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Ottoman palace weavings between different periods: material characterization, comparison and suggestions for conservation

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Abstract

Historical textiles, which are an invaluable part of the cultural material heritage, and the materials used in their production bear witness to the social past. Although a textile object was originally produced out of necessity, later it became a symbol of magnificence, power, and might. The most important basic elements that contribute to these properties are the materials used in its production, among which silk fiber, and metallic threads containing gold and silver are the leading ones. In addition to the aging behavior of textile objects due to their organic structure, the deterioration process is accelerated due to various factors such as use, environmental factors, mismanagement, inappropriate storage and display conditions, incorrect restoration-conservation practices, natural disasters, etc. In this study, a total of 7 metallic threaded textile works dated between the 16 and 19 centuries and used by the Ottoman Palace dynasty in the textile collection of the Topkapı Palace Museum (TPM) were examined. In this context, visual evaluation/documentation, color measurement, technical analysis, dyestuff analysis, elemental composition, and corrosion products were determined in the historical textiles. In this study, the following analytical instruments were used for the analyses: a CIEL*a*b* spectrophotometer, an optical microscope (OM), high-performance liquid chromatography with photodiode array detection (HPLC–PDA), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM–EDX). Thanks to this study, it was aimed to document the palace fabrics containing silk and metallic yarn used in the Ottoman period, to characterize the materials they contain, to determine the production method, and to determine of the deterioration products that occur over time. According to the results obtained from the analyses, insect-origin dyestuffs in red, pink, and purple were used. When the fabrics of the sixteenth century and the fabrics of the nineteenth century were compared, it was determined that there was a decrease in the quality of weaving. In addition, it was determined that the fiber in the metallic yarn core in the textile object dated to the end of the 19th/beginning of the twentieth century was produced by using cotton instead of silk, and also the thickness of the metal strip and the wrapping density were decreased. No significant difference was detected in the chemical composition of the strips in the metallic yarns found in the examined historical textiles, but only the silver element was detected in the metal strip, although the metallic yarn core in the last period textile object was yellow in color. All these results showed that there was a difference between the sixteenth-century textiles of the rise of the Ottoman Empire and the nineteenth-century textiles of the dissolution period. This difference is especially evident in the quality of the weaving, the density of the materials used, and the chemical composition of the metal strip. In addition, all these analyses will guide textile experts in possible restoration-conservation studies.

Keywords Ottoman palace weavings, Silk fabrics, Natural dyes, Metal thread, Deterioration, Conservation

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Introduction

All objects such as manuscripts, paintings, ornaments, clothes, carpets, and rugs possessed by a civilization are reflections of the formation of that civilization. All of these objects embody ideas and values and are cultural elements that contain much more than representations [1].

Since ancient times, organic coloring materials have been attractive to human beings, and have obtained these materials by using living things in nature such as plants, insects, and lichens [2, 3]. Natural dyes and colorants are an important part of cultural heritage and throughout history, these natural materials have played an important role in economic and cultural exchanges between countries [2, 4].

The dyes used and the dyeing industry by the Ottomans were handed down from father to son as a secret for generations and reached us almost without any significant change. Due to the careful production process in the Ottoman Empire, dyestuffs were of great commercial importance. Some natural dye resources and dyed textiles were used to pay taxes in the Ottoman Empire, and dye workshops paid some of their production or harvest to the state in this way instead of cash. In general, it is understood from the Ottoman archives that the Ottoman Empire was rich in the production of dye sources and dyed textiles in the sixteenth and seventeenth centuries [5].

The use of natural dyes in textiles continued until the second half of the nineteenth century. The discovery of the first synthetic organic dye (mauveine) by William Henry Perkin in 1856 and its subsequent introduction to the market created a major breakthrough in the dye industry. In addition, synthetic dyes have replaced natural dyes due to their cheapness and easier application on the textile surface, and this result has led to a cultural revolution [4]. With the spread of synthetic dyes, these dyes entered the Ottoman market, and dyehouses started to close one by one [6].

Metallic threads in textiles, especially those wrapped using gold and silver, have been used throughout history both to adorn textile products and as a visible proof of magnificence, power, abundance, and wealth [7]. Early textiles decorated with different metallic threads have often been among the most valuable and admired historical objects in museum collections. At the end of the nineteenth century, with the spread of cheaper synthetic threads, the use of metallic threads in weaving, embroidery, and other decorations (tassel, lace, etc.) became widespread, and accordingly, the value of textiles with metallic threads decreased [8].

The main elements in wire and metallic threads used to decorate textile objects are gold, silver [9–11], and copper. Each element can be used alone or together [10–12]. That is, gold-like copper alloys such as gold alloyed with silver, silver coated with gold, copper, or brass coated with silver have been used in the production of metallic threads [10]. The most commonly used material to imitate gold is brass [8]. Since the beginning of the twentieth century, some new materials such as synthetic yarn and aluminum have also been used in making metallic thread [11, 12].

In this study, an examination was made on the palace weavings with metallic thread found in TPM. For this purpose, a total of 7 metal threads palace weavings, the earliest of which is dated to the sixteenth century and the latest to the end of the 19th/beginning of the twentieth century, have served various purposes were selected. By using non-destructive (color measurement and OM) and micro-destructive (HPLC–PDA and SEM–EDX) analytical methods and techniques, material characterization, production technology, and deterioration/corrosion products due to various factors were determined.

Within the scope of the analysis, color measurement was carried out using the CIEL*a*b* spectrophotometer from the colored areas in each textile object. An OM was used for documentation and determination of technical characteristics such as fiber type, weaving technique, yarn twist direction, and warp/weft density. Many studies on historical textiles using OM have been reported [13–17] and in these studies the determination of fiber type, various technical analyses such as the determination of the twist direction of wire, strip, and core fiber, detection of surface wear and corrosion, and defining the color of core fiber in metal threads.

Analytical identification of dyestuffs in order to preserve cultural heritage and convey it to future generations is extremely important in terms of obtaining information about which dyes were used in the past, habits, and social status of textile owners, trade-in artifacts, and dyeing technology. In addition, for conservators, having detailed information about dyes enables them to choose suitable materials and methods for conservation studies [18]. The biggest reason for this is related to the conditions in which textile works can be exhibited in a museum environment. In their study, Padfield and Landi performed a light fastness test on wool samples dyed with natural dyes to understand the reaction of dyestuffs to light, and they reached sufficient information on wool fiber at that time [19]. Knowing these facts helps the curator and conservator to make decisions regarding the safety of exhibition lighting, storage conditions, and preservation processes [20]. In this study, HPLC–PDA was used for the detection of dyestuffs. HPLC is the most preferred method for the detection of dyestuffs and the natural dye sources used. Many studies have been reported in the literature on this subject [14–16, 21–28]. With the technology developed in HPLC, analysis can be performed much faster and in a short time, and the name of this new technology is ultra-high performance liquid chromatography (UHPLC). Li et al. and Serrano et al. are some of the researchers working with UHPLC on dyes in historical textiles [29–31]. Serrano et al. conducted a study on 66 historical samples and 141 dyed wools using the UHPLC method [31]. Another innovation in HPLC is seen in the mass spectrometer working with it. Most researchers [32–41] were able to identify small amounts of dyes that were difficult to identify with HPLC–DAD using HPLC–MS or HPLC-MS^n methods.

Scanning electron microscopy-energy dispersion X-ray spectrometry (SEM–EDX/EDS) is an analytical method frequently used to determine the elemental composition in metallic threads found in textile artifacts [8, 25, 26, 42, 43]. Many studies have been reported in the literature on this subject [13–15, 17, 25, 26, 43–49]. It is described as a non-destructive technique, even though there is no detectable electron beam damage [50].

Ottoman weavings

Turkish fabrics have an important place in world fabric production in terms of material and pattern richness [51]. Ottoman weavings are fabrics with earmark character and style, which started with the Great Seljuks and then became richer with the Anatolian Seljuks [52–54]. The fact that the Ottoman Empire was a bridge between the East and the West not only developed commercial exchanges but also developed the interaction of culture and art [55].

The ornaments, richness, and splendor of weaving are striking in the weaving samples, miniatures, and written documents that have survived to the present day. The weavings used by the sultan, her harem and rulers in all areas are examined under the name of "palace weavings". The materials used in these weavings were mostly silk, gold, silver, and precious stones such as pearls [56].

The woven fabrics (upholstery, curtains, bundles, etc.) that are specially woven for the sultan and the courtiers and meet the needs of the palace, not only as clothes, are called palace fabrics [51, 56]. These fabrics were obtained through orders, gifts, war spoils, and purchases [51]. The sultan wore caftans called "seraser" in big ceremonies attended by the public, but since these caftans were stiff, they preferred kemha (silk brocade), velvet, or plain fabrics on less formal occasions [57].

As a tradition, Ottoman palace clothes and fabrics were kept in bundles until the last period of the Ottoman Empire and managed to reach the present day. Thanks to the labels on each bundle, it is known to which palace member the clothes such as caftan and dress belong [51, 52, 57, 58]. One of these clothes, which belonged to the sultan or a member of the dynasty, was put in her tomb after she died [57].

Red color has been dominant in Turkish fabrics [52, 55, 59]. The second rank is blue [55]. Other frequently used colors are green, white, beige, golden yellow [52, 59] and purple. It is known that the Turks developed and produced many color tones apart from these basic colors. The fact that Anatolia has a wide variety of plants has also facilitated the acquisition of new colors in the art of dyeing [59]. Colors and tones vary according to the periods. Two-colored fabrics were woven before, and it was seen that seven-colored fabrics began to be woven in Bursa in the fifteenth century [52]. Color harmony in Turkish weavings was not achieved by using the same color tones, on the contrary, it was achieved by bringing opposite colors side by side [55].

Although examples of woven fabrics were seen in the fourteenth and fifteenth centuries at the earliest, the sixteenth century is very important for Ottoman weaving, and Turkish cloth-making reached its peak in this century. In this century, Turkish silk fabric weaving became unrivaled and silk fabrics were sold to most countries of the world [60]. Turkish weaving experienced its heyday in the sixteenth century, but the deteriorating economic situation towards the end of this century also affected weaving [55]. There was a pause in the seventeenth century and a decline in the Ottoman fabric industry towards the end of this century [54, 61]. From the tailor's notebooks found in Topkapı Palace, it is understood from the orders that plain and modest fabrics increased gradually in the seventeenth century. In the seventeenth century, there was a decline in the production of fabrics with gold and silver, which caused changes in colors and motifs. The decline seen towards the end of this century continued in the eighteenth century [61]. Sultan Ahmed III (1703–1730) banned the use of silver wire in fabrics in order to reduce the consumption of silver. When the quality of Turkish fabrics began to deteriorate, fabrics from Europe entered the market and the quality of old fabrics was gradually forgotten [52]. The decrease in material quality in the nineteenth century also affected the quality of the fabric produced. Although various fabric factories were established within the borders of the empire in the nineteenth and twentieth centuries, the old quality and splendor were not seen in fabrics [54, 61].

Silk weaving in the Ottomans was carried out in a guild system called "hirfet" and there were people belonging to different duties in this system. The first of these is those who meet the raw material needs, the second is the weavers and the third is the investors who market the product. Apart from this, "hamcılar" who buy raw silk and produce weft and warp yarn, loom manufacturers, "simkeş" who makes gold and silver metallic yarn/wire, and dyers have formed the sub-industry branch that provides materials to weavers [57].

TPM and its textile collection

After Istanbul was conquered in 1453, the construction of Topkapı Palace was started in 1460 at the request of Fatih Sultan Mehmed (Mehmed II), it was completed in 1478 and continued to expand with the structures added to its structure until the nineteenth century. Topkapi Palace, which was built on an area of 700.000 m^2 on the East Roman Acropolis in Sarayburnu, was the residence of the Sultans for about 400 years, as well as the administrative, educational, and artistic center of the Ottoman Empire. Topkapi Palace, which was turned into a museum on April 3, 1924, after the foundation of the Republic of Türkiye, has the distinction of being the first museum of the Republic. In addition, it is one of the largest palace museums in the world with its architecture and unique collections [62].

It is known that the tradition of bundling, which started with Fatih Sultan Mehmed in the Ottoman Empire, continued until the beginning of the twentieth century, and the majority of the textile objects that were saved during this period are now preserved in the TPM. There are approximately 2500 historical textiles in this collection, and most of these objects consist of velvet, silk brocades (Turkish names are *kemha*, and *seraser*) weaving caftans and shalwars. It has been observed that the fabric types of the caftans in the collection have changed over time, but their forms have remained the same [51].

Experimental

Historical textiles

In this study, a total of 7 metal thread palace weavings, dated to the 16th-19th/beginning of the twentieth centuries, which contain the most unique examples of Ottoman palace weavings and are included in the textile collection of TPM, were examined and researched. The visuals of the examined historical textiles are presented in Fig. 1 (except Inv. No. 13/1060), general information about them and the number of samples taken for analysis are shown in Table 1.

Some OM images of the historical objects examined for this study, color measurements, taking samples for dyestuff and elemental analysis, and pictures of the historical textiles are within the scope of the "Project of Restoration and Conservation of the Sultan Clothes in the Topkapi Palace Museum" performed [63, 64]. Colored and metallic thread samples from historical textiles were carefully taken from the damaged areas and the inner parts of the object.

