus process on paper. The samples were incubated at 25°C for four weeks and the diameter of the zone of inhibition was measured to the nearest millimetre by means of a celluloid millimetre ruler. A magnifying glass was used when needed (see fig. 6).

In the second stage, further analytical work was carried out in a different laboratory at the Centre for Environmental Research in the Department of Environmental Health Engineering, University of Tehran. This time, the research aimed to investigate the effects of henna dye on the *aspergillus flavus* fungus in different ratios, and more specifically on the relation between the henna concentration advised by masters – with a ratio of one part henna to ten parts water – and the growth of fungus directly on henna dye.[21] Pure henna leaves from Yazd were prepared. This time, Sabouraud dextrose (from Merck) was prepared instead of potato dextrose agar due to its availability and lab procedure. All the samples were diluted in double-distilled water and then sterilised in an autoclave for 15 minutes at 121°C. The laboratory work was conducted directly on the henna solution in concentrations of 2.5%, 5%, 7.5%, 10%, 12.5%, 15% and 17.5%. These solutions were incubated for two hours at 75°C. To get the complete extract, the solutions were kept at room temperature for 24 hours and then filtered. The extracted solution was used to culture the fungus. One gram of Sabouraud dextrose agar brass was mixed into 15 ml of henna solution extracts where the samples were all sterilised. In this phase, the research was only done on the henna solution to see the result. In the next phase, which is still to come, the result on henna paper will be examined as well. *Aspergillus flavus* fungi were inoculated into all the henna samples: 2.5% (plate a), 5% (plate b), 7.5% (plate c), 10% (plate d), 12.5% (plate e), 15% (plate f) and 17.5% (plate g), including untreated samples (plates 1 to 4), and the samples were studied every twelve hours (see fig. 7).

Results and summary

In the first stage, the results showed that the samples which were dyed with henna had a greater tendency to inhibit the growth of *aspergillus flavus* fungus than the undyed paper samples. The samples dyed with henna showed that the growth of the fungus depended on the concentration of henna and the length of application: the growth of the fungus decreased if the concentration of henna was higher and the application took longer. As for the type of paper used, this did not lead to any significant difference in behaviour. It should be noted that even when the highest concentration of henna was employed and the dye was applied for a long time, the growth of the fungus decreased, but it was still noticeable – perhaps due to the lower concentration of henna dye used in the experiments (1.8–3.3 and 5%) rather than the advised ratio of 10% in the masters' recipes.

In the second phase, our experiment showed that henna dye can only act as a fungicide that combats the *aspergillus flavus* fungus if it is used in a concentration of more than 10%. Fungal growth in a henna extract with a higher concentration than 10% was reduced by 60% and was further reduced by 80% in a 17.5% henna concentration (see fig. 8).

This means that the recipes suggested by Iranian masters in the fifteenth and sixteenth centuries may have been based on their knowledge of empirical chemistry and that henna dye was used to prevent fungus growth on paper, more specifically to counter *aspergillus flavus*. To be able to

[21] Barkeshli, Ataie, and Alimohammadi 2008a.

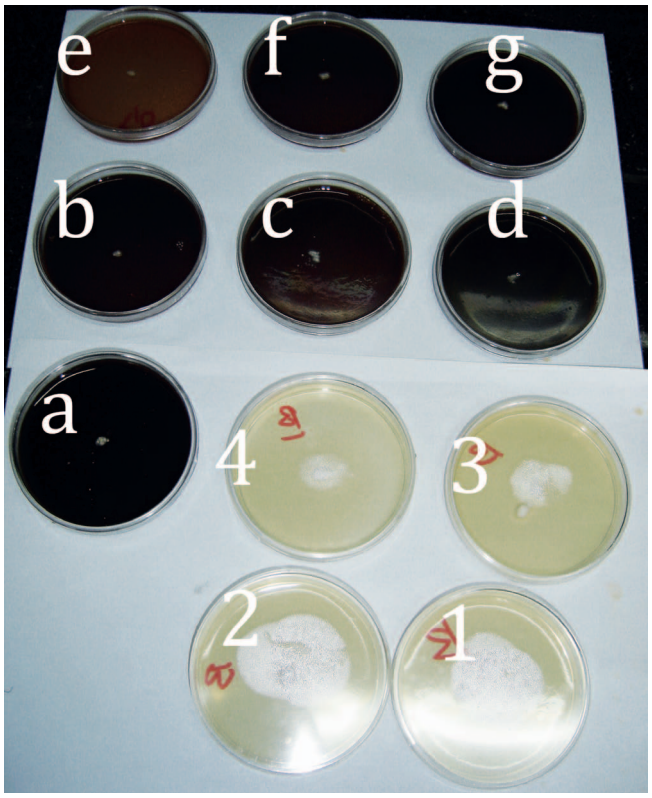


Fig. 7: Culture of *aspergillus flavus* on untreated samples (Petri dishes 1 to 4) and henna treated samples 2.5% to 17.5% (Petri dishes a to g).

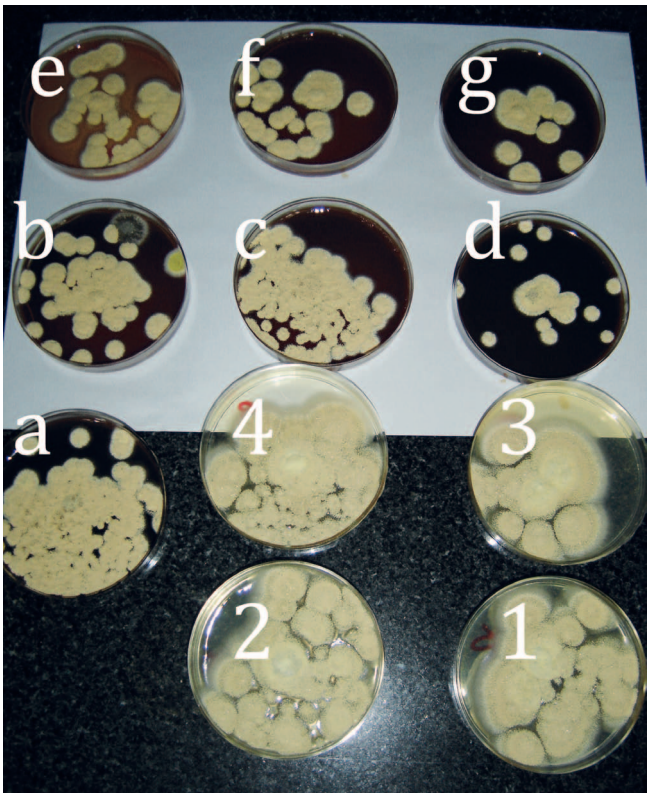


Fig. 8: Culture of *aspergillus flavus* on untreated samples (Petri dishes 1 to 4) and henna treated samples, 2.5% to 17.5% (Petri dishes a to g) in eight days.

confirm this statement, though, further research needs to be carried out on other species of fungus and different types of paper, of course.

Case study III: techniques and materials used in sizing paper

'Sizing' (*āizi*) paper is a process of preparing the surface of paper to make it suitable for writing, illuminating or painting on. After a sheet of paper has been formed and dried, the cellulose fibre it contains can continue to absorb water unless it has been 'sized', i.e. impregnated with a substance like starch, glue or wax to prevent such penetration. There are different techniques available for sizing paper, depending on requirements, such as soaking or applying one or a number of layers of sizing material on the paper surface with the help of a soft brush.

