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MULTIBAND IMAGING TECHNIQUES INCORPORATED INTO THE STUDY OF DYED ANCIENT EGYPTIAN TEXTILE FRAGMENTS

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Abstract

The main aim of this research is presenting the application of the Multiband Imaging (MBI) techniques applied to the investigation of three ancient Egyptian dyed textile fragments from different chronological periods, stored in the collection of the Cairo Egyptian Museum. The documentation of these fragments can be a support for the textile conservator thanks to its easy detection of variances compared with analytical spectra. Moreover, presenting how these portable, non-invasive and inexpensive techniques can be used to provide heritage documentation, enhancing the features of the textile, providing qualitative information on the composition of different dyes used and a first recognition of the state of conservation. Preliminary visual investigation and Ultraviolet-Visible (UV-VIS) microscopy examinations were applied to better understand weaving techniques, fibre classification and dyeing methods, followed by the non-invasive multiband imaging techniques. The MBI techniques carried out on textiles are visible reflected (VIS), ultraviolet-induced visible luminescence (UVL), ultraviolet reflected (UVR), ultraviolet reflected false colour (UVRFC), visible induced luminescence (VIL), near-infrared reflected (NIR) and infrared reflected false colour (IRRFC) photography, which gives evidence of the colourants and materials used and their spatial distribution. At this phase, some dyes can already be determined such as madder and indigo/woad.

***Keywords**: Archaeological textiles; Natural dyes; MBI techniques; UV-VIS microscopy; Optical microscopy*

Introduction

Historical and archaeological coloured textiles are considered one of the most significant elements of archaeological findings. They give us important historical proof of civilization and the progress of their archaeological times, in addition to reflecting the development of the ancient societies in their technological and industrial advancements [1, 2]. Art historians and conservators require a thorough understanding of archaeological materials components, particularly inorganic pigments, organic dyes and colouring techniques to choose the appropriate treatment process [3].

Normally, to determine the colouring material in either archaeological or historical textiles, a sample is taken and manipulated to extract the colouring components from the fibres and identify each separately. This invasive method should be followed carefully, even if they provide beneficial information about the components of the colourants.

Dyed historical textiles show high variability of properties, associated with their natural character, thus a comparison among samples is difficult due to the variation in results caused by the nature of specimens rather than conservation or dyeing techniques [1].

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Besides, very often textiles undergo a colour variation, such as light fading, caused by the organic nature of dyes and their interaction with radiations. Colour variations in deteriorated textiles are not easily recognised, even in clear, obvious-coloured textiles, because of the countless colour shades achievable with multiple baths and different mordants. For example, various tones of dark and light brown cannot be recognised as red-brown, yellow-brown or green-brown. It is, therefore valuable to use multiple lights with different spectral emission for highlighting these variations [4].

A non-invasive, portable and inexpensive investigation approach as Multiband Imaging techniques is desirable as an extensive first recognition among multiple samples and a starting point to oriented further spectroscopic investigations. In addition, more often objects analysed in the Cultural Heritage field are unique findings, frequently fragile and with small dimensions, therefore sampling is often discouraged or even prohibited in some cases.

Under the MBI (Multiband Imaging) acronym are gathered a group of photographic techniques using various wavelengths, from ultraviolet to near-infrared, to highlight several material behaviours. The MBI techniques include visible reflected (VIS), near-infrared reflected (NIR), ultraviolet reflected (UVR), ultraviolet-induced visible luminescence (UVL), visible induced luminescence (VIL), visible induced visible luminescence (VIVL) photography.

Infrared reflected false colour (IRRFC) and Ultraviolet reflected false colour (UVFC), with the introduction of digital photography become post-production techniques [5, 6].