Fig. 1 The historical textiles examined from Ottoman palace weavings belonging to different periods

Table 1 Characteristics of the examined historical textiles

Trial no.	Inv. no.	Period (century)	Historical textile	Who belongs	Fabric type	Materials used in weaving	Colors	Number of sample	The form of the historical textile
1	13/218	16th	Caftan	Murad III (1546–1595)	The main fabric is animal skin, on which there are pieces of silk brocade fabric with metallic threads in different ground colors	Peltry, silk yarn, yellow and white metallic threads	Ground: brown leather Pattern: blue, dark blue, green, brown, red-brown, shell pink, orange Lining (headwear): shell pink	3 (1 metallic thread, 2 fibers)	It is a caftan made of leather fleece with long sleeves, a V-neck, a hood, and two laces in the front. There is a lining fabric on the back of the headwear with the post
2	13/1455	16th	Fabric	–	The main fabric is silk brocade, and the lining fabric is the atlas	Silk yarn, yellow metallic thread	Ground: dark red Pattern: yellow, white, blue Lining: purple	3 (1 metallic thread, 2 fibers)	The fabric is 120 cm long and 65 cm wide. Fabric edges are not smooth
3	13/584	16th	Caftan	Osman III (1699–1757)	The main fabric is silk brocade, and surrounding the inner edge fabric, and lining fabric are atlas	Silk yarn, yellow metallic thread	Ground: dark red Pattern: yellow, blue, cream Surrounding the inner edge fabric: light green Lining: purple	2 (1 metallic thread, 1 fiber)	It has short sleeves, a cut-out front, a round neckline, a waist cutout, and a skirt that widens down from the waistline. There are buttonhole pockets on both sides of the caftan and slits on both sides of the skirt. The front closure features metallic thread laces and cylindrical buttons in a herringbone motif. Its height is 137 cm
4	13/929	Early 17th	Sleeve	Ahmed I (1590–1617)	The main fabric is silk brocade, surrounding the inner edge fabric is silk, and the lining is cotton	Silk yarn, yellow metallic thread, cotton yarn (at lining)	Ground: dark red Pattern: yellow, blue, light green, white Surrounding the inner edge fabric: light green Lining: light orange	3 (fibers)	It has a shape that narrows slightly from the shoulder to the wrist. Length: 43 cm, width: 18 cm, wrist width: 15 cm

Table 1 (continued)

Trial no.	Inv. no.	Period (century)	Historical textile	Who belongs	Fabric type	Materials used in weaving	Colors	Number of sample	The form of the historical textile
5	13/1893	17th	Shalwar	Murad IV (1612–1640)	The main fabric is silk brocade, surrounding the inner edge fabric is silk, and the lining is cotton	silk yarn, yellow and White metallic threads, cotton yarn (at lining)	Ground: orange Pattern: yellow, blue, ivory color Surrounding the inner edge fabric: orange Lining: raw cotton	4 (2 metallic threads, 2 fibers)	The waist section is quite wide and has a form that narrows at the ankle level. There is a rope lacing at the waist and thin bands of silk fabric sewn from the inside on both sides of the ankle
6	13/816	First half of the nineteenth century	Dress	Saliha Sultan (daughter of Murad II) (1811–1843)	The main fabric is silk brocade, the lining is cotton	Silk yarn, yellow metallic thread, yellow metal wire, cotton yarn (at lining)	Ground: cream Pattern: yellow, light green, light blue, pink, purple Lining: raw cotton	6 (1 metallic thread, 1 metal strip, 4 fibers)	It has long sleeves, a round neckline, and a flared skirt that extends down from the waistline. There are pockets, and arm slits, and slits on the sides of the skirt. There are 7 buttons and buttonholes on the sleeve slits. All the edges of the dress are surrounded by embroidery made of yellow wire with flower and leaf patterns. The embroidered edges are also surrounded by lace patterned with metallic thread cords. Its height is 70 cm
7	13/1060	Second half of the nineteenth century or the beginning of the twentieth century	Piece of fabric	–	The main fabric is silk brocade, with no lining	Silk yarn, yellow metallic thread	Ground: blue Pattern: yellow	2 (1 metallic thread, 1 fiber)	–

Chemicals and dyestuff standards

The reference dyestuff standards and chemicals were provided by Turkish Cultural Foundation-Cultural Heritage Preservation and Natural Dyes Laboratory (TCF-DATU) in Istanbul, Turkey. Acetonitrile, trifluoroacetic acid (TFA), methanol, and dimethylformamide (DMF) were purchased from Merck (Germany), also dimethyl sulfoxide (DMSO) was obtained from Sigma Aldrich (the USA). All chemicals employed in this investigation were of analytical grade and were used as received unless stated otherwise. High-purity water was obtained by passing water through a Milli-Q treatment system (Millipore, Bedford, MA, the USA), and the HPLC mobile phase was prepared using Milli-Q water. A standard gradient elution program was used for chromatographic separation by HPLC–DAD [15, 26, 65–68].

The following dyestuff standards were obtained from commercial sources and used as references: ellagic acid from Alpha Aesar (the USA), luteolin from Roth (Germany), and indigotin, indirubin, carminic acid, apigenin, alizarin, and purpurin from Sigma Aldrich (the USA). Flavokermesic acid, xhantopurpurin, and sulphuretin were obtained from the analysis of plant and insect extracts. Details on the retention time and UV–Vis data belonging to these dyestuff standards are shown in Table 2.

Color measurement

Konica Minolta branded CM-2300d model, a CIEL*a*b* spectrophotometer (6500 °K) with Spectra Magic NX software was used for the numerical value of the colors that can be measured in the textile objects examined.

OM

Thanks to OM, images of different magnifications (max. X90) from historical textiles were taken, contributing to the documentation work. In addition, it was determined that the type of weave, weft-warp density, and yarn twist directions. A polarized OM with model SZ2-ILST from Olympus SZ61 was used for this study.

HPLC–PDA

Sample preparation

All colored samples were weighed (0.5–1.2 mg) before HPLC analysis. Later, all samples were hydrolyzed in 400 mL of a solution mixture of 37% HCl:MeOH:H_2O (2:1:1, v/v/v) in conical glass tubes for exactly 8 min in a water bath at 100 °C to extract organic dyestuffs. After rapid cooling under cold running water, the solution was evaporated just to dryness in a water bath at 60–65 °C under a gentle stream of nitrogen. The dry residues were then dissolved in 400 mL of MeOH:H_2O (2:1, v/v). For the green samples, solubilization was also applied by passing 400 mL of DMF or DMSO over the remaining colored residue. Then, the samples were centrifuged at 4000 rpm for 10 min. After centrifugation, the upper clear part was taken into vials. 100 µL of the supernatant from each sample was analyzed in the HPLC [25, 26, 69, 70].

Instrumentation

Chromatographic separations were carried out using an Agilent 1200 series system (Agilent Technologies, Hewlett-Packard, Germany) including G1322A Degasser, G1311A Quat pump, G1329A autosampler, G13166 TCC, and G1315D Diode Array Detector. PDA detection was performed by scanning from 191 to 799 nm with a resolution of 2 nm, and the chromatographic peaks were monitored at 255, 268, 276, 350, 491, 520, 580, and 620 nm. A Nova Pak C18 analytical column (39 × 150 mm, 4 µm, Part No WAT 086344, Waters) was used. An analytical column protected by a guard column

Table 2 The retention times and the UV–Vis spectra (absorbance maxima) at HPLC–PDA of reference dyestuff standards

Trial no.	Reference dyestuffs	Retention time (min)	Absorbance maxima (nm)
1	Alizarin	28.359	249, 279, 331sh, 429
2	Apigenin	25.350	219, 267, 293sh, 337
3	Carminic acid	16.715	233, 275, 310, 351sh, 469sh, 495, 531sh
4	Ellagic acid	16.476	253, 305sh, 368
5	Flavokermesic acid	26.370	219, 285, 343sh, 431
6	İndigotin	28.396	243, 285, 331, 609
7	İndirubin	30.684	241, 289, 362, 541
8	Luteolin	22.442	255, 265, 291sh, 349
9	Purpurin	28.465	229, 255, 295, 481, 513sh
10	Sulphuretin	23.059	257, 269, 395
11	Xhantopurpurin	29.851	243, 281, 337sh, 411

filled with the same material was used. Analytical and guard columns were maintained at 30 °C and the data station was the Agilent Chemstation. Two solvents were utilized for chromatographic separations of the hydrolyzed historical samples. Solvent A: H_2O-0.1% TFA and solvent B: CH_3CN-0.1% TFA.

SEM–EDX

Sample preparation

The analyses were performed by SEM–EDX at energy levels of 5, 10, 20, and 30 keV and under a high vacuum. Since it will be worked under a high vacuum, metallic thread samples were fixed on the sample holder by being attached to a carbon band that did not affect the analysis result. Since the morphology and elemental analyzes of the metal strips in the samples were carried out, no coating process was applied. SEM images were obtained using BSE and SE detectors.

Instrumentation

A SEM with a VEGA3 model of TESCAN brand (TESCAN, Brno, Czech Republic) equipped with a backscattered electron (BSE) detector, secondary electron (SE) detector, and EDX was used for this study. Also, a thermionic emission tungsten heated filament was used as the electron source, and a Bruker brand XFlash 410-M model EDX detector (ESPRIT Compact Esprit 1.9 software) was used for elemental analysis. Thanks to the EDX detector, semi-quantitative results were obtained as atomic and percent by weight. Qualitative microanalysis was carried out using the ZAF method, which allows the simultaneous determination of the concentration of each element in a multi-element material and is based on the correction of the matrix effect. This method provides X-ray intensity correction, absorption correction, and fluorescence correction produced by the composition and depth of electron penetration, and the atomic number effect of each element by secondary fluorescence, respectively.

Results and discussion

Visual assessment for documentation

The first step in the analysis of archaeological and historical objects is a visual and photographic examination. This approach is particularly useful when working with colored objects and samples [3]. In this study, firstly, a naked-eye examination was made both to assist the documentation studies and determine the current status of the historical objects. In addition, some images were obtained with a camera and a three-dimensional scanner. Accordingly, the deteriorations detected in the examined historical textile objects are as follows.

- When the general condition of the object with Inv. No. 13/218 is examined, and it is observed that it is good. It was determined that discoloration of the leather formed the ground of the textile, discoloration of some silk brocade fabric pieces (especially in the silk brocades with blue and dark blue grounds), embrittlement in fiber strength, and fiber abrasions. In addition, it has been determined that there is corrosion and breaks in metallic threads.
- When the general condition of the object with Inv. No. 13/1455 is examined, and it is observed that it is not good. It was determined that there were abrasions on the ground of red-colored silk, and some fibers and metallic threads were lost by breaking off. It has been determined that the integrity of the pattern is deteriorated due to color breakage in the areas with fiber abrasions. It was observed that the ground's dark red color faded and also corrosion occurred on the metallic threads. In general, it is evident that deformation occurs in the historical textile.
- It has been observed that the condition of the historical textile with Inv. No. 13/584 is good. There are no two rows of ornamental front closing threads (When looking at the front of the object, although there are 24 rows of front closing thread on the left side, there are 22 rows of front closing thread on the right). The locations of the missing front closing threads on the right are obvious. One is the top first row, and the other is the 7th from the top (with the missing front closure string in the first row). In addition, it was determined that one of the cylindrical buttons at the end of the front closing threads was missing (at the top), and there were losses in the white metallic threads wrapped around the other existing buttons. It has been observed that the colors on the back of the object are more high-colored than the front, and this is probably due to the exposure of the front face to inappropriate light and lighting during the exhibition. Apart from these, it was detected that fold lines, and corrosion on the metallic threads.
- When the general condition of the object with Inv. No. 13/929 is examined, and it is observed that it is good. Abrasions and thread breaks were observed in the metallic threads in the wide part of the object. It is thought that this is probably related to the use in the period. At the same time, insect holes in the fabric surrounding the light green inner edge and staining due to insect droppings were observed around these holes. In addition, it was determined that the metallic thread was corroded.
- When the general condition of the object with Inv. No. 13/1893 is examined, and it is observed that there are different types of deterioration in the his-

torical textile. According to this, discoloration of the fabric surrounding the ground and inner edge, intense thread breaks and thread losses in the pattern with white metallic thread, breaks in yellow metallic thread, corrosion in all metallic threads, embrittlement in fiber strength, and abrasion in ground yarns, fold line, loss of parts in the orange silk fabric in the waist area, and staining on the cotton lining fabric were observed.

- It has been observed that the condition of the objects with Inv. Nos. 13/816 and 13/1060 is good. Only, corrosion has been detected on metallic threads and metal wires.

Color measurement

The colors in each textile object were measured using a CIEL*a*b* spectrophotometer in the fabric storage where the historical textiles are located. Color measurement is necessary for contributing to possible restoration studies for the textile objects rather than a comparison between periods. In determining the modern fabric and/or yarn colors to be used in restoration works, there is a need for the numerical value of the existing colors in the historical textile. For this, first of all, it becomes a necessity to measure the existing colors in the historical textile and then the dyed modern materials that will be used in restoration works. The ΔE value is used for the difference between the dyed material to be used in the restoration and the existing color in the historical textile. If the ΔE value is below 1, there is an invisible difference, and if it is in the 1–2 range, there is a slight color difference with a very close observation [71]. In this study, the numerical values of the measured colors are shown in Table 3.

Technical analysis by OM

Thanks to the non-destructive analytical examinations carried out on the historical textiles using OM, the technical properties of the textile objects such as the type of weave and the warp-weft density can be determined. For this research, in-situ investigations with OM are necessary for determining whether the quality of the weavings has changed between periods and using which types of weaves. This is important in determining the twist directions of the fabric or yarn to be used as a support fabric in restoration work and the weaving type of the fabric to be used. In addition, it is important to determine the technical features and to use appropriate materials in the restoration work so that the restoration area is not understood by a foreign eye and the restored textile object is seen as a whole.

Table 3 Color values of the examined historical textiles

Inv. no.	Color	Color parameters				
		L*	a*	b*	C	h
13/218	Blue	56.82	− 3.33	4.38	5.50	52.76
	Dark blue	30.33	− 1.57	− 15.21	15.29	84.10
	Green	43.16	− 7.82	8.53	11.57	47.48
	Brown	28.09	4.78	11.04	12.03	66.59
	Red-brown	33.91	12.54	10.79	16.54	40.71
	Shell pink	65.17	7.97	23.73	25.03	71.43
	Orange	61.41	14.53	28.76	32.22	63.19
	Shell pink (header lining)	53.75	14.08	20.38	24.77	55.36
13/1455	Red (ground)	33.77	36.61	9.00	37.70	13.81
	Blue	41.79	− 2.55	0.73	2.65	15.98
	Purple (lining)	27.33	32.46	− 0.78	32.47	1.38
13/584	Red (ground)	36.06	38.35	8.55	39.29	12.57
	Light green (surrounding the inner edge fabric)	51.15	− 1.12	36.95	36.97	88.26
	Purple (lining)	34.63	34.10	6.96	34.80	11.54
13/929	Dark red	37.10	36.05	10.16	37.45	15.74
	Light green (surrounding the inner edge fabric)	46.09	− 11.22	23.06	25.67	64.05
	Light orang (lining)	65.44	12.52	28.79	31.40	66.50
13/1893	Orange (ground)	56.64	29.28	28.12	40.60	43.84
	Orange (surrounding the inner edge fabric)	59.82	33.71	27.53	43.52	39.24
13/1060	Blue (ground)	49.84	− 18.57	− 20.80	27.90	48.24

NOTE: Color measurement could not be performed because the sizes of all colors in Inv. No. 13/816 are smaller than the measurement area of the spectrophotometer

In this study, some images obtained with OM are shown in Fig. 2. In addition, measurements were made with the help of the images obtained with OM, and thus the warp-weft density, which determines the quality of the weaving, could be determined. The results of the fabric type (main fabric and, if any, surrounding in the edge fabric, and lining fabrics) and warp-weft density of the examined textile objects are given in Table 4.

In addition to these images, the images of metallic threads samples taken from the historical textiles were obtained using OM (Fig. 3).

Dyestuff analysis by HPLC–PDA

Dye identification for historical and archaeological textiles is usually based on comparison with known reference materials based on the qualitative and quantitative composition of the main colorant components [3, 41]. The analysis of textile dyes by HPLC determines which chemical class or dyeing group they belong to, by identifying the compounds. In addition, qualitative and quantitative information about compounds detected in a chromatogram help identify the dyestuff source. Absorbance detection has a wide range of uses in the identification of dyes, and these compounds respond well to the UV–Vis region of the electromagnetic radiation spectrum [72].