Specimens from China (third century CE) indicate that contemporary papermakers used a range of sizing techniques, from coating the surface of the paper with gypsum to treating it with gum, glue or starch to prevent ink from spreading in an undesirable way.[22] According to Hunter, one of the earliest methods of sizing paper was covering the surface of the sheets with a thin coating of gypsum. The next improvement was to render the body of the paper and the surface of it impermeable to ink by the use of lichen, starch or rice flour.[23]

In Iran, according to Canby, once the paper was dried, it was sized by soaking it in albumen or a starchy solution to fill in and even out the surface for painting.[24] Before the Islamic era, in the Sassanid period (fifth–sixth century CE), the Iranians used sizing materials over the cloth to prepare the surface for writing and painting.[25] After learning the process of papermaking from the Chinese, Iranians started the tradition of sizing paper to prepare a suitable surface on it for writing and painting. The chief contribution of Iranian papermakers working under Arab rule was the perfection of rag paper thanks to improved techniques for beating the

[22] Bloom 2001, 33.

[23] Hunter 1957, 194.

[24] Canby 1993, 14.

[25] Māyel Heravi, 1993, 572.

fibres and by preparing the surface for writing by sizing it with starch.[26]

Certain scientific investigations have also revealed valuable information on materials used in the sizing process. According to Wulff[27] and based on chemical investigation, the Iranian papermakers at Samarqand made an important contribution to papermaking by introducing a new method in sizing paper to make it more suitable for writing on with ink and a reed pen. Wheat starch and later gum tragacanth[28] or asphodel[29] (*seriš*) were used as sizing substances.

Persian recipes

A number of different sizing materials were prescribed in Persian historical treatises. Our historical analysis was preliminarily based on eleven treatises from the thirteenth to the eighteenth centuries. Most of the authors of these historical treatises are known to us today, while others are anonymous. These sizing materials are described in historical treatises from the late Seljuk and early Ilkanid (seventh–eighth century Hijra/twelfth–thirteenth century CE), Timurid (eighth–ninth century Hijra/fourteenth–fifteenth century CE), Safawid (tenth–twelfth century Hijra/sixteenth–eighteenth century CE) and Qajar periods (1193-1344 Hijra/17791925 CE), as we shall see below.

In his treatises *Ādāb al-Mašq*, *Rasm al-Ḵaṭṭ* and *Savād al-Ḵaṭṭ*, Solṭān Aḥmad Majnun Rafiqi Heravi advises the use of soft, smooth and even paper to write or draw on. To make fragile paper strong enough, reduce the fluffiness of paper fibres and make the surface of the paper smooth enough to write on, Mohammad Boḵāri also recommends applying sizing materials in his work *Favāyed al-Ḵoṭuṭ*.

In *Ḥaliyyat al-Ketāb,* the term *dāru* is used for sizing, whereas Teflisi calls the sizing *gune dādan*. Simi uses this last term just once when referring to a marshmallow starch. Three elements are involved in the sizing process: a base (*taḵte*) to spread paper on it during the sizing process, sizing substance (*āhār*) to apply on the paper in order to smooth the paper fibres, and burnishing tools (*mohre*) to make the sizing adhere to the paper fibres and make the paper even and ready for writing on.[30]

Historically, besides the type of fibre it contained and the place of its production, paper was known by different names, partly depending on the sizing of the sheets. In his book, Yves Porter quoted from *Resāle-ye ḵošnevisi*, where *ḵaṭṭaiʾi* paper is described thus: 'to size *ḵaṭṭaiʾi* paper, whether it is meant for exercise or for calligraphy, if the starch is thick, we repeat the process two or three times'.[31]

In *Ḥaliyyat al-Ketāb* and *Majmuʿat al-Sanāʿi* we can find recipes for sizing paper in such a way that the paper becomes similar to Baghdadi paper, a kind of well-known paper made in Baghdad and mentioned in historical treatises.[32] Also, different sizes were used as an appropriate base or support for calligraphy or painting according to requirements. Different types of paper, such as a single sheet of paper, two-layered paper (*kāḡaḏ-e do puste*) or three-layered paper (*kāḡaḏ-e se puste*), paper board (*muqawwā*) and albums (*muraqqaʿ*) were made using sizing materials. Gholam Dehlavi describes the process of album preparation by instructing the pages of manuscripts to be sized and burnished on both sides: 'Size the paper on the front but not on the back, with great care, like a fresh colourful flower. Then polish the paper on the other side until it shines brighter than a mirror for writing'.[33]

From our study, the materials can generally be categorised as proteinaceous materials, which include animal glue, starch from rice or wheat, vegetable gum, or mucilage from plants and seeds, fruit or sugar. A number of burnishing materials were also employed, such as agate stone (*ʿaqiq*), jade (*yašm*), ivory (*ʿāj*), glass (*zejāj*), crystal (*bolur*) and shell (*jis*). Teflisi uses the term *abgine* for glass used as a polishing tool. Sometimes even a person's bare hands were used to smoothen the surface of paper. A hard and smooth base made of flint (*čaqmāq*) was also employed, and a wooden board was used as the base for burnishing and sizing paper.

[26] Bloom 2001, 68f.

[27] Wulff 1976, 237.

[28] Gum tragacanth is called *katirā* in Persian. It is a natural gum obtained from the dried sap of several species of Middle Eastern plants of the genus *Astragalus*. The sap is drained from the root and stems of the plant and then dried.

[29] Asphodel belongs to the family of the *Liliaceae*. In Iran, a glue called *seriš* is made from the bulbs of this plant, which are first dried and then pulverised. The powder forms a strong glue when mixed with cold water.

[30] Cf. Canby, 1993, 14.

[31] Porter, 1994, 28.

[32] Bloom 2001, 48ff.

[33] Gholam Mohammad Dehlavi, *Taḏkere-ye ḵošnevisan* ('Biographies of Calligraphers'; 1221 Hijra/1806 CE), ed. M. Hidayet Husain, Calcutta 1910; cf. Porter 1994, *Painters, Paintings and Books,* 28.

Vegetable base sizes

The first category is vegetable base sizes, which include types of starch, gum, plant mucilage, fruit juice and sugar.

1. Starch (nešāste)

A general term for starch, *nešāste*, which we believe to be rice starch, was mentioned in seven treatises. The process of sizing with starch (*nešāste)* was discussed in detail in *Bayān al-Ṣenāʿat* by Teflisi, *Jowhar-e Simi* by Simi Neyšapuri, *Ṣerāt al-Ṣoṭur* by Soltān Ali Mašhadi, *Favāyed al-ḵoṭuṭ* by Boḵāri, *Ādāb al-Mašq* by Bābā Shāh-e-Isfahāni and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān* by anonymous authors. The eminent calligrapher Solṭān Ali Mašhadi, for example, devoted several couplets of his treatise on calligraphy, *Ṣerāt al-Ṣoṭur*, to sizing and glazing paper by hand, as shown here:

در باب آهار ساختن و کاغذ آهار کردن

ساز آهار از نشاسته کن　　بشنو این زپیر پخته سخن
اولاً کن خمیر وآب بریز　　پس بجوشش دمی به آتش تیز
پس لعاب سرش به او کن ضم　　صاف سازش نه نرم ونه محکم
رو به کاغذ بمال وسعی نمای　　تا که کاغذ نیوفتد از جای
کاغذِ خویش چون دهی آهار　　مال آبی به روی او زنهار

About producing sizing material and paper sizing

Prepare the size (*āhār*) from starch learn these words from an old man.