To collect the full spectrum, one or two digital cameras may be used, depending on the modification done on the cameras and filters used. Usually, one unmodified camera was used to collect the visible images, to be confident of a correct chromatic balance and to take the advance of the inner filter already designed to cut UV/IR radiation. The same camera can collect UVL, limiting the UV reflected radiation and cutting the small amount of infrared radiation caused by certain UV light sources. In the last decade, the introduction of LED lights solved more of these problems [7]. A modified digital camera without the internal ICF/AA filter could be used to collect all the other wavelengths as ultraviolet reflected, near-infrared reflected and visible induced luminescence. A colour balance checker should be included in every picture to obtain a correct calibration in the post-production process and a reproducible and comparable method [5, 8, 9].

The MBI imaging can provide information for documenting the state of conservation, the distribution of pigments or dyes and to highlight the spatial distribution of restoration materials and deteriorated areas. Multiband methods are also used to identify features not visible to the naked eye, to provide meaningful information relevant for the classification of artefacts and evidence for appropriate conservation protocols [10].

However, the use of MBI cannot be resolute for the complete characterisation of dyes, due to the misinterpretation when dyes are mixed or the discrepancy in the results with the variation of mordants used for the textile dyeing.

Ageing, colour fading, photo-deterioration, atmospheric pollutants, surface dirt and spotting can affect the recognition of dyes; likewise, the use of modern reference sample must be carefully evaluated due to modern processing procedures of both fibres and bath techniques [11].

Nevertheless, the use of images to provide a report is helpfully for the easy spreading of results, more than the analytical spectra that require extensive knowledge in chemistry and physics to understanding them. The MBI techniques can be used both by conservators, to better understand the artefact, likewise used as integrated parts of dissemination to the public through institutional sites, conferences and exhibitions.

Even though the employ of the MBI approach in the study of polychrome artefacts is well known, it has been slightly and often unsystematically applied to the examination of archaeological coloured fabrics. The literature on their application in the investigation of archaeological or historical textiles is sprinkled. Of these, *Coremans* [12] was an early adopter of utilising near-infrared photography (NIR) to investigate and document tapestry treatments.

Haldane et al. [13] effectively employed MBI methods, as near-infrared reflected (NIR) and ultraviolet-induced visible luminescence (UVL) photography to document spots on an ancient Egyptian tunic of a late period from Victoria and Albert Museum collections. The combination of hyperspectral and multiband imaging was used by *Webb et al.* [14] to identify the materials of four archaeological painted Andean textiles from the National Museum of American Indians collection. All these applications of various spectral imaging techniques are important tools that provide a non-destructive option for material characterisation within the context of the entire object [14]. In 2014, *Borrego and Vega* [15] have used the MBI approach especially UVL photography for distinguishing between wool and linen fibres in the textiles dated to the late period from the Monserrat Museum collections. Recently, *Dyer et al.* [16] present the application of Multiband-reflected (MBR) and visible-induced visible luminescence (VIVL) methods, illustrated their capability for mapping blue and red dyes of ancient dyed textiles from Egypt, dated to (c. 250-800 AD). Other scientific achievements have featured in the literature [17] together with the implementation of the methodologies and instrumentation.

Besides the conservation knowledge, all these applications are helpful in museum conservation to minimise the time for preparing comprehensive reports about the artefacts, especially for large collections. Furthermore, preliminary multispectral image examination could guide in planning analytical procedures, orienting them on meaningful areas.

The main goal of this paper is to collect for the first time, with the application of a non-invasive method, as much information as possible by the investigation of three archaeological textile fragments dated to Greek-Roman, Coptic and Islamic periods from the collection of the Cairo Egyptian Museum.

Materials and methods

Three coloured textile fragments from different chronological periods ranging from Greek-Roman to Islamic period (ca. 30 BC –641 AD) were selected. The objects studied are in the collection of the Cairo Egyptian Museum. The registry does not give any information about the exact site of their discovery. The samples are labelled here as A, B and C consequently. The details of the studied samples and the summary of their technical investigation results are presented in Table 1.