In this study, a total of 15 colored fiber samples from 7 metallic threads palace weavings belonging to different periods were analyzed by HPLC–PDA. The chromatograms obtained according to the analysis results are shown in Fig. 4, and also the detected spectra are shown in Fig. 5.. Since no spectrum could be determined in the yellow color sample in the historical textile with Inv. No. 13/584, the chromatogram was not shown.

The dye sources used were determined according to the detected dyestuff spectra. A summary of all results is shown in Table 5.

Red, orange, pink, and purple dyes

The dyestuffs used to obtain the red color and shades in dyeing are divided into two groups as plant and animal origin [2]. The main color obtained from insects is red and the dyestuffs it contains are anthraquinone structure. Dyeing performed with natural sources with anthraquinone structure is highly resistant to photo-oxidative reactions (reactions caused by light) [3]. According to Table 5, it was determined that natural dyes of insect origin were used in a total of 4 samples, red (×2), pink, and purple.

Carminic acid dyestuff is the main dyestuff of Mexican cochineal (*Dactylopius coccus* Costa), Armenian cochineal (*Porphyrophora hameli* Brandt), and Polish cochineal (*Porphyrophora polonica* L.) insects [2, 3, 73, 74]. The color of one of these samples analyzed is purple, and the Ottomans generally used insect-based dyes together with indigo for the purple color [15, 25, 26, 75, 76]. Additionally, carminic acid derivative dyestuffs such as dc? and dcIV were detected in some samples (Table 5).

The most widely used plant in dyeing in Anatolia is the madder plant (*Rubia tincrorum* L.) [79]. The dyestuffs (color components) in *Rubia tinctorum* L. are anthraquinones, which are hydrolysis products of the main dye component, rubierythrin acid. The main coloring components from these anthraquinones are alizarin and purpurin. Other anthraquinones are pseudopurpurin, rubiadin, munjistin, xanthopurpurin, and other small-scale anthraquinone structures [80]. In the 1700s, the Ottoman Empire met two-thirds of the world's need for madder. It is known from the records that the income obtained from the sale of madder, which was made only from the Izmir port in 1875, exceeded 500.000 gold. Until the middle of the nineteenth century, the madder plant took third place in the foreign trade of the Ottoman Empire after silk and grain. However, this situation decreased after 1882 with the spread of synthetic dyes [59]. According to Table 5, alizarin, purpurin, and xanthopurpurin were detected in only one sample with orange color (Inv. No. 13/1893). These data are also compatible with the dyestuff analyses previously performed on Ottoman textiles [76]. This result shows that the roots of the madder plant are used to obtain the orange color. However, since the color is orange, either the first or second water of the dye bath was used, or this color tone was obtained by changing the factors such as pH, temperature, plant ratio, mordant, etc. according to the dyeing conditions.

Yellow and green dyes

Organic natural dyes that give yellow color are obtained from plants and constitute the largest dye group. The primary source of yellow dyes are plants that contain coloring agents belonging to the chemical class called flavonoids [2]. According to Table 5, dyestuff in flavonoid structure was detected in 3 samples. Luteolin and apigenin dyestuffs were detected in both green samples taken from fabrics used in different areas (pattern, and surrounding in the inner edge) in the historical textile with Inv No 13/929. The presence of these dyestuffs shows that one of the most commonly used weld (*Reseda luteola* L.) and sawwort (*Serratula tinctoria* L.) plants is used in dyeing [37]. However, it is highly probable that the weld plant, which grows in Anatolia and is known to be used frequently by the Ottomans in yellow and green dyeing, was used [76, 79].

In the analysis of green color in historical textile with Inv. No. 816, only indigotin dyestuff was detected, but yellow dyestuff components could not be determined.

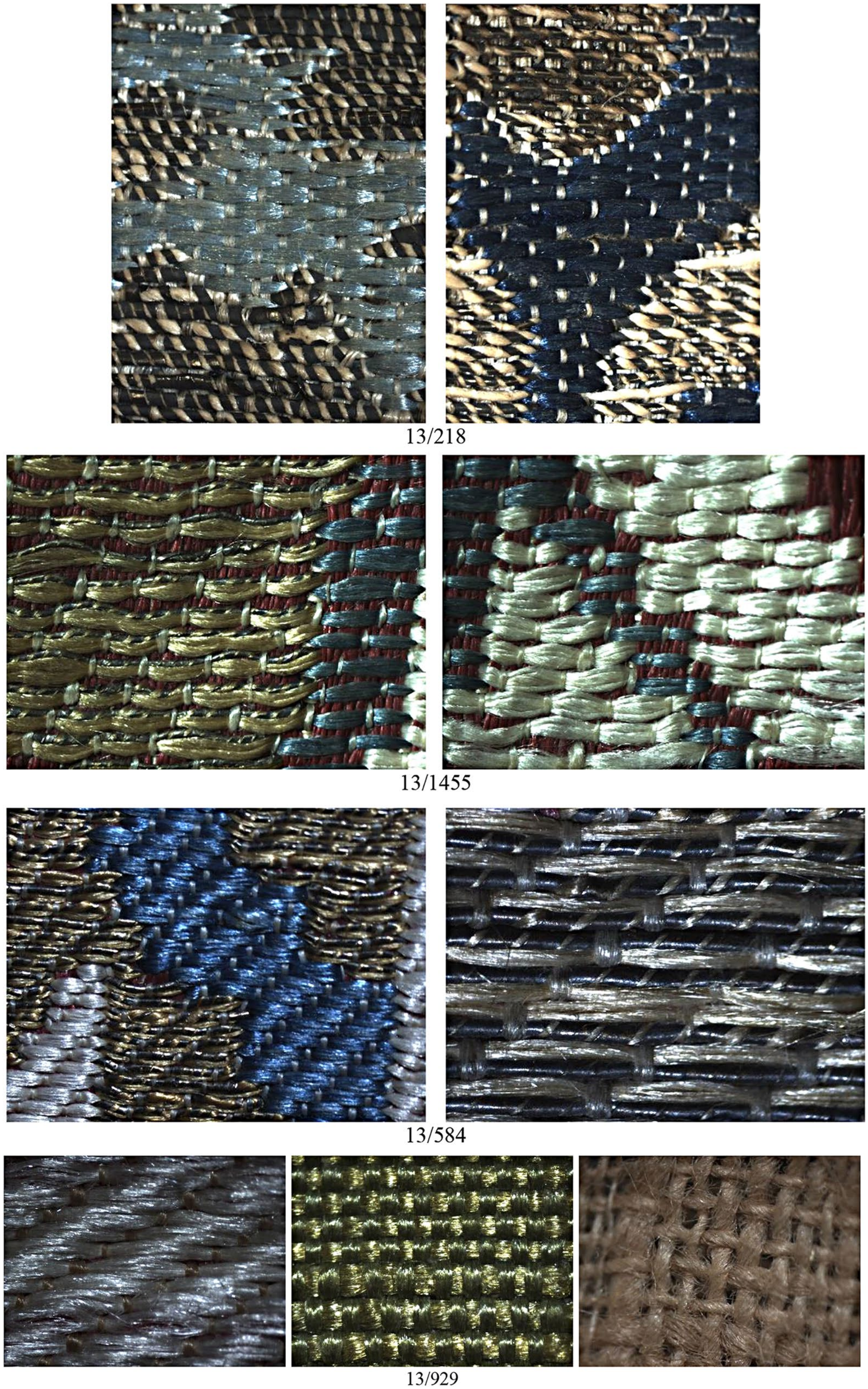


Fig. 2 Some OM images of the textile objects. (all images X10 magnification for Inv. Nos. 13/218, 13/1455, and 13/816; X10 and X30 magnification from left to right for Inv. Nos. 13/584 and 13/1060; X30, X45, and X30 magnification from left to right for Inv. No. 13/929; X30 magnification for all images for Inv. No. 13/1893)

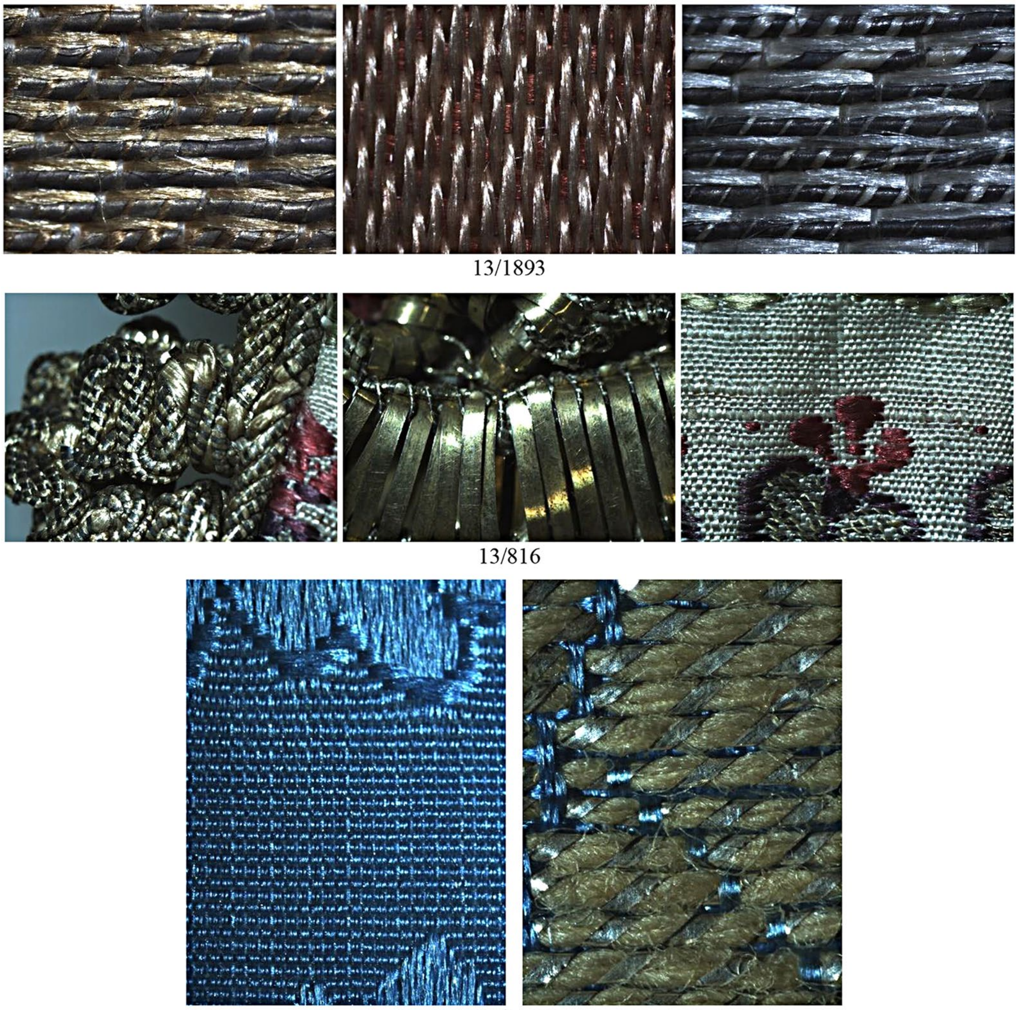


Fig. 2 continued

Also, no color component was detected in the analysis in yellow sample of the historical textile with Inv. No. 584.

When Table 5 is examined, only in one sample (Inv. No. 1893-yellow) determined the sulfuretin. Sulfuretin dyestuff is found in young fustic plant (*Cotinus coggygria* L.). The yellow color obtained from the young fustic has been known since the Roman Empire period and is said to have been used in leather dyeing in ancient times, according to Roman Pilinus (23–79 AD). In the nineteenth century, this plant was frequently used to dye silk fiber yellow in Europe and to obtain yellow yarn in carpets in Anatolia [79]. It has also been reported that this plant was used to dye in yellow some Ottoman silk fabrics [25, 81, 82].

Blue dyes

Blue dyes are divided into two animal and plant dyes depending on the sources obtained. But the most widely used is indigo, which is obtained from plants. The main dye sources of indigo are Indian indigo (*Indigofera tinctoria* L.) and woad (*Isatis tinctoria* L.) plants [83]. Although natural indigo has different dyestuffs, all of them produce indoxyl, and these dyestuffs can be converted into each other. Indoxyl dyes are indican, indigotin, isatin, indirubin, and other minor indigoid dyes (isoindirubin-red color and isoindigo-brown). In the dyestuff analysis of textiles dyed with natural indigo, indigotin, and indirubin dyestuffs are mostly detected, while it is very difficult to determine which plant source it belongs to [2]. In this study, indigotin was detected in a total of 6 samples, blue (×3), green (×2) and purple (Table 5). At the same time, indirubin dyestuff was also detected in the blue sample in the historical textile with Inv. No. 13/218. The blue color component could not be determined in the pattern green sample of historical textile Inv. No. 13/929.

These results show that in addition to the color blue in Ottoman weavings, they used indigo, a color component,

Table 4 Results of technical properties of palace fabrics

Inv. no.	Location of weaving	Weaving type	Warp density (± yarns/cm)	Weft density (± yarns/cm)
13/218	Fabric with brown ground	Silk brocade	–	19
	Fabric with brick-color ground	Silk brocade	–	26
	Fabric with dark blue ground	Silk brocade	–	21
	Fabric with blue ground	Silk brocade	–	23
	Fabric with shell pink ground	Silk brocade	–	25
	Fabric with green ground	Silk brocade	–	26
	Shell pink (heading lining)	Taffeta	70	58
13/1455	Main weaving	Silk brocade	76	16
13/584	Main weaving	Silk brocade	86	27
	Red lining	Taffeta	72	38
	Yellow fabric surrounding the inner edge	Taffeta	68	36
13/929	Main weaving	Silk brocade	92	40
	Light pink lining	Tabby weave	28	20
	Light green fabric surrounding the inner edge	Taffeta	60	36
13/1893	Main weaving	Silk brocade	82	26
	Uncolored lining	Tabby weave	30	25
	Orange fabric surrounding the inner edge	Taffeta	54	46
13/816	Main weaving	Taffeta	60	41
13/1060	Main weaving	Taffeta	30	27

The values of the warp-weft density are ± 1

to obtain green and purple colors. This result is similar to other studies reported on Ottoman textiles [15, 25, 26, 76, 77].