First make a paste, then pour in water, then boil this on a hot fire for a moment,

Then add some glue (*seriš*) to thin starch, strain it [so that it is] neither too thin nor too thick,

Spread it on paper and make sure, that the paper does not move from its place.

When you are applying size to your paper, moisten the paper slightly with water, carefully.

It is worth mentioning that *Ṣerāt al-Ṣoṭur*, *Favāyed al-ḵoṭuṭ* and *Resāle dar Bayān-e Ḵaṭṭ va Morakkab va Kāḡaḏ va Sāḵtan-e Ranghā* specifically advise mixing asphodel glue (*seriš*) to the starch paste. To prepare layered paper, Simi Neyšapuri describes the technique using starch size thus:

قدری نشاسته، آهار تنك كند وبيالايند، وكاغذ را به آهار بر هم ميتوان چسباند؛ چنانكه هر دو يكى شود، مهره زند وبنويسد، كه خط بر وى بغايت خوانايى وزيبايى بنهايت مى آيد. وبا كاغذ سلطانى برابر آيد.

Cook some starch and size paper. Pieces of sized paper can stick together in such a way that they become one sheet. This can then be burnished and written on. Calligraphy on this paper is legible and beautiful, and is as good as it is on *soltāni* paper.[34]

Wheat starch (nešāste-ye gandom):

This is specified in *Golzār-e Ṣafā* by Ali Seyrafi and in *Ḵaṭṭ va Morakkab* by Hossein Aqili Rostamdari. *Ḵaṭṭ va Morakkab* describes the technique as follows:

در بیان آهار کردن

چون خواهد که کاغذ را آهار کنند باید که اول شیره گندم بگیرند وصاف کنند وبعد از آن بپزند. وچون آهار پخته شد تخته بیاورند وبر بالای آن تخته نمدی یا کرباسی بیندازند وآهار را در قدحی ریزند ویک قدحی دیگر آب در پیش هم بگذارند وبعد از آن اندکی آهار از پنبه بردارند وبر آن چیز مالند، بعد از آن پنبه دیگر از آب تر کنند فی الحال بر آن مالند وبیندازند.

To size a piece of paper, take some wheat starch, filter it and then cook it to make a paste. Then take a wooden board and cover it with felt (*namad*) or a muslin cloth. Take two bowls; pour the starch into one and some water into the other. Moisten a ball of cotton with starch and rub it over the paper. Finally, take another piece of clean cotton ball, moisten it with water and rub it over the starched paper. The paper can be sized this way.

In *Golzār-e Ṣafā*, Seyrafi describes the process beautifully in the form of a poem:

صفت آهار نشاسته

ای مرا دیده ودل سوی تو باز　　طلبم ناز تو هر دم به نیاز
حال آهار که وافی باشد　　شیره گندم صافی باشد
طبخ کن شیره گندم بسیار　　پس بپالای وببر باز بکار
چونکه آهار کنی ای مهوش　　بشنو از من صفت آن دلکش
تختهای پیش نه از روی قیاس　　نمد افکن به سرش یا کرباس

[34] The term *soltāni* means 'royal' in Persian. According to Bābā Shāh-e Isfahani (tenth century Hijra/sixteenth century CE) in his treatise *Ādāb al-Mašq, soltāni* is high-quality paper, which is also known as *dolatābādi*. In his book *Kāḡaḏ dar Zendegi va Farhang-e Irāni* (1390 Hijra/2011 CE), Iraj Afšar says that *soltāni* paper refers not only to *dolatābādi* paper but also to *samarqandi* paper – the high-quality paper made in Samarqand in the eighth century. See Barkeshli 1998, 102, table 1.

قدحی پر کن از آهار دگر قدحی آب همان پیشآور
جز وی آهار به پنبه بردار کاغذ ای سرو روان ده آهار
تر کن از آب دیگر پنبه پاک پس به آهار بمالش چالاک
که همان مصلح آهار شوی صفحه زین قاعده هموار شوی

Attributes of Different Sizings

My dear: my eyes and my ears are open to you, I always long for your grace.

The perfect kind of sizing is a fine clear extract [starch] made of wheat.

Cook (boil) the wheat extract many times and filter it and use it repeatedly.

While you size [the paper], oh moon-faced one, hear from me the attributes of that heart attracting one.

Bring correctly measured boards and place over them felt or muslin cloth.

Fill a bowl with sizing up to the brim and bring forward another bowl filled with water.

Take an amount of sizing with a piece of cotton, oh gracefully flowing cypress tree, apply sizing on paper.

Make wet another piece of clean cotton and rub it over the sized paper.

Hence you become a restorer of sizing and the page becomes smooth with this foundation.

Rice starch (nešāste-ye berenj):

Rice was specified in various sources – Teflisi's *Bayān al-Ṣenāʿat,* Simi's *Jowhar-e Simi* and the anonymous *Ḥaliyyat al-Ketāb* (the tenth chapter of *Bayān al-Ṣenāʿat*). In *Ḥaliyyat al-Ketāb*, the process of making starch paste from rice and using it as a sizing material is stated as follows:

در صنعت دارو دادن کاغذ که مانند بغدادی شود ونشف نکند

بیارد برنج سفید اعلا، وبا نمک می مالند وبه آب می شویند تا سپید وروشن شود وطعم نمک از او برود وآنگه قدری آب در او کنند ویک شبانروز بنهند تا نرم گردد چنانکه به انگشت بمالند حل شود. پس در هاون کند وبه آب می سایند وآنچه نرم می شود در ظرفی پاکیزه کند تا جمله جمع شود آنگه بپالایند ودر پاتیله کنند وبه آتش نرم می جوشانند وبه چوبی می جنبانند تا غلیظ شود آنگه بنهد تا سرد شود. بعد از آن کاغذ را بر بالای تخته ای پاکیزه بگستراند واز این دارو به رکویی سفید پاکیزه بر کاغذ می مالند وکرباس دیگر برآفتاب بگسترانند کاغذ را بر بالای آن افکنند تا خشک شود، آنگه لعاب بدهند ومهره زنند که بسی لطیف باشد. دیگر از هر رنگ که خواهند در میان این دارو کنند که کاغذ رنگین نیکو آید وکسی از بغدادی فرق نتواند کرد.

Take the best-quality white rice, rub it with salt and wash it until it is clean and the taste of salt disappears. Then add some water and keep it for a whole day until it becomes soft and dissolves by rubbing. Place it in a mortar (*hāvan*) and grind it together with water. Put the soft parts into a clean pot so that it all comes together. Then filter it and put it into a large copper vessel. Boil it on a slow fire; stir it with a wooden stick till it becomes a paste. Let it get cold. Spread the paper on the wooden board. Size the paper with a clean cloth moistened with the paste. Spread a piece of cloth in the sun and put the paper over it till it dries. Finally, burnish the paper until it is very smooth. Dyes can be added to the paste to get coloured paper. By using this method, nobody will be able to distinguish this paper from Baghdadi paper.

Simi and an anonymous person in *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* describe a number of sizing materials that could be used when the paper is very thin and the pen used for writing gets stuck and is unable to move over it smoothly. One of the sizing materials they recommend for use is oil-free rice porridge (*ḥalim-e berenji bi roḡan*).