Table 1. details of studied samples and the summary of technical investigation results

Sample code No.	Description	Period	Location	Colourants	Wave structure	Fibre type	Twist direction S/Z
A	Fragment of a tunic	Greek-Roman	Egyptian Museum	Blue, red, yellow	Tabby 1/1 tapestry	Linen wool	Z
B	Fragment of a wall hanging loose	Coptic	Egyptian Museum	Reddish-purple	Tabby 1/1 tapestry	Cellulosic wool	Z
C	Fragment of a carpet	Islamic	Egyptian Museum	Black, green	Not recognised	Cellulosic wool	Z

A preliminary visual examination and UV-VIS microscopy investigation of the textile fragments were conducted to study weaving techniques, fibre classification and production process and to identify the composed materials and manufacturing techniques used in their production. Afterwards, non-invasive MBI techniques were carried out to provide information about the dyes, their spatial distribution and conservation status of the textile objects under study.

In this paper, a single light source was used for all the wavelengths along with the different combination of filters, in order to obtain all the diagnostic images.

Visible reflected (VIS), near-infrared reflected (NIR), ultraviolet-induced visible luminescence (UVL) photography and infrared reflected false colour (IRRFC) were acquired. Images of the three fragments were acquired also in UVR but the low-intensity signal obtained from the camera sensor combined with the low fluency of filtered flashes, with considerable noise, cannot allow good quality images [18, 19]. The problem of low SNR in the images acquired with flashes is most prominent in the camera used for the acquisitions due to its CFA array characteristics [8].

Also, VIL images were acquired for every sample but results do not show any appreciable luminescence.

Therefore, VIL, UVR and consequently the UVRFC will not be discussed in this paper.

UV-VIS microscopy observation is helpful to distinguish between threads dyed only with one colour or mixed colours; threads consisted of various colours which are dyed either separately and then twisted, for getting a mixture of colours or double-dyed since the same threads were dyed with consecutive baths of dye [20]. The textile samples were set on a glass slide and investigated by NIKON ECLIPSE E600 with a high-pressure mercury lamp as an ultraviolet source (UV - 2A - EX330 – 380 - DM400- BA 420) and fibres Optic Visible source (Shott KL 1500).

The cameras used for capturing the images are NIKON DS- FI1C, NIKON DS-U3 Digital Sight. Nikon ACT-V2.6 software was used to visualise and save images.

The images for MBI were acquired using a digital camera Canon 7D (18 Megapixel, APS-C sensor 22.3x15.0mm) for UVL and VIS photography, and a modified digital camera Canon 400D (10.1 Megapixel, APS-C sensor 22.3x15.0mm), without the internal ICF/AA filter, for NIR photography. On both cameras a Canon EFS 18-135mm, F/3.5-5.6 IS lens was mounted.

To provide a combination of different wavelengths for every technique, three Schneider optics B+W filters were utilized: 486 UV/IR cutter, B+W UV Black 403 and B+W 093 IR infrared. As a source of radiation were used two flashes Quantum T5D-R, with the support of two QF80 Qflash UV/IR Wave Reflectors that provide a filter holder.

For imaging calibration, a Spectralon® Diffuse Reflectance target (Labsphere) and a Colorchecker (X-Rite ColorChecker Passport Photo) were placed in every image.

The combinations of filters used both on the camera lens and flashes to obtaining images are summarised in Table 2.

Table 2. combinations of camera and filters to achieve the images for every MBI technique

Technique	Camera	Filter on flashes	Filter on camera
UVR	CANON EOS 400D	B+W 403 UV black	B+W 403 UV black
UVL	CANON EOS 7D	B+W 403 UV black	B+W 468 UV/IR cut
VIS	CANON EOS 7D	B+W 468 UV/IR cut	B+W 468 UV/IR cut
VIL	CANON EOS 400D	B+W 468 UV/IR cut	B+W 093 IR
NIR	CANON EOS 400D	B+W 093 IR	B+W 093 IR

All images were acquired in *.RAW format, which contains low processed data to preserve entirely the information recorded by the image sensor and to allow a better elaboration through the graphics editor program. In this case, the commercial program, Adobe Photoshop, was used. After the elaboration, files were converted into TIF (tagged image file) format, with 3888x2592 pixel resolution at 16-bit. The images were acquired in Neutral mode to turn off all the enhancements provided by the camera’s software.