Tannin

Tannins are very common in the plant world and have been used to obtain beige, brown, gray, and black colors in various cultures since prehistoric times [2]. Tannins are polyphenols that are divided into two main categories hydrolyzable (gallotannins) and proanthocyanidins and have many common properties [2, 3]. Throughout history, gallotannes have been frequently used in tanning leather, in black inks in manuscripts, in weighting silk, as a mordant in the dyeing of Turkey red of cotton, and for dyeing textiles made of various fibers [3]. In this study, ellagic acid, one of the tannin group dyestuffs, was detected in a total of 3 samples (Table 5). It is thought that it was used as the main dyestuff in the brown sample of the historical textile with Inv. No. 13/218, and also in red and blue colors of the historical textile with Inv. No. 13/1455, as a secondary dye or for the purpose the weighting of the silk.

Synthetic dyes

In this study, the historical textile with Inv. No. 13/1060 is dated as the second half of the nineteenth century or the beginning of the twentieth century. Synthetic dyestuff (Fig. 5, Table 5), was detected in the analysis of the blue color taken from this object, and it was determined that this synthetic dyestuff is one of the alkali blue 4B dyestuffs [84].

It is seen that all of the natural organic dyestuffs detected as a result of the dyestuff analysis (except the synthetic alkali blue 4B) were also found to comply with the newly established natural organic dye standard (NODS) standards [85].

Elemental and morphological analyses by SEM–EDX

In this study, metallic thread and wire samples were studied in more detail by SEM microscope after preliminary examination with the help of OM. From the images obtained by SEM microscope, the production method of the metal strip (cutting, rolling, etc.), the presence of physical deterioration, the type of the core fiber, and the corrosion products (such as characteristic Ag_2S compound) were determined. In addition, the SEM microscope was used to determine the technical properties of the metal strip. In this study, Technical properties such as the winding width of the metal strip after it is wound on the core yarn, the measurement of the strip width, and the measurement of the thickness of the produced metallic material were determined with the help of an SEM microscope. Some SEM images of a total of 8 samples analyzed for this purpose are shown in Fig. 6.

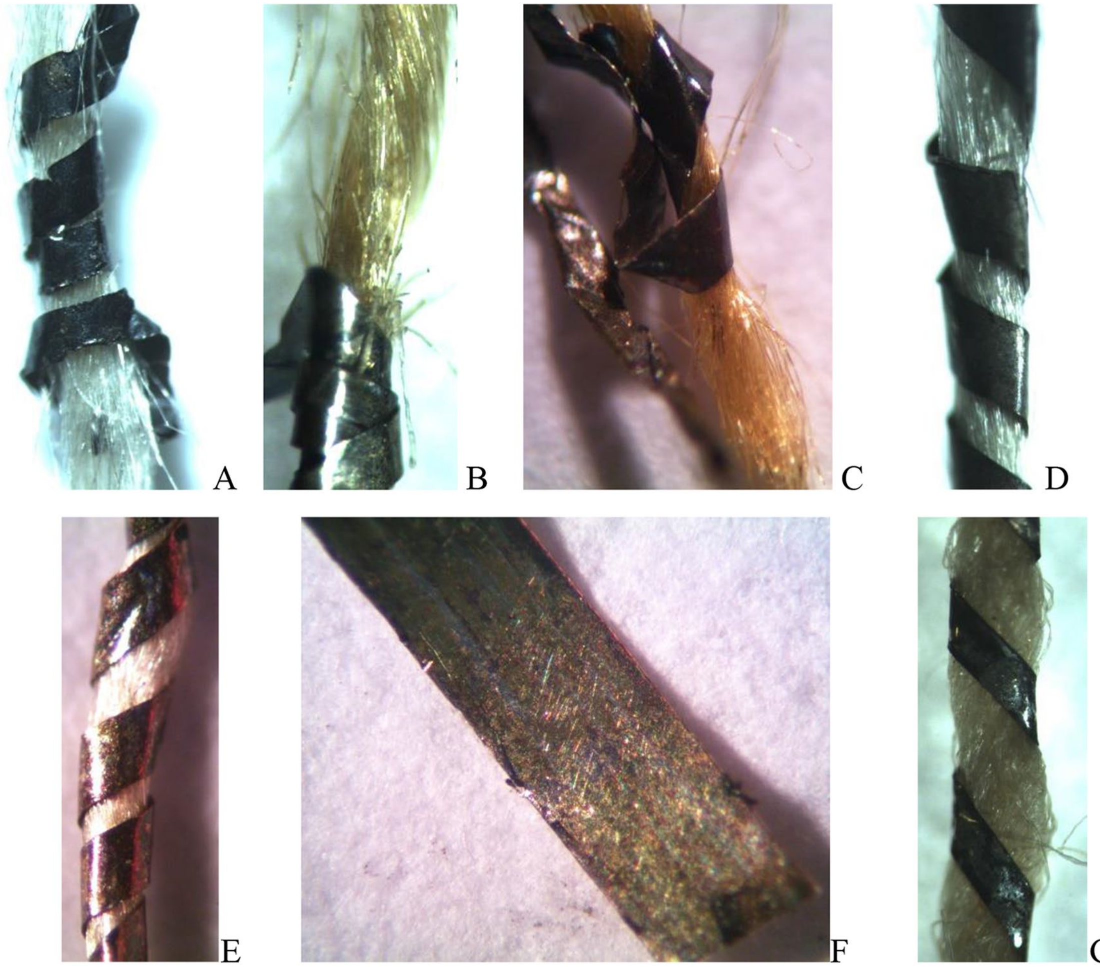


Fig. 3 OM images of metallic thread and wire samples taken from historical textiles. (**A** Inv. No. 13/218, X40; **B** Inv. No. 13/1455, X90; **C** Inv. No. 13/584, X40; **D** Inv. No. 13/1893 from white metallic thread, X50; **E** Inv. No. 13/816 metallic thread, X63; **F** Inv. No. 13/816 metal wire, X50; **G** Inv. No. 13 /1060, X70)

According to Fig. 6, it was determined that the metal strip in the metallic thread samples of the historical textiles with Inv. Nos. 13/218, 13/584, and 13/816 were physically deformed. In addition, it was determined that corrosion occurred on the surface of the metal strip in all samples. When the core fiber type in metallic threads is examined, except for one sample (Inv. No. 13/1060), all of them were silk, and it was determined that the sample in the historical textile with Inv. No. 13/1060 was cotton. In addition, it was determined that the metal strip in the metallic threads and the wire sample were produced by first drawing and then rolling. As proof of this, the edges of all metal strips are rounded, and smooth. The technical specifications determined by the SEM microscope are shown in Table 6. These results are similar to the analysis results previously reported on metal threads in Ottoman textiles [15, 25, 26, 76–78].

In this study, surface EDX analysis was performed to determine the chemical structure of metal strips found in metallic thread and wire samples and to detect corrosion products formed on the surface. In addition, elemental analyses were carried out at different energy levels (5 kV, 10 kV, 20 kV, 30 kV) to determine the chemical production method (gilded, alloy, etc.) of the metal strip. The analysis results obtained are presented in Table 7.

According to Table 7, the main elements in the yellow metallic thread and wire samples are Au and Ag (except Inv. No. 13/1060). The study was carried out with increasing voltage values and the chemical production method of each sample was determined. Accordingly, it was determined that 5 of 6 yellow samples [Inv. Nos. 13/1455, 13/584, 13/1893, 13/816 (×2)] were produced by Au gilded on Ag. In addition, as the voltage value increased, the percentage of the Au element decreased, while the percentage of the Ag element increased. As a

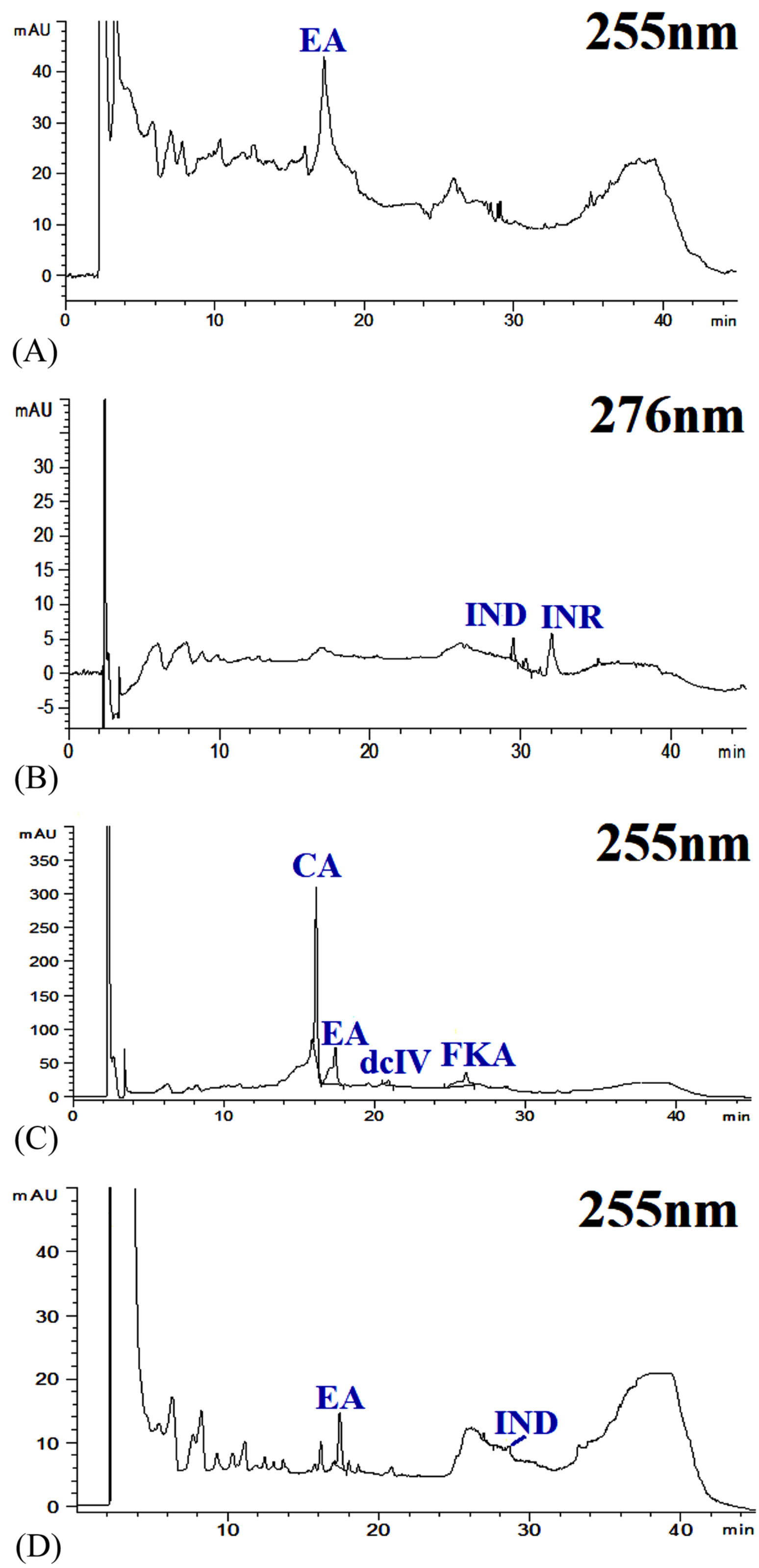


Fig. 4 Chromatograms belong to colored yarn samples. (**A** brown, **B** blue for Inv. No. 13/218; **C** ground red, **D** blue for Inv. No. 13/1455; **E** ground red, **F** light green, **G** light green-inner edge trim for Inv. No. 13/929; **H** ground orange, **I** yellow for Inv. No. 13/1893; **J** light blue, **K** purple, **L** purple with DMF, **M** light green, **N** pink for Inv. No. 816; **O** blue for Inv. No. 1060)