2. Gum:

Two other sizing materials mentioned in the historical treatises that fall into this category are gum arabic (*samḡ-e arabi*) and gum tragacanth (*katirā*).

Gum arabic (samḡ-e arabi):

This substance is mentioned in *Jowhar-e Simi*, *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*, *Golzār-e Ṣafā*, *Ḵaṭṭ va Morakkab* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. According to these sources, gum arabic is a very good sizing material and is suitable for writing. Hosseini Aqili Rostamdari says in *Ḵaṭṭ va Morakkab*:

نوع دیگر آن که صمغ را آب کنند وکاغذ را بدان آهار کنند.

… and furthermore dissolve gum arabic in water and size the paper with it.

In one of his couplets in *Golzār-e Ṣafā*, Seyrafi mentions gum arabic as the last material for sizing:

صمغ است دگر آخر کار این همه هست به جای آهار

… the last one is gum arabic, these are all used as sizing.

Gum tragacanth (katirā):
Katirā is known to have been employed as a sizing material, but in the Persian sources we studied, only Teflisi mentions its use for this purpose.

3. Asphodel (seriš):
This is a well-known vegetable glue which has already been mentioned above and was traditionally used for binding books in Iran; see Sultan Ali Mashhadi in *Ṣerāt al-Soṭur* and Moḥamad Boḵāri in *Favāyed al-Ḵoṭuṭ*. As mentioned above in the rice-starch recipe, Soltān Ali Mašhadi devotes several couplets of his treatise on calligraphy, *Ṣerāt al-Ṣoṭur*, to sizing and glazing paper by hand. In the couplet, he mentions *seriš* being added to rice starch to make the size for paper as follows:

پس لعاب سرش به او کن ضم صاف سازش نه نرم و نه محکم

Then add to thin starch some glue (*seriš*), strain it [so that it is] neither too thin nor too thick.

4. Plant mucilage (loʿāb):
Mucilage is a gummy or gelatinous substance produced in certain plants by the action of water on the cell wall, as in the seeds of quinces, flax, etc. It is also a polar glycoprotein and an exopolysaccharide. Mucilage in plants plays a role in the storage of water and food, seed germination and thickening of membranes. A number of kinds of mucilage were used as sizing materials to size paper in Iran according our historical analysis. *Jowhar-e Simi*, *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān, Golzār-e Ṣafā, Ḵaṭṭ va Morakkab* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān* state a number of sizing materials made from plant mucilage, but the descriptions are not as detailed as that of starch.

Rice mucilage (loʿāb-e berenj):
In *Golzār-e Ṣafā* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*, mucilage from rice is mentioned as a sizing material. The difference between rice mucilage and rice starch is that in the case of rice starch, the whole rice is cooked and used as a sizing material. As for rice mucilage, however, only the mucilage part is collected from the upper part of the boiled rice and then used as sizing material. In some of his couplets on sizing material in *Golzār-e Ṣafā*, Seyrafi mentions rice mucilage as being the fifth material for sizing after starch and fish glue:

از برنج است دگر بار لعاب کو بود خالی از چربی آب

… the other (sizing) is rice mucilage, the water (used) should be free of oil

Fleawort seed (espāghol, esfarze, qeṭūnā):
Fleawort[35] seeds are mentioned in the following sources: *Jowhar-e Simi*, *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*, *Golzār-e Ṣafā*, *Ḵaṭṭ va Morakkab* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. The techniques stated in the first four sources are the same; they only differ in the duration the paper is dipped in mucilage. *Golzār-e Ṣafā* and *Ḵaṭṭ va Morakkab* use the term *qeṭūnā* for these seeds. Hossein Aqili Rostamdari explains the process thus in his book *Ḵaṭṭ va Morakkab*:

نوعی دیگر بذر قطونا را در آب ریزند تا لعاب بدهد بعد از آن کاغذ را در لعاب او بگذارند یک ساعت، و بیرون آورند.

Pour some fleawort seeds into water [and leave them in it] until you get some mucilage. Leave the paper in the mucilage for one hour and then take it out.

In *Jowhar-e Simi* and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* (ninth century Hijra), the duration the paper is dipped in fleawort-seed mucilage is shorter. The sources say: ‘Size a sheet of paper with mucilage from fleawort seeds all at one go, then let it dry’, but Simi stresses that the mucilage from fleawort seeds must be filtered first and then used. In some of his couplets on sizing material in *Golzār-e Ṣafā*, Seyrafi, after discussing rice starch and fish glue, mentions that there are six more sizing materials: first of all, fleawort-seed mucilage; second, sweet melon juice; third, cucumber seed; fourth, grape syrup; fifth, rice mucilage; and last of all, gum arabic. In the first three couplets, he advises the reader on using fleawort seed as the best material for sizing after starch and fish glue:

[35] Fleawort is *Plantago psyllium*.

هست شش چیز دگر ای دلدار که مقوّی است بسان آهار
او لا بذر قطونا باشد که لعابش چو مصفّا باشد
کاغذ انداز در او یک ساعت پس برون آر که یابی راحت

Attributes of Different Sizings

There are six more materials, my dear, which are suitable for sizing

First there is fleawort seed, which has mucilage that is clear

Immerse the paper in it for an hour, then take it out and then you are done.

Cucumber seeds (toḵm-e ḵiār):

Another sizing material is cucumber seeds, which is stated in *Golzār-e Ṣafā* and *Ḵaṭṭ va Morakkab*, albeit in a very brief description. In *Golzār-e Ṣafā*, in some of his couplets on sizing material, Seyrafi mentions cucumber-seed mucilage as the third material for sizing, after starch and fish glue. Hossein Aqili Rostamdari says the following in his book *Ḵaṭṭ va Morakkab*:

طریقی دیگر آن که تخم خیار را در آب ریزند تا لعاب باز دهد وبعد از آن کاغذ در آن اندازند وبیرون آورند.

Another method is to place cucumber seeds in water until their mucilage is extracted. Afterwards, place the paper in [the mixture] and remove it.

Melon seeds (ab-e toḵm-e khiārein):

In *Jowhar-e Simi* and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*, the authors state *āb-e tohkm-e ḵiārein* as one of the sizing materials. This term can refer to both the mucilage from cucumber seeds and all the seeds from the melon family since in some parts of Iran, *ḵiarein* is the term used for plants and fruits which are similar to the melon family, such as *ṭālebi* and *ḵarboze*. The word *āb*, usually used to mean juice or extract, is probably used in the sense of mucilage here since it refers to the seeds of the fruit.

Marshmallow mucilage (loʿāb-e ḵeṭmi):

Mucilage of marshmallow[36] is mentioned in *Jowhar-e Simi* (ninth century Hijra), *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* (ninth century Hijra) and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. In the sources, the term 'dye' (*rang*) is used rather than 'size' (*āhār*). In the last source mentioned, for example, it says:

دیگر خطمی را یک شب و یک روز [نم کند و] کاغذ را بدان رنگ کند خط بروی خوب آید.

Soak marshmallow (in some water) for a night and a day. Dye the paper with it. The calligraphy on it will be nice.

Referring to marshmallow mucilage, *Jowhar-e Simi* and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* state:

دیگر تخمی خطمی شبانروزی در آب کند وبیالاید وکاغذ را بدان گونه دهد. واین بغایت مختار وپسندیده وکاغذ را نرم سازد وخط بر وی خوب آید.