The IRRFC was elaborated combining visible reflected and near-infrared reflected images with a post-production method.

Results and discussion

Textile fragment A

Visual and UV-VIS microscopy

This textile is a fragment of a tunic from the Greek-Roman period. Observation of the fibres visually and by using UV-VIS microscopy (Fig. 1), clear that the textile fragment is made of linen warp fibres with tabby weave 1/1, Z-twisted threads. The basic decorative motifs as a leaf of plant figure were weaved by tapestry using coloured wool threads with red, green, pale yellow and dark blue dyes, in Z thread torsion [21-23].

Depending on many previous studies, most of the Egyptian made spun threads were twisted from right to left ('S' thread torsion) [24], suggesting that this fragment was not spun and made in Egypt. Moreover, UV-VIS investigation of the coloured fibres (Fig. 1) showed that the blue coloured fibres are more intensive and highly shining, probably indicating that the threads might be dyed with several dye baths or perhaps variation in pH. However, since the dyed yellow fibres of the leaf figure show slightly dyed or paled, the green area threads were possibly double-dyed.

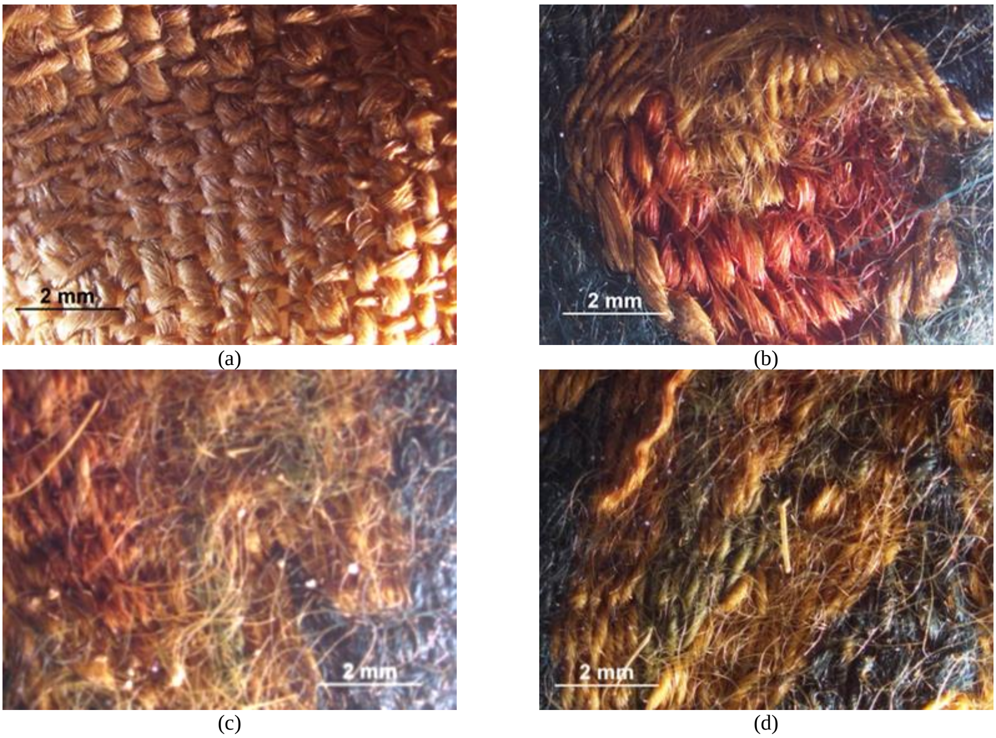


Fig. 1. Microscope images of the textile fragment A, (a) Show weave structure of the warp ground with tabby weave 1/1. (b, c, d) Illustrate that the decoration technique of the dyed leaf figure is tapestry weave

Multi-band Imaging (MBI)

The visible image shows the leaf motifs of fragment A (Fig. 2). It consists of dyed threads with blue, red, green and light-yellow colours, as well as the yellowish-brown colour of the ground warp fibres. An undertone area is visible in the lower-left corner of the fragment.