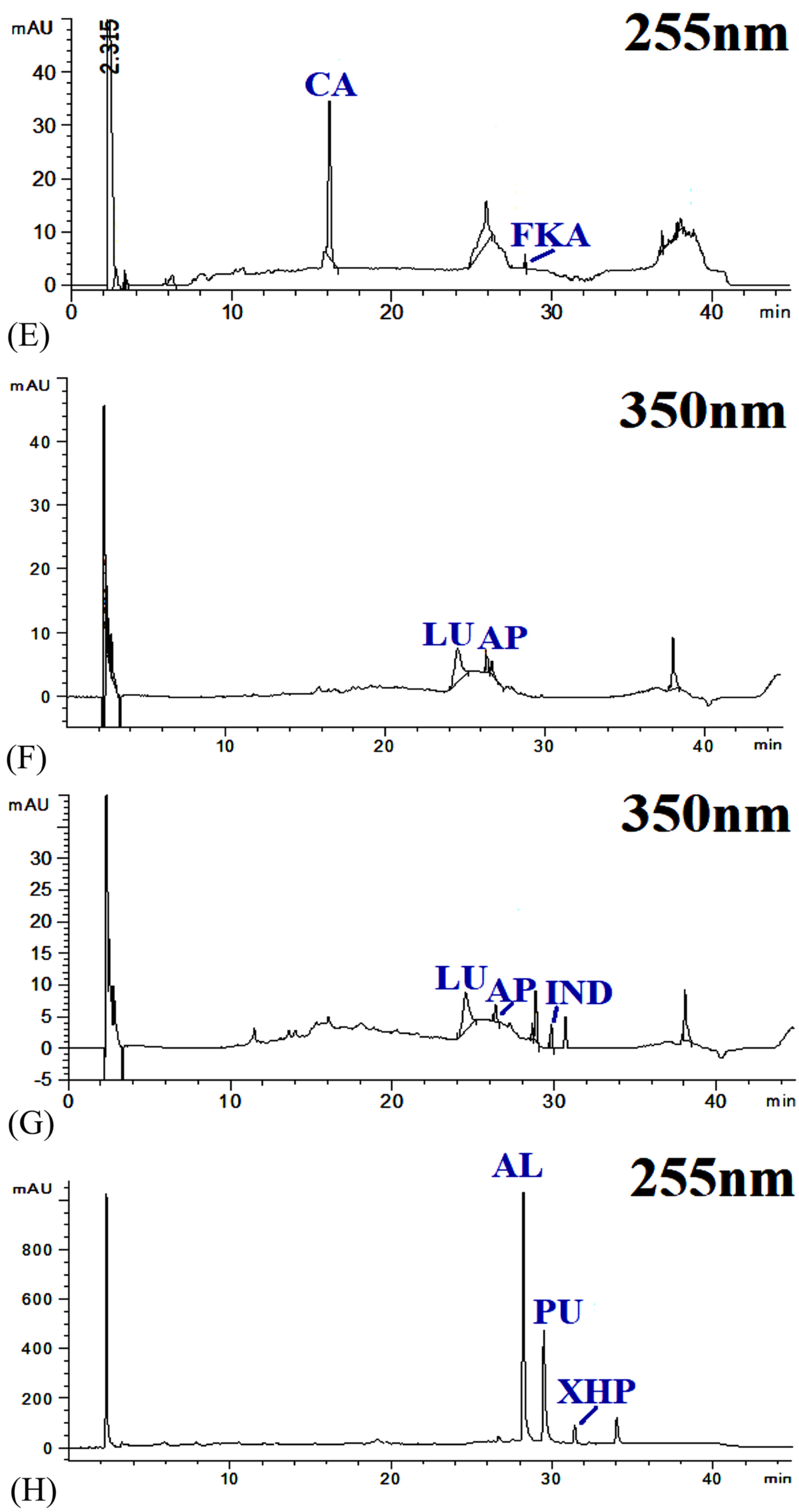


Fig. 4 continued

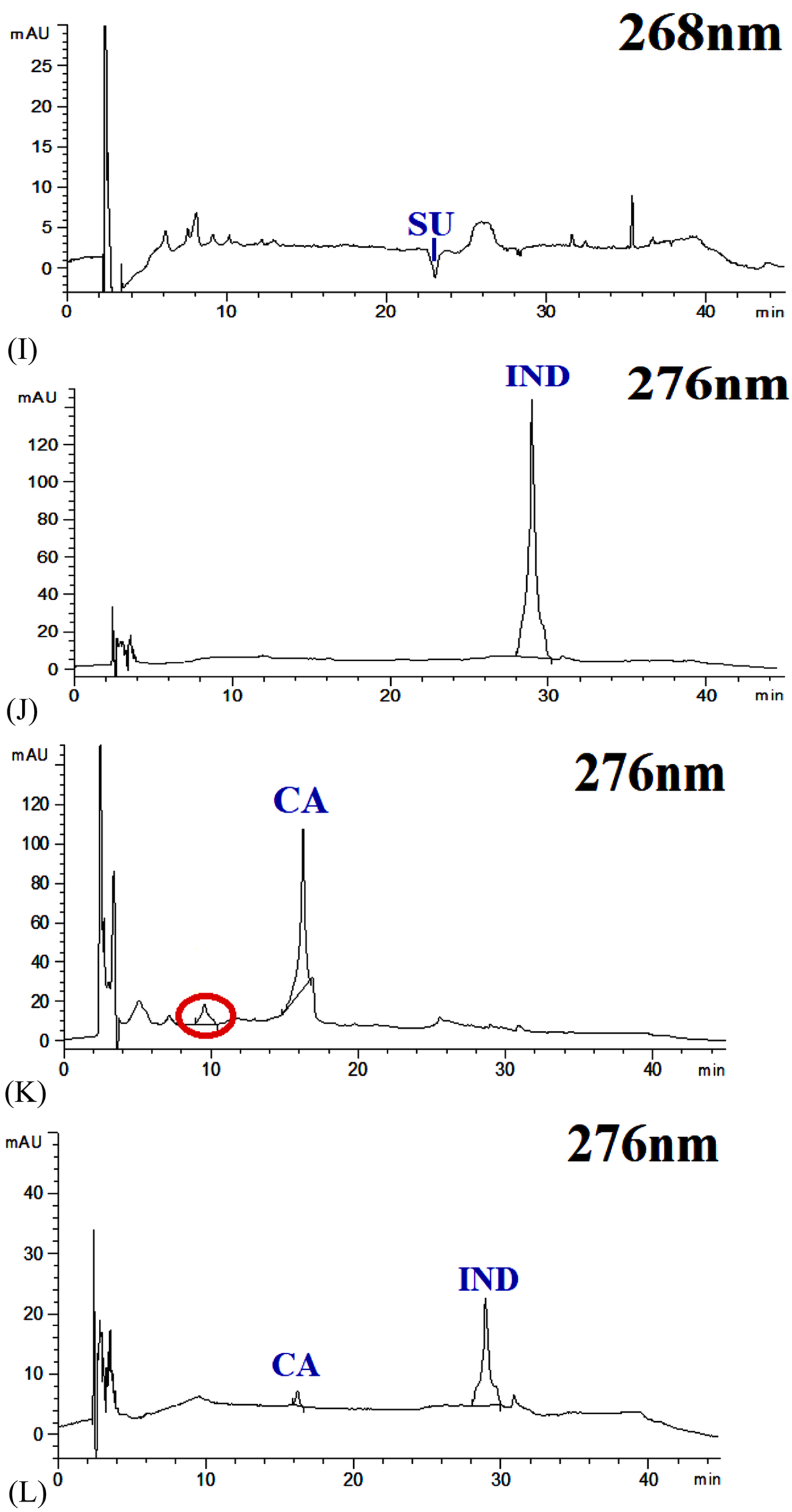


Fig. 4 continued

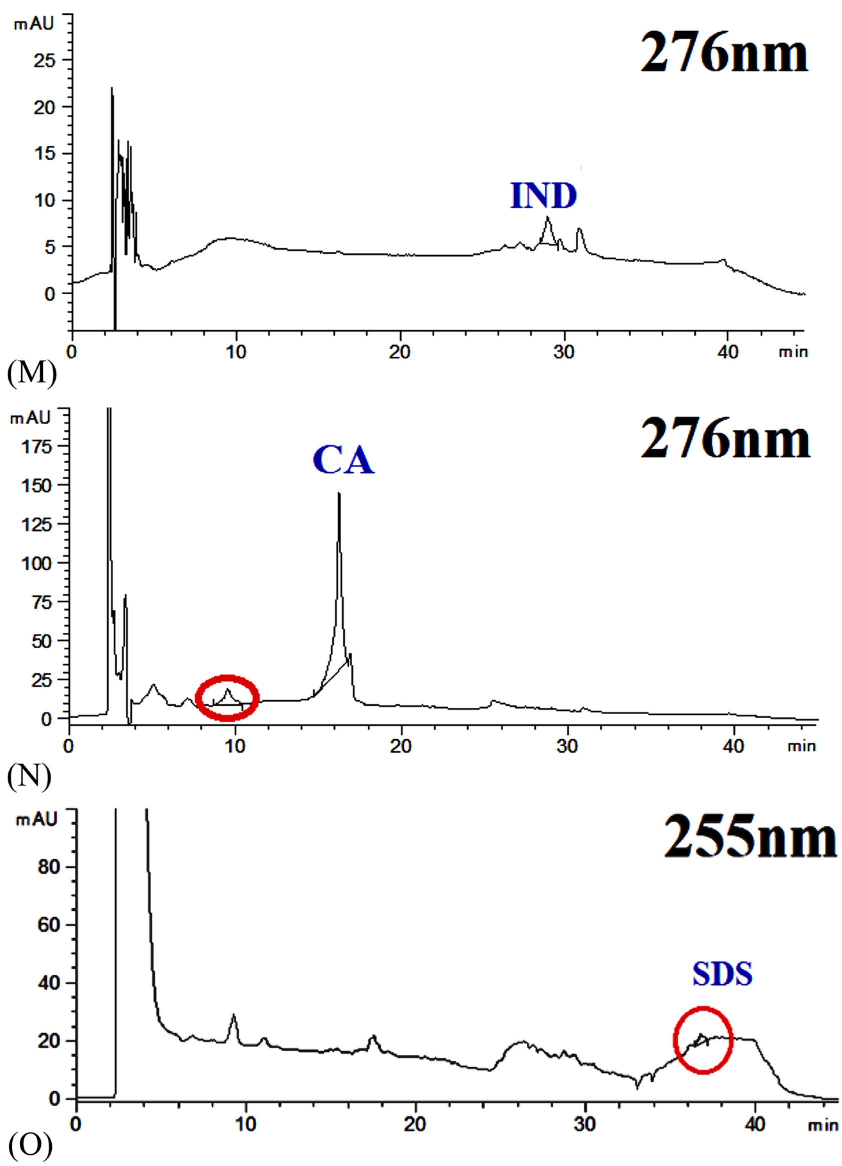


Fig. 4 continued

production method, amalgam was formed with Au element Hg and gilded by heating. However, no trace of Hg element was found in the analysis. Considering that the most recent historical textile was from about 100–120 years ago, it would not be wrong to comment that even the remaining mercury evaporated over time and completely disappeared according to the environmental conditions.

The gilded of silver wires is usually performed in the form of interdiffusion bonding. In this way, gold leaf is coated on the hot sub-layer. The mutual diffusion of gold and silver elements results in a strong metallurgical bond between the two metals. Diffusion bonding is rarely used in copper alloys, as surface oxidation inhibits efficient bonding when copper is heated outdoors [86].

Looking at the results in Table 7, Cu element was detected in all samples. However, except for one sample (Inv. No. 13/816 YS), the copper content in all other samples is very low, so it is highly likely that the copper is an impurity.

Although the color of the core fiber of the metallic thread sample belonging to Inv. No. 13/1060 historical textile was yellow, no Au element was detected in the elemental analysis of the metal strip (Table 7). As it is known, if Au is used in strips or wires in metallic threads,

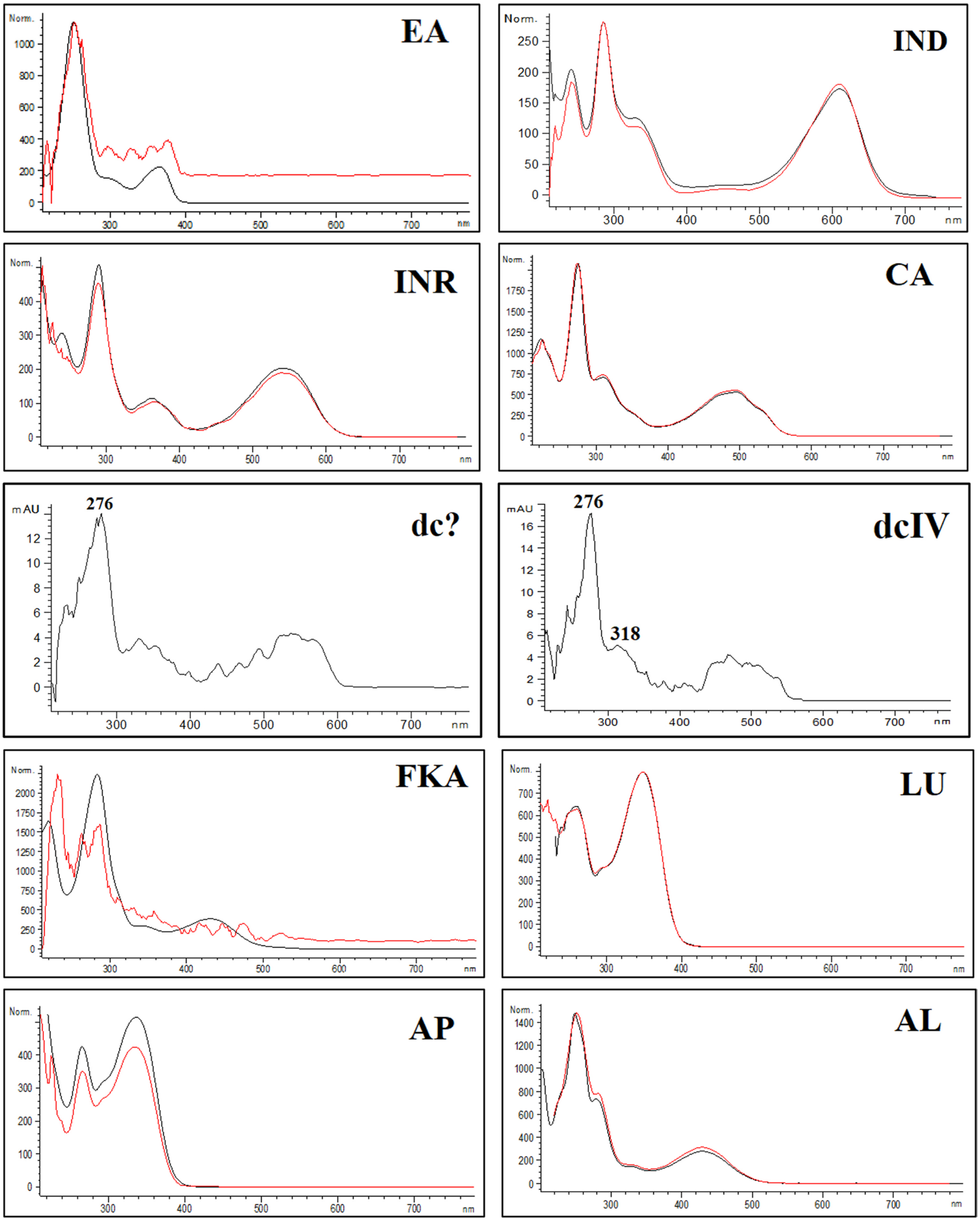


Fig. 5 Dyestuff spectra detected in the samples. (*EA* ellagic acid, *IND* indigotin, *INR* indirubin, *CA* carminic acid, *dcII* dye component II, *dcIV* dye component IV, *FKA* flavokermesic acid, *LU* luteolin, *AP* apigenin, *AL* alizarin, *PU* purpurin, *XHP* xhantopurpurin, *SU* sulphuretin, *SDS* synthetic dyestuff spectrum)

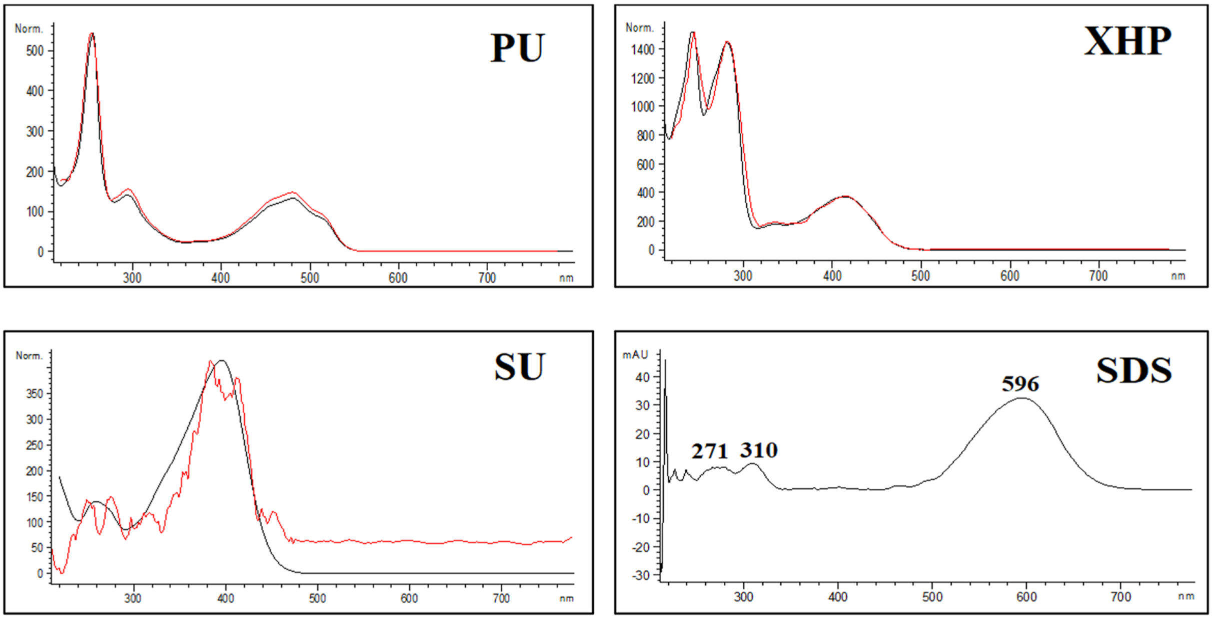


Fig. 5 continued

Table 5 Dyestuff analysis results of the analyzed samples and possible dye sources