Keep marshmallow seeds in water for a night. Then dye the paper with the mucilage. This process is highly appreciated, it softens the paper, and the calligraphy stands out well on it.

Mucilage from myrtle[37] seeds (toḵm-e mord):

This is only mentioned in *Jowhar-e Simi* and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*. The second source explains the process as follows:

دیگر کاغذی که دارای رنگ پیروزه ناک باشد ومانع قلم باشد، تدبیر آن است که به آب خربزه شیرین یا به آب نبات مصری یا به آبِ مورد وبا لعاب اسفیقول ولعاب برنج بی روغن [بگذارد که] مجموع مقوی کاغذ است، وچون کاغذ مهره زند مثلِ آینه نماید.

The paper that is of a turquoise colour and prevents the pen from moving smoothly on it [during writing] can be fixed by sizing [paper] with sweet melon juice or Egyptian rock sugar, mucilage from myrtle seeds, mucilage from fleawort seeds or oil-free rice mucilage, which all make the paper strong. And when the paper is burnished, it is like a mirror.

5. Fruit juice:

It is interesting to note that in the historical treatises, fruits such as melons and grapes are used as sizing material.

[36] Marshmallow is *Althaea officinalis*.

[37] Myrtle is *Myrtus communis*.

Juice of a sweet melon (ḵarboze):
This juice is mentioned as a good sizing material in *Jowhar-e Simi, Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān, Golzār-e Ṣafā*, *Ḵaṭṭ va Morakkab* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. Seyrafi mentions melon juice as the next-best material after starch and fish glue in *Golzār-e Ṣafā*:

دومین خربزه شیرین است آبش آهار پی تزیین است.

… Second is sweet melon, its extract is size to adorn [paper].

After mentioning fleawort in his work *Ḵaṭṭ va Morakkab*, Hossin Aqili Rostamdari continues:

دیگر آنکه آب خربزه شیرین را بگیرند وکاغذ در آن کنند.

… and furthermore, they take the juice of a sweet melon (*ḵarboze*) and dip the paper in it for sizing.

Grape syrup (širey-e angur):
Grape syrup is mentioned as a sizing material in *Jowhar-e Simi*, *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*, *Golzār-e Ṣafā* and *Ḵaṭṭ va Morakkab*. Seyrafi discusses grape syrup as the third material for sizing after starch and fish glue in his couplets on sizing materials in *Golzār-e Ṣafā*. The source *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* mentions grape syrup as a sizing material and stresses the point that the grapes should be seedless. In *Ḵaṭṭ va Morakkab*, Hosseini Aqili Rostamdari maintains:

ودیگر آن که شیرهٔ انگور صاف کرده کاغذ بدان برکشند.

… and moreover, grape syrup is filtered and applied on paper as size.

6. Sugar syrup:
Besides different kinds of fruit juice, another glucose extract is also mentioned in some historical treatises: rock sugar. Egyptian rock-sugar solution (*āb-e nabāt-e meṣri*) is mentioned as a sizing material in *Jowhar-e Simi* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*. In the second of these sources, rock sugar is described along with other sizing materials mentioned above under the lemma ‘mucilage of myrtle seeds’. It is to be applied on turquoise paper if the writer’s pen is unable to move smoothly over the paper.

7. Mixed sizes
In *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*, sweet melon juice, myrtle extract and sugar syrup are described as materials to be added to plant mucilage in order to size paper. It says:

دیگر کاغذی که دارای رنگ پیروزه ناک باشد ومانع قلم باشد، تدبیر آن است که به آب خربزه شیرین یا به آب نبات مصری یا به آبِ مورد وبا لعاب اسفیقول ولعاب برنج بی روغن [بگذارد که] مجموع مقوی کاغذ است، وچون کاغذ مهره زند مثلِ آینه نماید.

If a [piece of] paper has a deep turquoise colour and it is difficult to write on, the advice is to apply either sweet melon juice (*abi karboze*) or syrup of Egyptian rock sugar (*āb-e nabāt-e meṣri*) or myrtle extract (*āb-e mord*) with mucilage of fleawort seed (*espāghol*) and mucilage of oil-free cooked rice (*loʿāb-e berenj*). All these materials make paper strong, and if it is then burnished, it becomes smooth, just like a mirror.

It is possible there was no deliberate intention to introduce these sizing materials as mixed sizes since the above text is quite similar to *Jowhar-e Simi* and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*. Myrtle is mentioned as an extract (*āb-e mord*) in the second source, whereas in the first source, it is in the form of myrtle seeds (*toḵm-e mord*).

Animal base sizes

The next category is animal base sizes; animal glue obtained from fish is actually the only size found in the recipes in this category.

Fish glue (sirišum-e māhi):
This type of size is mentioned in *Jowhar-e Simi*, *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān*, *Golzār-e Ṣafā*, *Ḵaṭṭ va Morakkab* and *Resāle dar Bayān-e Tariqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān*, where its use is described as follows:

دیگر، قدری سریشم ماهی سفید را، سه شبانروز در آب پاک کند. وبعد از آن به اتش، نرم گرم کند: در حال شود بیالاید، وکاغذ بدان برآرد وبا احتیاط خشک کند ومهر زند وبنویسد.

Soak a small amount of white-fish glue [*sirišum*] in water. Change the water and fill [the bowl] with fresh water for three days until it clears thoroughly. Heat the *sirišum* till it melts, then filter it with a piece of muslin cloth. Apply the fish glue on paper as sizing material. Let it dry in the sun carefully. They burnish [it] and then they write.

Ali Seyrafi describes the process as follows in his treatise *Golzār-e Ṣafā*:

صفت آهار سریشم ماهی

بعضی آهار بدین سان دادند فرقه ای رسم دگر بنهادند
از سریشم که بُوَد از ماهی اداده آهار به خاطر خواهی
که سریشم سه شبانروز به آب بنهادند که تا گشت لعاب
نرم کردند به آتش در کار چونکه شد نرم نمودند آهار

Fishglue as sizing

Some size [paper] this way, others do it another way.

Sirišum, which is from fish, gives adorable size.

They leave *sirišum* in water for three days, until a mucilage is obtained.

They make it turn smooth over a fire, when it is soft, they use it as size.

Jowhar-e Simi and *Resāle dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* both specify that Caspian white fish should be used; this is found in the Caspian Sea and used to be very common in Iran.

Scientific analysis

In order to investigate the presence of sizing materials mentioned in historical literary references, the research was carried out in two stages. In the first of these, the sizing materials that were identified through historical analysis were prepared according to recipes for fingerprint data collection.[38] In the second stage, a series of sample analyses were conducted on the sizing materials of eleven historical Persian and Indian miniature paintings, illuminated manuscripts belonging to the Iran Bastan Museum and private collections from the sixteenth (Safawid) to nineteenth (Qajar) centuries.[39]

Materials and techniques

In the first stage, sizes were identified from our historical analysis. The materials were categorised as proteinaceous materials, which include animal glue, starch from rice or wheat, vegetable gum, mucilage from plants and seeds, types of fruit juice, and sugar syrup. Based on each category identified from the historical treatises, ingredients were collected from the local markets in Iran, viz. fish glue, rice and wheat starch, asphodel (*seriš*), fleawort seeds, cucumber seeds, melon seeds, marshmallow seeds, raw rice, grape syrup, melon syrup and sugar syrup. The sizings were prepared on the basis of the historical recipes. The duration of boiling, cooking and soaking the materials followed the recipes' specifications as much as possible. However, since the exact length of time was not specified in the recipes, the experiments needed to be repeated several times in order to get the consistency suitable for sizing. Handmade paper was selected from the conservation laboratory of the Iran Parliament (Congress) Library in Tehran and pieces of paper were divided into eleven groups for each sizing material under investigation. In each group, the pieces were divided into eight items of 2.5 cm^2 in size for the sample experiments. Each eight-item group was then divided into two sub-groups: four paper samples for sizing using a dipping technique and four other paper samples for sizing with a brush. In the case of the dipping technique, the paper samples were sized for four different lengths of time: 15, 30, 45 and 60 seconds. As for the brushing technique, the samples of paper were sized using a soft brush and one to four coats of size were applied. The paper samples were sized with the different materials identified in the recipes, left to dry at room temperature and then individually burnished with an agate stone on a flat wooden board.

In the second stage of the investigation, the large collection of sizing materials that was prepared on the basis of the historical recipes was compared with the spectra of original samples of paper. An analysis of the sizing materials used in the original samples was carried out using a staining method and Fourier transform infrared spectrometry (FTIR). The spectrometry was conducted with a Nicolet 510 P instrument equipped with a microscope attachment. Sample preparation

[38] Barkeshli 1997, 338, 420-422.

[39] Barkeshli, 2003, 2005.

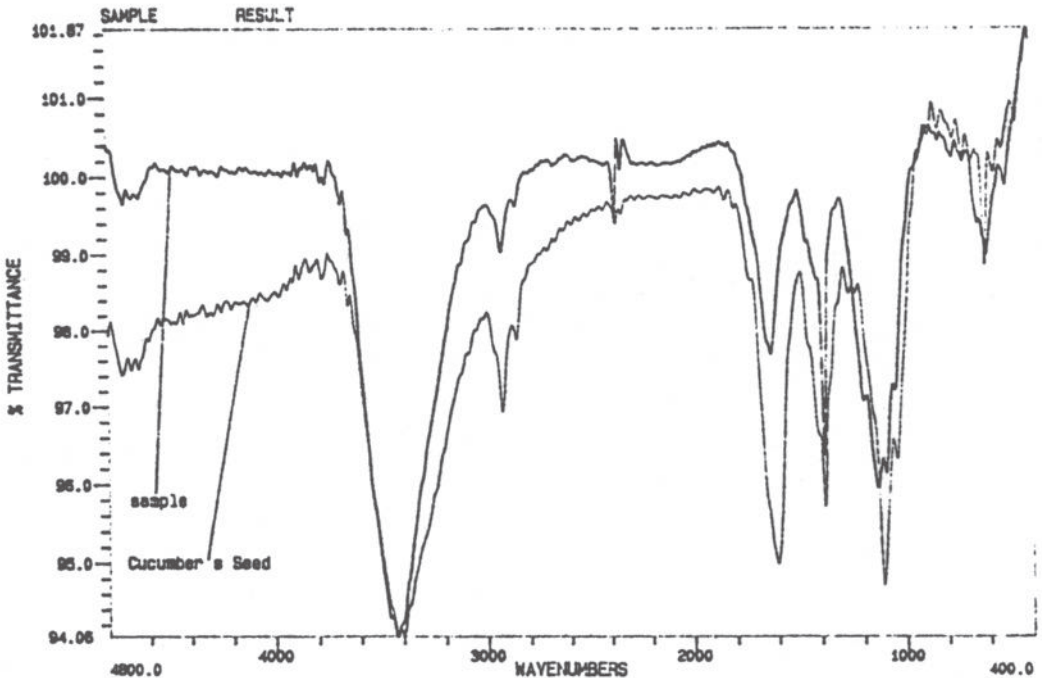


Fig. 9: The spectra of the sizing material of cucumber-seed mucilage (appendix B, table 1, checklist no. 18), Atiqi Collection, Tehran, Iran.

was done by mixing KBr and the unprepared sample (100:1). Identification of the materials in the samples was achieved by comparing the infrared spectrum with the reference spectra via recognition of specific bands.

Starch was detected on paper by the formation of the characteristic blue colour when a dilute aqueous solution of iodine-potassium iodide was added (see appendix B, table 2).

Results and discussion

The intention of preparing sizes based on historical recipes in the first phase was to collect data for a further analysis of original samples in order to identify the sizing material in stage two. However, our research in the first phase showed that each sizing material has its own particular properties and gives a certain effect to the paper. Further investigation is required here to collect more detailed data. Our visual and physical observations will hopefully be valuable for future research. We found that starch paste gives more body to paper and makes it firmer. In contrast, plant mucilage – especially from cucumber seed – gave the paper a lighter body and made it softer than the effect obtained using starch paste. Fruit and sugar syrups gave more shine to the surface of the paper we examined and made it stiffer compared to plant mucilage. As for vegetable and animal glue, they both added a lustre to the paper, but animal glue made the paper stiffer than vegetable glue did.

In terms of drying, the sizing material sometimes took a while to dry, depending on the duration of dipping and the number of layers of it that had been applied. The drying process was prolonged if the dipping or application process was repeated during the sizing procedure. It is interesting to note that cucumber-seed mucilage was what dried the fastest and paper sized with it was also easier to burnish than with other sizing materials.

In the second stage, our investigation showed that out of six categories of sizing materials recommended, mucilage from cucumber seeds was the most common sizing material on the paper samples identified by the FTIR method (see fig. 9). Out of the nine Persian miniature paintings and illuminated manuscripts examined, one of the sizes used was starch, seven were cucumber-seed mucilage and one was a mixture of tragacanth and cucumber seed. The reason why cucumber-seed mucilage was used more than other recommended sizes needs more investigation. According to our observations, paper sized with cucumber-seed mucilage gave better results in terms of aesthetics, giving the paper a lighter body and softer look. In terms of the sizing process, it dries faster and is easier to burnish. Moreover, I believe that there may well have been a reason behind it being recommended for sizing since cucumber-seed mucilage is less prone to attack by micro-organisms than starch, vegetable gum, animal glue, fruit extracts and sugar due to its nature and chemical composition. This assumption will be reported on in more detail in future.

Conclusion

There is a huge amount of information that can be found in historical treatises and recipes relating to the art of bookmaking in Iran. Most of these literary references are written in the form of poetry or mystical language. This paper has tried to show how it is possible for researchers to discover the reasons for authors choosing particular ingredients, which can be explained in terms of chemistry, and has presented some examples to show how scientists should look at such pieces of information. The research outlined here focused on introducing the author's theoretical and methodological approach by presenting three exemplary case studies.

To this end, twenty-four Persian treatises from the thirteenth to the nineteenth century were selected and their texts were studied in a bid to understand the techniques and ingredients explained and recommended by different masters in the art of calligraphy and bookmaking. Many of these texts are written in poetic language; the terms that were picked for them were used and understood in a specific way at the time of writing. The information we sought was collected and categorised in three areas: pigments used in illumination and painting, dyes used in paper-dyeing, and sizing materials used to prepare paper. From the huge amount of data collected in these three areas, three ingredients were selected as case studies to show just how modern science can contribute to an understanding of the reasons for using certain ingredients or certain techniques, or even using certain proportions of substances that were recommended.