Inv. no.	Sample color	Location of color	Identified dyestuffs	Figure no.	Dye source
13/218	Brown	Ground	EA	Figure 4A	Tannin containing plant
	Blue	Ground	IND, INR	Figure 4B	İndigo plant
13/1455	red	Ground	CA, EA, dcIV, FKA	Figure 4C	One of the cochineal insect + tannin containing plant
	Blue	Pattern	EA, IND	Figure 4D	Tannin containing plant + indigo plant
13/584	Yellow	Pattern	–	–	–
13/929	Red	Ground	CA, FKA	Figure 4E	One of the cochineal insect
	Light green	Pattern	LU, AP	Figure 4F	Weld plant
	Light green	The silk fabric surrounding the inner edge	LU, AP, IND	Figure 4G	Weld plant + indigo plant
13/1893	Orange	Ground	AL, PU, XHP	Figure 4H	Madder roots
	Yellow	Pattern	SU	Figure 4I	Young fustic
13/816	Blue	Pattern	IND	Figure 4J	İndigo plant
	Purple	Pattern	CA, dc?, IND	Figure 4K, L	One of the cochineal insect + indigo plant
	Light green	Pattern	IND	Figure 4M	İndigo plant
	Pink	Pattern	CA, dcIV	Figure 4N	One of the cochineal insect
13/1060	Blue	Ground	SDS (synthetic dyestuff/alkali blue 4B)	Figure 4O	Synthetic dye

the color of the core fiber is also dyed yellow in order to make this fiber more prominent. However, this was not the case in this sample. It is understood from this that the perception that Au is used in the metal strip is intended to be given by using yellow core fiber. It is thought that this effect is created because the winding density of the metal strip is also not frequent (Fig. 3G).

They determined the chemical composition of the metal strips as well as the corrosion products formed on the surface. In this study, the elements detected as pollution/corrosion, especially in the results obtained from the 5 kV energy level, are C, O, Mg, Al, Si, S, and Cl. The presence of S and Cl elements shows the formation of Ag_2S and AgCl products typical of the element Ag.

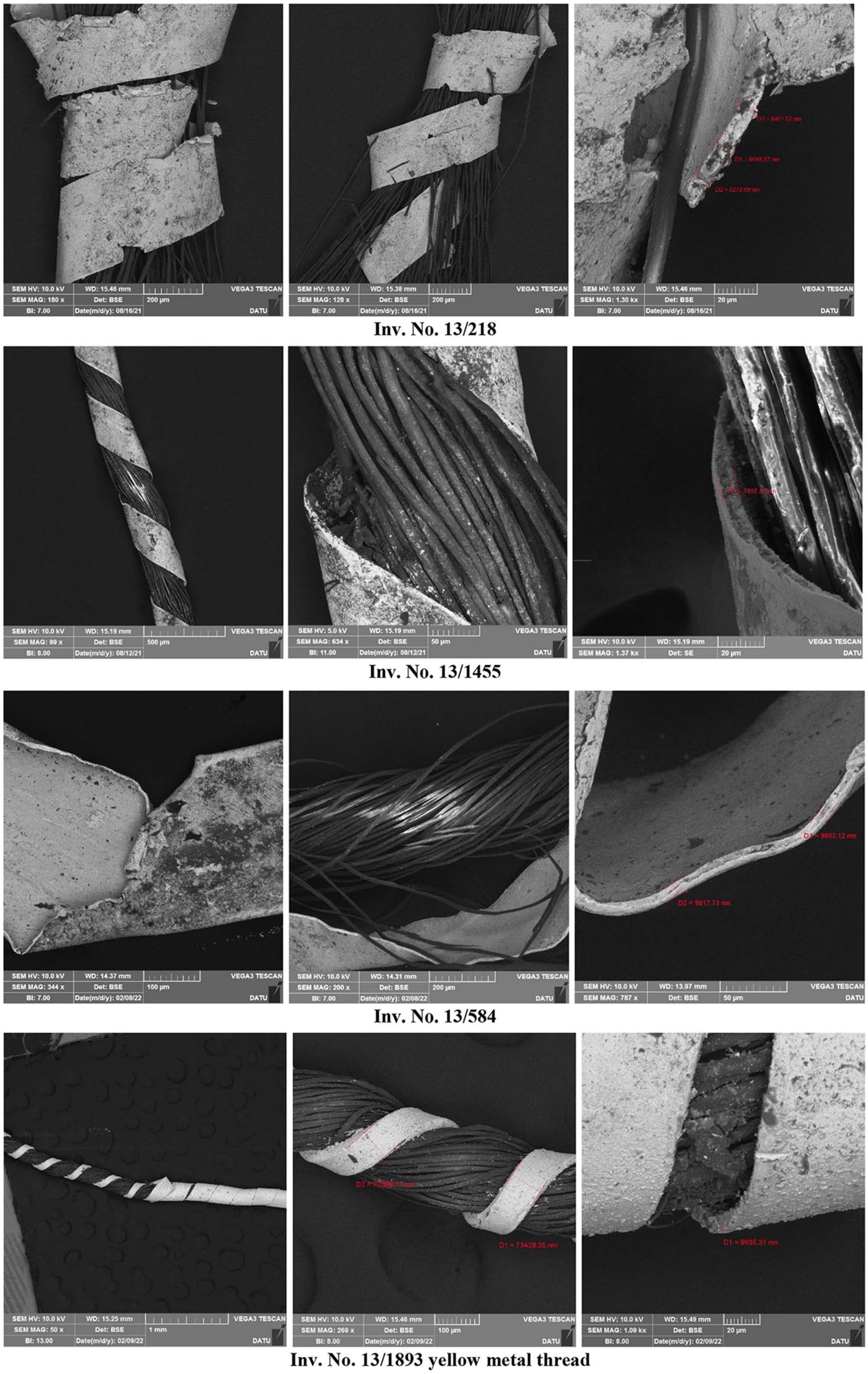
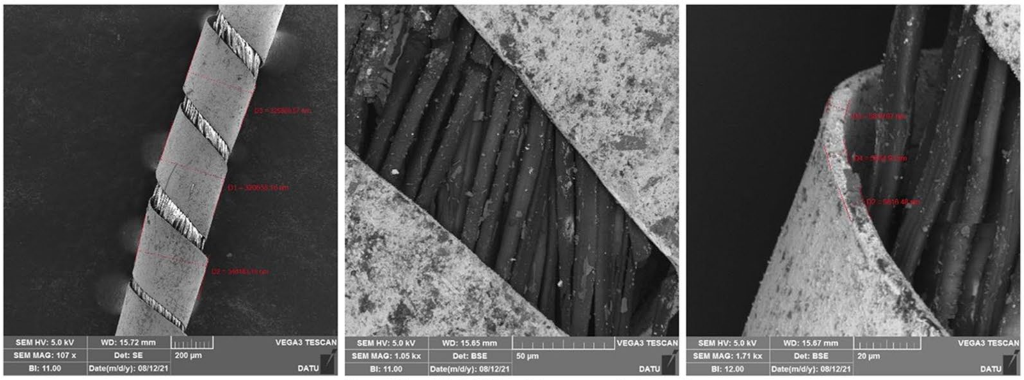
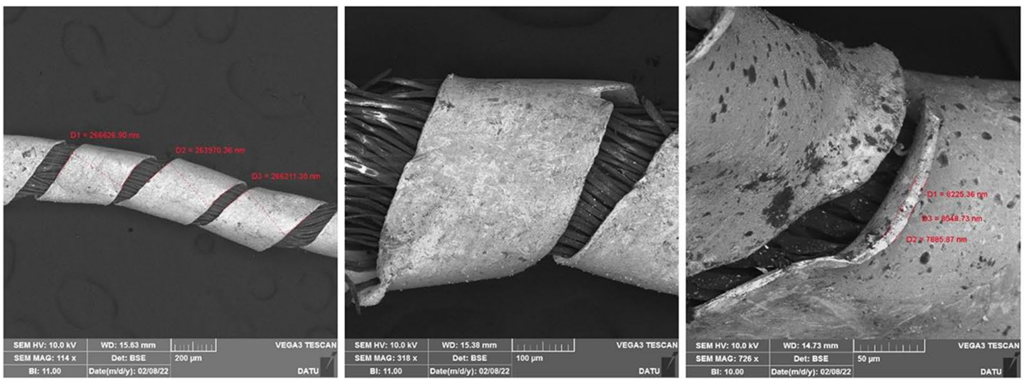


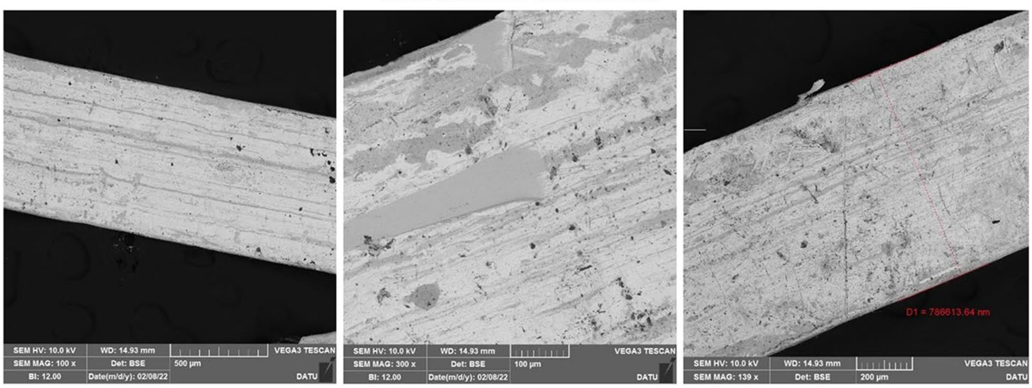
Fig. 6 SEM images of the metallic thread and wire samples



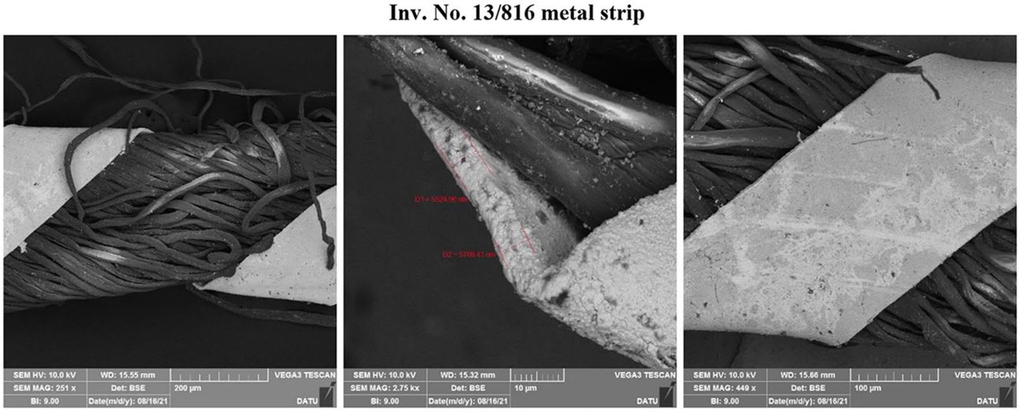
Inv. No. 13/1893 white metal thread



Inv. No. 13/816 metal thread



Inv. No. 13/816 metal strip



Inv. No. 13/1060 metal thread

Fig. 6 continued

Table 6 Technical specifications of the metallic thread and wire samples

Inv. No	Sample[a]	Core fiber type	Core fiber color[d]	Core fiber twist direction	Metal strip twist direction	Production method	Strip width (μm)	Winding width of strip (μm)	Strip thickness (μm)
13/218[b]	WMT	Silk	White	Z	Z	Rolling	250.53	626.51	8.46
13/1455	YMT	Silk	Yellow	S	S	Rolling	260.61	241.16	7.90
13/584	YMT	Silk	Yellow	S	S	Rolling	377.50	519.67	9.81
13/1893	YMT	Silk	Yellow	S	S	Rolling	217.40	223.07	8.67
	WMT	Silk	White	S	S	Rolling	321.22	328.90	5.83
13/816	YMT[c]	Silk	Yellow	S	Z	Rolling	265.60	268.05	8.22
	YS	–	–	–	–	Rolling	786.61	–	–
13/1060	YMT	Cotton	Yellow	Z	S	Rolling	204.46	382.75	5.62

The average was taken by making more than one measurement of each numerical value, and the results were arranged so that the decimal tab was two-digit numbers

[a] *WMT* white metallic thread, *YMT* yellow metallic thread, *YS* yellow strip

[b] This sample is taken from silk brocade fabric with light pink ground (Inv. No. 13/218)

[c] This sample is the metallic thread belonging to the edge embroidery of the historical dress

[d] The colors belonging to core fibers are shown in the OM images in Figs. 2 and 3

When the S and Cl values were examined, it was determined that the percentage ratios decreased as the voltage value increased and one went deeper from the surface (Table 7).

The most common corrosion product of silver is silver sulfide (Ag_2S), also known as argentite or acanthite. This brown-gray mineral is generally passive and this means that it does not readily support further corrosion reactions that can cause metal loss. Therefore, it is considered a protective layer, and usually, the greatest damage it causes is visual [87]. All possible corrosion products (oxides, chlorides, sulfides) are formed on silver surfaces, and the metallic threads found in most historical textiles appear tarnished by oxidation [9]. In this study, the findings obtained from the metal thread and wire samples taken from historical textiles and performed EDX analysis are related to the results of the analysis previously similarly conducted on Ottoman textiles [15, 25, 26, 76–78].

There are many air pollutants that can have adverse effects on historical objects in a closed environment. These pollutants can originate from the indoor or outdoor environment. The pollutants found and produced indoors are carbonyl compounds, alternatively called organic acids. The most common pollutants are acetic acid (CH_3COOH), formic acid (CH_2O_2), and formaldehyde (CH_2O). The pollutants that can have both internal and external sources are carbonyl sulfide (CS) and hydrogen sulfide (H_2S). Substances such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and ozone (O_3) are generally outdoor pollutants [88]. At the same time, since some cultural institutions such as TPM are located in towns or cities close to the sea, salt pollution occurs on the objects when O_3, NO_2, SO_2, H_2S, H_2SO_4 and HNO_3 vapors (typical outdoor pollutants) enter the museum building, which leads to some deterioration (especially corrosion on metals) causes [89]. After these gases are adsorbed on fiber surfaces, they cause chemical reactions that affect fiber properties and cause deterioration [90, 91]. When sulfur and nitrogen compounds combine with moisture and other pollutants in the air, they form H_2SO_4 and HNO_3. That is, they form acid in the presence of moisture, making the textile object acidic and ultimately embrittlement the material. Sometimes they change or fade dye colors [91].