The first case study presented in order to introduce our theoretical and methodological approach to material technology concerned the techniques used in conjunction with corrosive verdigris pigment, involving the addition of saffron to prevent the pigment from charring the paper. Our research showed that saffron is a very strong buffer and acts as an inhibitor, stopping the destructive effect that verdigris would otherwise have on paper.

The second case study presented was concerned with the art of paper-dyeing. In this part, we specifically focused on henna to see whether the ratio of 1:10 advised by master calligraphers had a factual reason behind it. Our research showed that henna has a fungicidal effect and can reduce the growth of *aspergillus flavus* fungus when used exactly in the advised ratio.

The third case study presented here focused on the sizing materials used in medieval and early modern Iran. Our study based on historical recipes showed that Iranians used a considerable range of materials in the sizing process. However, our scientific investigation revealed that only cucumber mucilage, starch and tragacanth gum were actually used in the original manuscripts. Moreover, our study showed that cucumber-seed mucilage was used more often than the other materials under investigation. The precise reason for this is still being investigated. However, I believe the rationale for this choice to be the notion that a microbiological attack on sized paper could be reduced due to the nature and chemical composition of cucumber-seed mucilage. This is a matter I am still investigating.

Our investigation has shown that art and applied science have been closely linked in the course of Iran's rich history. Moreover, we have been able to show that Iranian artists and masters of calligraphy had extensive knowledge of chemistry and the nature of the materials they employed in their work. They were also able to use mystical literary references as a means of passing on their knowledge to their pupils.

APPENDIX A:

1. Ali Seyrafi (tenth century Hijra/sixteenth century CE), *Golzār-e Ṣafā* (950 Hijra/1543/1544 CE) ('Garden of Joy'), Paris National Library (original), No. S.P. 1656; Tehran University Central Library (microfilm), No. 3637, Tehran, Iran.

2. Ali Hosseini, *Morakkab Sāzi va Jeld Sāzi* ('Ink-making and Binding'), part of the second, third, ninth, thirteenth and sixteenth chapters from *Kašf al-Ṣanāyeʿ* (attributed to the Qajar period), Tehran University Library copy, No. 2261, Tehran, Iran; Āyatollah Marʿaši Library copy, No. 4917, Qom, Iran.

3. Alkašfi, *Bayān al-Ṣanāʿat* ('Descriptions of Crafts'), (attributed to the Qajar period), personal library, A. M. Tākestānī, Tehran, Iran.

4. Anonymous, *Resāleh dar Bayān-e Kāḡaḏ Morakkab va Ḥall-e Alvān* ('A Treatise about Paper, Ink and Dissolving Dyes'), (early or mid-ninth century Hijra/fifteenth century CE), Parliament Library copies, No. 1 and No. 4767 (1100 Hijra), Tehran, Iran.

5. Anonymous, *Ḥaliyyat al-Ketāb* ('Lawfulness of Writing'), (attributed to the Safawid period) in *Majmuʿah al-Ṣanāʾiʿ* (thirtieth chapter), Tehran University Central Library copy, No. 3875 (1005 Hijra/1596/1597 CE), Tehran, Iran; Āyatullah Marʿaši Library copy, No. 4917, Qom, Iran.

6. Anonymous, *Resāleh dar Bayān-e Tarīqe-ye Sāḵtan-e Morakkab va Kāḡaḏ-e Alvān* ('A Treatise about the Technique of Preparing Coloured Paper and Inks'), (attributed to the Safawid period), Malek National Library copy, No. 2870, Tehran, Iran.

7. Anonymous, *Resāleh dar Bayān-e Rang Kardan-e Kāḡaḏ* ('A Treatise about Dyeing Paper'), (probably thirteenth century Hijra/nineteenth century CE based on Timurid and Safawid information), Ḵānqah Neʿmatollāhi Library copy, No. 304, Tehran, Iran.

8. Anonymous, *Resāleh dar Maʿrefat-e Kāḡaḏ-e Alvān* ('A Treatise about Coloured Paper'), (probably thirteenth century Hijra/nineteenth century CE based on Safawid and Timurid information), West Hamedan School Library copy, No. 5344, Hamedan, Iran.

9. Anonymous, *Resāleh Ṭalā va Noqreh va Ḥall Kardan-e ān* ('A Treatise on Gold and Silver and How to Dissolve Them'), (attributed to after the Safawid period), West Hamedan School Library copy, No. 5344, Hamedan, Iran.

10. Anonymous, *Resāleh dar Bayān-e Ḵaṭṭ va Morakkab va Kāḡaḏ va Sāḵtan-e Ranghā* ('A Treatise about Calligraphy, Ink and Making Dyes'), (attributed to a later date, probably thirteenth century Hijra/nineteenth century CE based on Safawid and Timurid masters' recipes), Malek National Library copy, No. 4211, Tehran, Iran.

11. Al-Razi (c. 250–311 Hijra/c. 864–925 CE), *Ketāb al-Asrār* ('The Book of Secrets'), research and translation into Farsi by Dr. H. A. Sheybany, published by Tehran University, 1992, Tehran, Iran.

12. Bābā Shāh-e Isfahani (tenth century Hijra/sixteenth century CE), *Ādāb al-Mašq* ('Manners of Writing'), Malek National Library copy, No. 526 (1271 Hijra/1854/1855 CE); No. 2284 (1284 Hijra/1867/1868 CE), Tehran, Iran; Āstān Qods Rażavi Central Library copy, No. 130 (1292 Hijra/1875 CE), Mashhad, Iran.

13. Hossein Aqili Rostamdari (c. 930–984 Hijra/c. 1523-1577), *Ḵaṭṭ va Morakkab* ('Calligraphy and Ink'), Āstān Qods Rażavi, copy No. 2033, Mashhad, Iran; British Museum, copy No. 3648, London, UK; Tehran University Central Library copy (microfilm) No. 4021, Tehran, Iran.

14. Mir ʿAli Heravi (mid-ninth century–951 Hijramid-fifteenth century–1544 CE), *Medād al-Ḵoṭuṭ* ('Ink of Scripts'), (after 900 Hijra/beginning of the sixteenth century CE), Ostād Reżā Māyel Heravi Personal Library copy, Ms. H (early or mid-tenth century Hijra/early sixteenth century CE), Tehran, Iran.

15. Mohammad Ibn-e Dust Mohammad Boḵāri (976– ? Hijra/1568/1569–? CE), *Favāyed al-ḵoṭuṭ* ('Advantages of Scripts') (995 Hijra/1586 CE), Bukhara Library copy, no. (2617) 460 (331) (1222 Hijra/1806 CE), Bukhara, Uzbekistan.

16. Moḥammad Moʾmen Hosseini, *Toḥfe-ye Ḥakim-e Moʾmen* ('Present of Ḥakim-e Moʾmen'), (a treatise attributed to the Safawid period, tenth century Hijra/sixteenth century CE), Mahmoodi Publications, 1982, Tehran, Iran.

17. Simi Neyšapuri, *Jowhar-e Simi* ('Jewel of Simi'), (d. ninth century Hijra/fifteenth century CE), Bodleian Lib. Oxford, Ms. Or. 7465, (no date), fols. 38a–49b, (Meredith Owens, *Persian Illustrated Manuscripts*, London 1965, 92); Bodleian Lib. Oxford, Ms. 1241 (dated 1122 Hijra/1710 CE), fols. 344–356b (Sachau and Ethé, *Catalogue of the Persian, Turkish, Hindustani, and Pushtu Manuscripts in the Bodleian Library*, Oxford, 1889, vol. I, col. 762); in Porter (1994), *Painters, Paintings and Books*, App. 2.

18. Ṣādeq Bek Afšār (940–1017 Hijra/1533-1609 CE), *Qānun al-Ṣovar* ('Canons of Painting') (before 1010 Hijra/16001CE), Malek National Library copy, no. 6325; Tehran University Central Library copy, No. 7395, Tehran, Iran; in Porter (1994), *Painters, Paintings and Books*, Appendix 2.

19. Seyyed al-Sādāt Seyyed Yusef Hossein (second half of sixth century Hijra/twelfth century CE, Indian origin), *Resāle-ye Ṣaḥḥāfi* ('A Treatise on Bookbinding'), Persian, Madras Government Library copy (twelfth century Hijra/seventeenth–eighteenth century CE), No. 437, Madras, India.

20. Solṭān Aḥmad Majnun Rafiqi Heravi (late ninth and early tenth century Hijra/late fifteenth and early sixteenth century CE), *Rasm al-ḵaṭṭ* (909 Hijra/1503 CE) ('Law of Writing'), Tehran University Central Library copy, No. 3522 (1056 Hijra/1646 CE), Tehran, Iran.

21. Solṭān Aḥmad Majnun Rafiqi Heravi (late ninth and early tenth century Hijra/late fifteenth and early sixteenth century CE), *Savād al-ḵaṭṭ* ('Blackness of letters') (after 930 Hijra/1523 CE), Malek National Library copy, No. 526 (1271 Hijra/1854/1855 /late fifteenth and early sixteenth century CE), Tehran, Iran.

22. Solṭān Aḥmad Majnun Rafiqi Heravi (late ninth and early tenth century Hijra/late fifteenth and early sixteenth century CE), *Ādāb al-Mašq* ('Manners of Writing'), Malek National Library copy, No. 4211 (1269 Hijra/1852/1853 CE), Tehran, Iran.

23. Solṭan Ali Mašhadi (841–926 Hijra/1437–1520 CE), *Ṣerāt al-Soṭur* (920 Hijra/1514 CE) ('Ink of Calligraphy'), Central Library of Tehran University copy, No. 4736 (1060 Hijra/1650 CE), Tehran, Iran; Malek National Library copy, No. 4765 (tenth century Hijra/sixteenth century CE); No. 4126, Tehran, Iran.

24. Teflisi, Habiš b. Ebrahim, *Bayān al-Ṣenāʿat*, ('Description of Crafts'), (d. 600 Hijra/1203 CE), Irağ Afšār (ed.) (1376/1377 Hijra/1957 CE), *Farhang-ī Irān-zamīn* (*FIZ = Revue trimestrielle des études iranologiques*), 5: 298–457.

APPENDIX B:

Table 1:
Sizing materials on selected paintings collected from the Iran Bastan Museum Collection and from private collections.

Origin	Owner	Object	Date	Check List No.	Sta	Cuc	Tra
IRAN	Iran Bastan Museum	M	16th c.	4555	sf		
	Atiqi Collection	I.M.	16th c.	11		f	f
	Atiqi Collection	I.M.	17th c.	12		f	
	Atiqi Collection	I.M.	17th c.	13		f	
	Atiqi Collection	I.M.	17th c.	14		f	
	Atiqi Collection	M	16th c.	15		f	
	Atiqi Collection	M	16th c.	16		f	
	Atiqi Collection	M	16th c.	18		f	
	Atiqi Collection	M	16th c.	19		f	
INDIA	Iran Bastan Museum	M	17th c.	4535	sf		
	Atiqi Collection	M	18th c.	17	sf		

Key to sizings
Sta = Starch
Cuc = Cucumber's Seeds
Tra = Tragacant (*katirā*)

The following sizing material were investigated without traces found: fish glue, gum arabic, ispagol, sweet melon, rice mucilage, grape syrup, sugar syrup, and myrtle juice.

Key to object
I.M. = Illuminated Manuscript
M = Miniature

Key to identification methods:
s = Determination of starch by staining the paper with iodinepotassium iodide solution.
f = Identification of sizing materials in the sample is obtained by comparing the infra red spectrum with reference spectra or by reorganizing specific bands.

Table 2:
Pigments collected from traditionally produced art objects and paintings in private collections and from selected paintings from the Iran Bastan Museum Collection.

Origin	Owner	Object	Date	Check list no	White			Red		
					Ldw	Cha	Tiw	Ver	Rld	Org R
Iran	Iran Bastan Museum	M	16th c.	4555	f			m	m	
	Atiqi Collection	I.M.	16th c.	11	m				m	
	Atiqi Collection	I.M.	17th c.	12	m			m	m	
	Atiqi Collection	I.M.	17th c.	13	m				m	
	Atiqi Collection	I.M.	17th c.	14	m				m	
	Atiqi Collection	M	16th c.	15					m	
	Atiqi Collection	M	17th c.	16	f			m	m	
	Atiqi Collection	M	16th c.	18	mfc			cm	cm	f
	Atiqi Collection	M	16th c.	19	fc			c		m
	Tavoosi Collection	Pb	16th c.	21	f				c	cf
	Bekhradi Collection	Pb	19th c.	31		f		c	cm	fc
	Saneie Collection	P.P.	19th c.	41			fc	mc	cm	cm
	Takestani Collection	P.P.	20th c.	51		f		xm	xm	mf
India	Iran Bastan Museum	M	17th c.	4535	mf			mc	mc	mf
	Atiqi Collection	M	17th c.	17						f

Key to Subjects
I.M. = Illuminated Manuscript
M = Miniature
Pb = Paintbox
P.P. = Paint Palette

Key to Pigments
Br = Brown Earth
Car = Carbon
Cha = Chalk
Cog = Copper Green
Gld = Gold
Idg = Indigo
Ind = Indian Yellow
Ldw = Lead White
Mal = Malachite
Org R = Organic Red
Orp = Orpiment
Rd = Red Earth
Rld = Red Lead
Rub = Rubarb
Tiw = Tin White
Ver = Vermilion
Ult = Ultramarine

Key to Identification Methods
c = Elements identified and solubility.
f = Identification of sizing materials in the sample is obtained by comparing the infra red spectrum with reference spectra or by reorganizing specific bands.
m = Appearance by transmitted light on a microscopic slide observed by polarized light microscopy.
u = Fluoresces in long-wave ultraviolet light.
x = Crystalline structure by x-ray powder diffraction.

*Saffron was mixed with verdigris (Cog).

Pigments											
Yellow			Green		Blue		Earths		Black	Metallic	Others
Orp	Ind	Rub	Cog	Mal	Ult	Idg	Rd	Br	Car	Gld	
m		f			fc	m	m	mc	m	m	
					fm				m	m	
					m					m	
m			mfc		m			m	m		
					m				m	m	
									m		
		mf	c		f			m	m	m	
m		f	mfc		mcf			c			Saffron
c			f		cf			c			Saffron
c		f	cf		f	f	c	c			Saffron
c		mf	mfc		fm		c	c			Barium Sulphate
mc		mf			mcf	mcf	mc	mc			Prussian Blue
mx		mf		fxc	mxf		mc	mx	m		Barium Sulphate
m	mfu		fc		fm	m		mc	m	m	Langite
	u		fc		f				m		Green Atachamite

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