Historical textiles containing metallic threads are adversely affected by indoor environmental pollutants as well as being exposed to inappropriate outdoor pollutants. In particular, attention should be not to keeping textile objects together with wool, felt, and rubber-based materials found in display and storage materials found in any area such as a showcase. Storing and displaying textiles and clothes containing metallic threads in the same area as wool fiber textiles should be avoided [92].

Conclusion

In this study, various analysis was carried out on a total of 7 metallic thread palace weavings, the earliest of which was dated to the end of the sixteenth century, the latest the end of the nineteenth century, or the beginning of the twentieth century. Thanks to the analyses performed, documentation of historical textiles, and material characterization were performed, also deterioration products formed over time were detected.

One of the aims of this study is to determine whether there is a difference between the textile objects produced

Table 7 Elemental analysis results of metal strips

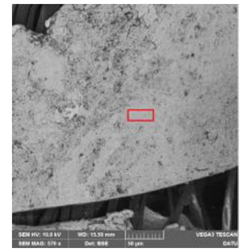
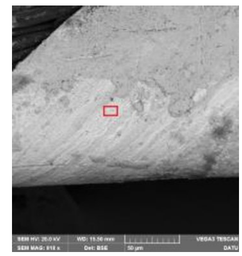
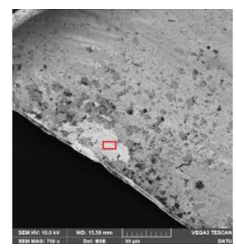
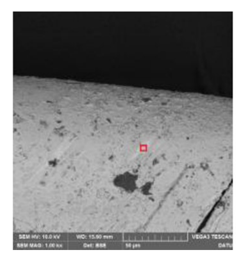
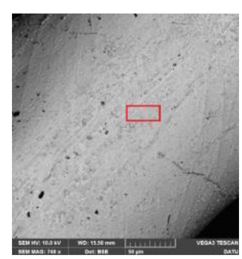
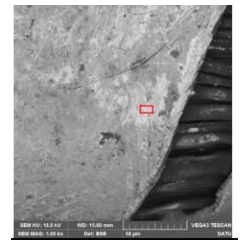
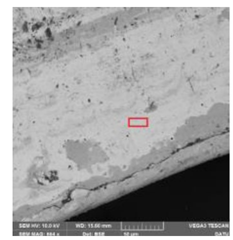
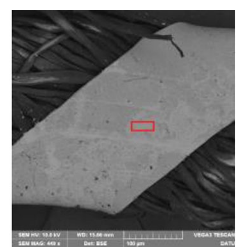
Inv. no.	Sample	Energy levels (kV)	Identified elements and their ratio (%)										SEM images
			C (K)	O (K)	Mg (K)	Al (K)	Si (K)	S (K)	Cl (K)	Cu (K and L)	Ag (L)	Au (L and M)	
13/218	WMT	5	2.78	1.04	–	0.26	0.41	13.36	0.18	0.80	81.18	–	
		10	3.34	2.18	–	0.33	0.31	10.50	0.70	0.81	81.85	–	
		20	2.13	2.14	–	0.26	0.03	5.11	0.53	1.25	88.55	–	
		30	2.93	2.56	–	0.63	0.16	3.51	0.19	1.24	88.78	–	
13/1455	YMT	5	4.60	1.98	–	0.41	–	-	3.53	0.71	47.53	41.24	
		10	4.40	1.65	–	0.08	–	-	3.07	0.24	51.93	38.62	
		20	3.97	2.93	–	0.36	–	-	1.26	0.46	70.74	20.29	
		30	3.45	3.03	–	0.42	–	-	0.32	0.77	79.90	12.11	
13/584	YMT	5	4.80	3.49	0.40	0.57	–	4.06	3.53	0.43	72.80	9.92	
		10	0.77	0.50	0.07	0.25	–	2.11	1.75	0.11	87.17	7.27	
		20	0.56	1.15	–	0.15	–	0.54	0.75	0.33	91.90	4.62	
		30	0.55	1.57	–	0.32	–	0.13	0.14	0.45	93.46	3.38	
13/1893	YMT	5	1.28	0.64		0.21	–	3.96	5.14	0.55	85.37	2.85	
		10	0.74	0.88		0.32	–	1.21	3.18	0.45	91.69	1.53	
		20	0.91	1.22		0.45	–	0.95	2.02	0.38	93.25	0.82	
		30	0.47	1.27		0.54	–	0.33	0.52	0.33	96.02	0.52	
	WMT	5	3.41	1.30	–	0.12	–	9.08	4.21	0.62	81.21	–	
		10	2.66	1.35	–	0.25	–	4.57	5.74	0.44	84.99	–	
		20	2.18	1.78	–	0.27	–	1.67	3.13	0.50	90.48	–	
		30	1.39	1.66	–	0.43	–	1.19	1.89	0.29	93.15	–	

Table 7 (continued)

Inv. no.	Sample	Energy levels (kV)	Identified elements and their ratio (%)										SEM images
			C (K)	O (K)	Mg (K)	Al (K)	Si (K)	S (K)	Cl (K)	Cu (K and L)	Ag (L)	Au (L and M)	
13/816	YMT	5	1.04	0.88	–	0.18	–	–	–	1.36	41.26	55.29	
		10	0.22	1.20	–	0.28	–	–	–	1.78	58.45	38.08	
		20	1.07	1.98	–	0.09	–	–	–	0.66	62.15	34.05	
		30	1.42	3.59	–	1.45	–	–	–	0.43	82.77	10.34	
	YS	5	1.51	0.65	–	0.13	–	–	–	2.87	11.17	83.66	
		10	1.99	0.21	–	0.12	–	–	–	1.12	14.75	81.80	
		20	2.40	2.21	–	0.56	–	–	–	1.52	44.60	48.71	
		30	1.34	3.03	–	0.94	–	–	–	1.72	60.07	32.90	
13/1060	YMT	5	1.82	0.52	0.06	0.06	–	2.32	1.75	1.05	92.42	–	
		10	1.08	0.50	0.03	0.19	–	0.65	0.68	0.86	96.02	–	
		20	0.89	0.71	0.14	0.30	–	0.20	–	0.76	96.99	–	
		30	0.68	0.67	–	0.55	–	0.06	–	0.78	97.26	–	

in different periods. The sixteenth century is a period when the Ottoman Empire was on the rise, and this shows itself in almost every field, as well as in the materials used in textile production. In textile objects, this situation is seen in the quality of weaving and material, the variety of patterns, the choice of dye, the intensity of the use of wire or metallic thread, the winding density of metallic threads, and the chemical content of wire or strips in metallic thread. This study also showed that the magnificence is evident in the textile objects of the sixteenth century when the Ottoman Empire was at its peak. At the same time, it was determined that there was a decrease in the use of materials, quality, and chemical content of materials in fabric production in the second half of the nineteenth century/the beginning of the twentieth century, which was the dissolution period of the Ottoman Empire.

In this study, it was determined that various types of deterioration occurred in most of the palace weavings examined, both with the help of observations and analytical methods and techniques. It is understood from this that these objects examined suffered from deterioration caused by unfavorable surrounding environmental conditions.

Before the conservation work is applied to historical textiles, the entire textile structure and the materials used should be defined with the help of various analysis methods and techniques. After determining the type and source of deterioration in a historical textile, the nature of the necessary preventive conservation methods will also be determined. For this purpose, keeping the environmental conditions at an optimum level, providing suitable environmental conditions, periodically auditing the provided conditions, and taking preventive measures when necessary are the primary principles. All these results show that analytical methods and techniques are necessary to begin the conservation and restoration works on textile objects, which are cultural heritage objects. This starts with observation and documentation and then goes to the type of intervention methods and material selection.

Abbreviations

TPM	Topkapı Palace Museum
OM	Optical microscope
HPLC–PDA	High-performance liquid chromatography-photodiode array detection
SEM–EDX	Scanning electron microscopy-energy dispersive X-ray spectroscopy
BSE	Back-scattered electron
SE	Seconder electron
UHPLC	Ultra-high performance liquid chromatography
HPLC–MS	High-performance liquid chromatography-mass spectrometry
TFA	Trifluoroacetic acid
DMF	Dimethylformamide
DMSO	Dimethyl sulfoxide
UV–Vis	Ultraviolet–visible
Inv. No.	Inventory number
EA	Ellagic acid
IND	Indigotin
INR	Indirubin
CA	Carminic acid
FKA	Flavokermesic acid
dc	Dye component
LU	Luteolin
AP	Apigenin
AL	Alizarin
PU	Purpurin
XHP	Xhantopurpurin
SU	Sulphuretin
SDS	Synthetic dyestuff
WMT	White metallic thread
YMT	Yellow metallic thread
YS	Yellow strip

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Author contributions
ETG: conceptualization, methodology, resources, writing-original draft, visualization, supervision, performed the analyses.

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References

1. Wolf GS. Managing textile collections. In: Henderson KL, Henderson WT, editors. Conserving and preserving materials in nonbook formats (Allerton Park Institute). Urbana: The Board of Trustees of the University of Illinoi; 2001. p. 113–26.
2. Cardon D. Natural dyes: sources, tradition, technology and science. United Kingdom: Archetype publications; 2007. p. 1–607.
3. Degano I, Ribechini E, Modugno F, Colombini MP. Analytical methods for the characterization of organic dyes in artworks and in historical textiles. Appl Spectrosc Rev. 2009;44(5):363–410.
4. Cardon D. Natural dyes, our Global heritage of colours. Textile Society of America. In: 12th Biennial Symposium. Lincoln-Nebraska; 6–9 Oct 2010.
5. Al-Sharairi N, Al-Saad Z, Sandu I. Identification of dyes applied to Ottoman textiles. Int J Conserv Sci. 2017;8(2):251–8.
6. Acıpınar M, Çanlı İ. Osmanlı dönemi Batı Anadolu boyahaneleri: İzmir örneği (Western Anatolian dyehouses in the Ottoman period: The example of Izmir). In: M.S. Teker MS, editor. II. Uluslararası Akdeniz Sanat Sempozyumu (II. International Mediterranean Art Symposium). Antalya-Türkiye. 2017; p. 152–62.
7. Hardin IR, Duffield FJ. Microanalysis of Persian textiles. Iran Stud J Soc Iran Stud. 1992;25(1/2):43–59.
8. Járó M, Toth A. Scientific identification of European metal thread manufacturing techniques of the 17–19th centuries. Endeavour. 1991;15(4):175–84.
9. Indictor N, Ballard M. The effects of aging on textiles that contain metal: ımplications for analyses. In: Járó M, editor. 7th International Restorer Seminar. Veszprem-Hungary. 1989; p. 67–75.
10. Járó M. Cold embroidery and fabrics in Europe: XI–XIV centuries. Gold Bull. 1990;23(2):40–57.
11. Karatzani A, Rehren T. Clothes of gold: metal threads in ByzantineGreek Orthodox ecclesiastical textiles. In: Moreau JF, Auger R, Chabot J, Herzog A, editors. Proceedings of the 36th International Symposiumon Archaeometry. Quebec City-Canada. 2006; p. 444-09-19.
12. Timar-Balazsy A, Eastop D. Chemical principles of textile conservation. London and New York: Routledge; 1998. p. 126–31.
13. Costa V, de Reyer D, Betbeder M. A note on the analysis of metal threads. Stud Conserv. 2012;57(2):112–5.
14. Karapanagiotis I, Mantzouris D, Kamaterou P, et al. Identification of materials in post-Byzantine textiles from Mount Athos. J Archaeol Sci. 2011;38(12):3217–23.
15. Karadag R, Torgan E, Yildiz Y. Analyses of dye, weaving and metal thread in Ottoman silk brocades and their reproduction. Textile Society of America. 13th Biennial Symposium Proceeding. Washington DC. 2012; p. 1–13.
16. Liu J, Guo D, Zhou Y, et al. Identification of ancient textiles from Yingpan, Xinjiang, by multiple analytical techniques. J Archaeol Sci. 2011;38(7):1763–70.
17. Muros V, Wärmländer SKTS, Scott DA, Theile JM. Characterization of 17th-19th century metal threads from the colonial Andes. J Am Inst Conserv. 2007;46(3):229–44.
18. Peets P, Vahura S, Kruve A, et al. Instrumental techniques in the analysis of natural red textile dyes. J Cult Herit. 2020;42:19–27.
19. Padfield T, Landi S. The light fastness of the natural dyes. Stud Conserv. 1966;11(4):181–98.
20. Orna MV. The chemical history of color. USA: SpringerBriefs in Molecular Science; 2013. p. 193–5.
21. Campanella B, Degano I, Grifoni E, et al. Identification of inorganic dyeing mordant in textiles by surface-enhanced laser-induced breakdown spectroscopy. Microchem J. 2018;139:230–5. https://doi.org/10.1016/j.microc.2018.02.034.
22. Chieli A, Sanyova J, Doherty B, et al. Chromatographic and spectroscopic identification and recognition of ammoniacal cochineal dyes and pigments. Spectrochim Acta Part A Mol Biomol Spectrosc. 2016;162:86–92.
23. Clementi C, Nowik W, Romani A, et al. A spectrometric and chromatographic approach to the study of ageing of madder (*Rubia tinctorum* L.) dyestuff on wool. Anal Chim Acta. 2007;596(1):46–54.
24. Wouters J. High performance liquid chromatography of anthraquinones: analysis of plant and ınsect extracts and dyed textiles. Stud Conserv. 1985;30:119–28.
25. Karadag R, Torgan E, Taskopru T, Yildiz Y. Characterization of dyestuffs and metals from selected 16–17th-century Ottoman silk brocades

by RP-HPLC-DAD and FESEM-EDX. J Liquid Chromatogr Relat Tech. 2015;38(5):591–9.
26. Karadag R, Torgan E. Advantages and importance of natural dyes in the restoration of textile cultural heritage. Int J Conserv Sci. 2016;7(Special Issue 1):357–66.
27. Karapanagiotis I, Sotiropoulou S, Vasileiadou S, et al. Shellfish purple and gold threads from a late antique tomb excavated in Thessaloniki. In: Vakirtzi S, Gleba M, editors. Occasional publication for the history of costume and textiles in the Aegean and Eastern Mediterranean. Arachne. 2018; 5:64–77.
28. Nowik W, Desrosiers S, Surowiec I, Trojanowicz M. The analysis of dyestuffs from first- to second-century textile artefacts found in the Martresde-Veyre (France) excavations. Archaeometry. 2005;47(4):835–48.
29. Li Y, Wei S, He Q, Fu M. Multi-analytical techniques used for the identification of the dyeing techniques of several textile of ancient China. Microchem J. 2020;156:104790. https://doi.org/10.1016/j.microc.2020.104790.
30. Serrano A, van Bommel M, Hallett J. Evaluation between ultrahigh pressure liquid chromatography and high-performance liquid chromatography analytical methods for characterizing natural dyestuffs. J Chromatogr A. 2013;1318:102–11. https://doi.org/10.1016/j.chroma.2013.09.062.
31. Serrano A, van den Doel A, van Bommel M, et al. Investigation of crimson-dyed fibres for a new approach on the characterization of cochineal and kermes dyes in historical textiles. Anal Chim Acta. 2015;897:116–27. https://doi.org/10.1016/j.aca.2015.09.046.
32. Calà E, Benzi M, Gosetti F, et al. Towards the ıdentification of the lichen species in historical orchil dyes by HPLC-MS/MS. Microchem J. 2019;150:104140. https://doi.org/10.1016/j.microc.2019.104140.
33. Han J, Wanrooij J, van Bommel M, Quye A. Characterisation of chemical components for ıdentifying historical chinese textile dyes by ultra high performance liquid chromatography—photodiode array—electrospray ıonisation mass spectrometer. J Chromatogr A. 2017;1479:87–96. https://doi.org/10.1016/j.chroma.2016.11.044.
34. Lech K, Jarosz M. Identification of Polish cochineal (*Porphyrophora polonica* L.) in historical textiles by high-performance liquid chromatography coupled with spectrophotometric and tandem mass spectrometric detection. Anal Bioanal Chem. 2016;408:3349–58.
35. Liu J, Mouri C, Laursen R, et al. Characterization of dyes in ancient textiles from Yingpan, Xinjiang. J Archaeol Sci. 2013;40(12):4444–9. https://doi.org/10.1016/j.jas.2013.06.034.
36. Petroviciu I, Albu F, Medvedovici A. LC/MS and LC/MS/MS based protocol for ıdentification of dyes in historic textiles. Microchem J. 2010;95(2):247–54.
37. Petroviciu I, Berghe IV, Cretu I, et al. Identification of natural dyes in historical textiles from Romanian collections by LC-DAD and LC-MS (single stage and tandem MS. J Cult Herit. 2012;13(1):89–97. https://doi.org/10.1016/j.culher.2011.05.004.
38. Petroviciu I, Medvedovici A, Albu F, et al. LC-MS as analytical technique for the ıdentification of natural dyes in historic textiles. Romanian Rep Phys. 2012;64(2):507–15.
39. Petroviciu I, Albu F, Cretu I, et al. Investigation of natural dyes in 15th c. documents seal threads from the Romanian Academy Library, by LC-DAD-MS (triple quadrupole). J C Herit. 2017;28:164–71. https://doi.org/10.1016/j.culher.2017.05.015.
40. Petroviciu I, Teodorescu I, Albu F, et al. Dyes and biological sources in nineteenth to twentieth century ethnographic textiles from Transylvania, Romania. Herit Sci. 2019;7(15):1–15. https://doi.org/10.1186/s40494-019-0255-0.
41. Surowiec I, Szostek B, Trojanowicz M. HPLC-MS of anthraquinoids, flavonoids, and their degradation products in analysis of natural dyes in archeological objects. J Sep Sci. 2007;30(13):2070–9.
42. Nord AG, Tronner K. A note on the analysis of gilded metal embroidery threads. Stud Conserv. 2000;45(4):274–9.
43. Tronner K, Nord AG, Sjöstedt J, Hydman H. Extremely thin gold layers on gilded silver threads. Stud Conserv. 2002;47(2):109–16.
44. Cakır AF, Simsek G, Tezcan H. Characterisation of gold gilt silver wires from five embroidered silk Qaaba curtains dated between the 16th and 19th centuries. Appl Phys A. 2006;83:503–11. https://doi.org/10.1007/s00339-006-3527-y.
45. Hacke AM, Carr CM, Brown A. Characterisation of metal threads in Renaissance tapestries. In: Proceedings of Metal 2004. National Museum of Australia Canberra ACT. 2004; p. 415–26.
46. Kohara N, Sasa Y, Sakurai K, Uda M. A note on the characterization of metal threads in historic textiles handed down by the Ainu people. Stud Conserv. 1998;43(2):109–13.
47. Oraltay RG, Karadag R. Surface investigation of metal threads and solid metals of Ottoman textiles in the Topkapi Palace Museum. Stud Conserv. 2020;65(1):59–64.
48. Rezić I, Ćurković L, Ujević M. Simple methods for characterization of metals in historical textile threads. Talanta. 2010;82(1):237–44.
49. Šimić K, Zamboni I, Fazinić S, et al. Comparative analysis of textile metal threads from liturgical vestments and folk costumes in Croatia. Nucl Instrum Methods Phys Res Sect B. 2018;417:115–20. https://doi.org/10.1016/j.nimb.2017.06.015.
50. Bindell JB. Scanning electron microscopy. In: Brundle CR, Evans CA, Wilson S, Fitzpatrick LE, editors. Encyclopedia of materials characterization: surface, ınterfaces, thin films. Butterworth-Heinemann: The USA Inc.; 1992. p. 70–84.
51. Altay F. Topkapı Sarayı 3: Kaftanlar (Topkapi Palace 3: Caftans). İstanbul: Yapı ve Kredi Bankası Kültür ve Sanat Hizmetlerinden; 1979. p. 3–18.
52. Aslanapa O. Türk sanatı (Turkish art). 8th ed. İstanbul: Remzi Kitabevi; 2007. p. 358–63.
53. İnalcık H. Türkiye tekstil tarihi üzerine araştırmalar (Researches on Turkish textile history). İstanbu: Türkiye İş Bankası Kültür Yayınları; 2008. p. 245–7.
54. Yatman N. Türk kumaşları (Turkish fabrics). Ankara: Maarif Matbaası; 1945. p. 5–31.
55. Tezcan H. Atlaslar atlası: pamuklu, yün ve ipek kumaş koleksiyonu (Atlas of atlas: a collection of cotton, wool and silk fabrics). İstanbul: Yapı Kredi Yayınları; 1993. p. 19–51.
56. Uğurlu A. Osmanlı dokumalarında süs ve ihtişam (Ornament and splendor in Ottoman weavings). Tekstil ve Mühendis. 1992;6(36):326–9.
57. Atasoy N, Denney WB, Mackie LW, Tezcan H. İpek: Osmanlı dokuma sanatı (İpek: the crescent and the rose: imperial Ottoman silks and velvets). İstanbul: TEB İletişim ve Yayıncılık A.Ş.; 2001. p. 21–163.
58. Kuban D. Çağlar boyunca türkiye sanatının anahatları (Outlines of Turkish art through the ages). İstanbul: Yapı Kredi Kültür Sanat Yayıncılık; 2002. p. 193–5.
59. İmer Z. Türklerin dokuma sanatında boyacılık (Dyeing in Turkish weaving art). Erdem İnsan ve Toplum Bilimleri Dergisi. 1999;10(29):331–53.
60. Dalsar F. Türk sanayi ve ticaret tarihinde Bursa'da ipekçilik (Silk making in Bursa in the history of Turkish industry and trade). İstanbul Üniversitesi Yayınlarından No:856. İktisat Fakültesi No:116. Sermet Matbaası. İstanbul. 1960; p. 25–30.
61. Öz T. Türk kumaş ve kadifeleri II: XVII–XIX yüzyıl (Turkish fabrics and velvets II: XVII–XIX century). İstanbul: Milli Eğitim Basımevi; 1951. p. 1–43.
62. Milli Saraylar. Topkapı Sarayı. 2021. https://www.millisaraylar.gov.tr/saraylar/topkapi-sarayi. Accessed 2 Oct 2021.
63. Arça S, Torgan E, Karadağ R, Dağcı K. Topkapı Sarayı padişah elbiselerinin restorasyon ve konservasyonunda tahribatsız-mikro analiz yöntemlerinin uygulanması projesi (The project of application of non-destructive micro-analysis methods in the restoration and conservation of Topkapı Palace sultan's dresses). 20. Müze Çalışmaları ve Kurtarma Kazıları Sempozyumu (20th Museum Studies and Salvage Excavations Symposium). Bodrum. 25–29 Nisan 2011; p. 259–69.
64. Arça S, Torgan E, Dağcı K, Karadağ R. Topkapı Sarayı müzesi padişah elbiseleri bölümü restorasyon ve konservasyon projesi (Restoration and conservation project of the sultan's clothing section of the Topkapı Palace Museum). İstanbul: Topkapı Sarayı Müzesi Yıllık-6; 2013. p. 278–90.
65. Alkan R, Torgan E, Karadag R. The investigation of antifungal activity and durability of natural silk fabrics dyed with madder and gallnut. J Nat Fibers. 2017;14(6):769–80.
66. Deveoglu O, Torgan E, Karadag R. Identification of dyestuffs in the natural pigments produced with Al^{+3}, Fe^{+2} and Sn^{+2} mordant metals from cochineal (*Dactylopius coccus* Costa) and walloon oak (*Quercus ithaburensis* Decaisne) by HPLC-DAD. Asian J Chem. 2010;22(9):7021–30.
67. Deveoglu O, Torgan E, Karadag R. Identification by RP-HPLC-DAD of natural dyestuffs from lake pigments prepared with a mixture of weld and dyer's oak dye plants. J Liquid Chromatogr Relat Tech. 2012;35(3):331–42.
68. Karadag R, Torgan E, Erkan G. Dyeing properties and analysis by Rp-hplc-dad of silk fabrics dyed with madder (*Rubia tinctorum* L.). Textile Sci Eng. 2014. https://doi.org/10.4172/2165-8064.1000154.

69. Torgan-Güzel E, Karadag R. Sustainability of organic cotton fabric dyeing with a natural dye (gallnut) and analysis by multi-technique approach. J Nat Fibers. 2021;18(8):1107–18.
70. Torgan-Güzel E, Karadag R, Alkan R. Durability, antimicrobial activity and HPLC, analysis of dyed silk fabrics using madder and gall oak. J Nat Fibers. 2020;17(11):1654–67.
71. Park J. Instrumental colour formulation: a practical guide. Raleigh: North Carolina State University; 1993.
72. Nowik W. Dyes, liquid chromatography. In: Reedijk J, editor. Reference module in chemistry, molecular sciences and chemical engineering. Amsterdam: Elsevier Academic Press; 2000. p. 2602–18.
73. Cooksey CJ. The red insect dyes: carminic, kermesic and laccaic acids and their derivatives. Biotech Histochem. 2019;94(2):100–7.
74. Wouters J, Verhecken A. The coccid insect dyes: HPLC and computerized diode-array analysis of dyed yarns. Stud Conserv. 1989;34(4):189–200.
75. Karadağ R. Türk halı, kilim ve kumaşlarında kullanılan doğal boyarmaddeler (Natural dyestuffs used in Turkish carpets, rugs and fabrics). Arış Dergisi. 1997;2:38–51.
76. Karadag R, Oraltay RG. Application of a new SEM–EDX technique associated with HPLC/DAD: manufacturing methods of historical textiles. Archaeol Anthropol Sci. 2023. https://doi.org/10.1007/s12520-022-01702-3.
77. Kahraman N, Karadag R. Characterization of sixteenth to nineteenth century Ottoman silk brocades by scanning electron microscopy–energy dispersive X-ray spectroscopy and high-performance liquid chromatography. Anal Lett. 2017;50(10):1553–67. https://doi.org/10.1080/00032719.2016.1236264.
78. Oraltay RG, Karadag R. Multi voltage SEM-EDX analysis of metals in historical textiles. Mater Lett. 2023;340:134169. https://doi.org/10.1016/j.matlet.2023.134169.
79. Karadağ R. Doğal boyamacılık (Natural dyeing) (in Turkish). T.C. Kültür ve Turizm Bakanlığı. Geleneksel El Sanatları ve Mağazalar İşletme Müdürlüğü Yayınları. Ankara. 2007; p. 72–5.
80. Derksen GCH, van Beek TA. *Rubia tinctorum* L. In: AttaUr-Rahman A, editor. Studies in natural products chemistry, vol. 26. Amsterdam: Elsevier; 2002. p. 629–84.
81. Karapanagiotis I, Karadag R. Dyes in post-byzantine and ottoman textiles: a comparative hplc sudy. Mediterr Archaeol Archaeom. 2015;15(1):177–89.
82. Yurdun T, Karadag R, Dölen E, Mubarak MS. Identification of natural yellow, blue, green and black dyes in 15th–17th centuries Ottoman silk and wool textiles by HPLC with diode array detection. Rev Anal Chem. 2011;30:153–64.
83. Zasada-Kłodzińska D, Basiul E, Buszewski B, Szumski M. Analysis of natural dyes from historical objects by high performance liquid chromatography and electromigration techniques. Crit Rev Anal Chem. 2021;51(5):411–44.
84. Tamburini D, Shimada CH, McCarthy B. The molecular characterization of early synthetic dyes in E. Knecht et al's textile sample book "A Manual of Dyeing" (1893) by high performance liquid chromatography—diode array detector—mass spectrometry (HPLC-DAD-MS). Dyes Pigment. 2021;190(28):109286. https://doi.org/10.1016/j.dyepig.2021.109286.
85. Karadag R. Establishing a new ınternational standard for natural dyed textile goods [natural organic dye standard (NODS)]. J Nat Fibers. 2023;20(1):2162187. https://doi.org/10.1080/15440478.2022.2162187.
86. Anheuser K. The practice and characterization of historic fire gilding techniques. JOM J Mineral Metal Mater Soc. 1997;49(11):58–62.
87. Jimenez-Cosme I, Contreras-Vargas J. Gilded silver threads: corrosion and cleaning. In: Fairhurst A, editor. Incompatible partners? the challenges of composite objects. Forum of the ICON Textile Group. The Victoria and Albert Museum. London. 2011; p. 28–37.
88. Lankester P, Thickett D. Delivering damage functions in enclosures. In: Ashley-Smith J, Burmester A, Eibl M, editors. Climate for collections: standards and uncertainties. Munich: Archetype Publications Ltd. İn Association with Doerner Institut; 2013. p. 335–40.
89. Heritage Collections Council (HCC). Guidelines for environmental control in cultural institutions. Australia: Consortium for heritage collections and their environment. Commonwealth Department of Communications. Information Technology and the Arts; 2002. p. 10–3.
90. Canadian Conservation Institute (CCI). Textiles and the environment. CCI Notes 13/1. Ottawa: Canadian Conservation Institute; 2013.
91. Dancause R, Wagner J, Vuori J. Caring for textiles and costumes. Ottawa: Canadian Conservation Institute; 2018.
92. Smith AW. An introduction to textile materials: their structure, properties and deterioration. J Soc Arch. 1999;20(1):25–39.

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