Some differences in luminescence behaviour, arising from various dyes, materials and different conservation occurrences. Thanks to the different behaviour between proteinaceous and cellulosic materials, in sample A, areas with flax and areas weaving with wool are easily distinguishable (Fig. 2).

Fig. 2. Results of MBI. Visible reflected (VIS), Ultraviolet induced visible luminescence (UVL), near-infrared reflected (NIR) and Infrared reflected false-colour (IRFC) images of textile fragment A (Tunic fragment from Greek-Roman period, Cairo Egyptian Museum)

Pale yellow luminescence usually arises from cellulosic materials but in this case, the area with flax shows a deep yellow luminescence, maybe related to the degradation process of the fibres, their manufacturing, or an absorbing additional material [25].

In addition, a yellow shadow is observed in the lower-left area of the fragment. Comparing the UVL image with the visible one, the area reflects the undertone part that could be the result of absorbing organic material into the fibres (Fig. 3).

The red threads at the top of the leaf figure appear red in the visible image and show a lightly, but visible, pink luminescence, that confirms the presence of madder as colourant [16]. In contrast, the red threads in the inner area of the leaf motifs clearly do not show any pink luminescence, even if both areas are optically similar in the visible image. A weak luminescence appears on the right side of these red threads, within a small area, and only if observed very closely. Luminescence comparison between these areas and the rest of the samples show similarities with the two threads surrounding the red blossom and the area with flax (Fig. 3). This behaviour could be related to a different pigment used for these threads or a material absorbed into the fibres that covered the light luminescence of a possible madder dye. Unfortunately, at this stage of the investigation, no further speculation can be done.

Fig. 3. UVL and VIS details of fragment A

Dyes used on fibres composing fragment A are mostly transparent to infrared wavelength (Fig. 2). Nevertheless, this characteristic help to highlight the textural details of the sample.

The IRRFC image provides the spatial distribution of areas containing natural indigo dye or woad, alone or in different mixtures. Areas observed in the IRRFC image that appears red, match perfectly the parts of blue thread in the visible image, suggesting that they are mainly coloured with indigo based dye [26].

Additionally, the areas that appear green in the visible image seem pale pink in the IRRFC image, which may suggest a mixture of indigo and yellow dye, such as the yellow weld [27], for yielding a green [28]. The red threads on the blossom appear bright orange/golden yellow in the IRRFC image, which confirms the presence of the madder [16]. A similar appearance, even if slightly darker, is shown by the two inner red parts on the leaves. As already discussed for the UVL, the result obtained might be related to the use of a different dye or different treatments. The flax area on the right shows red and cyan shadows due to the imperfect flat surface, which altered the result obtained.

Nonetheless, a red hue predominance is visible compared with the area on the leaves.

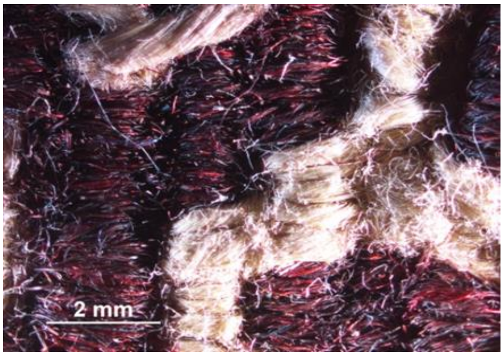
Textile fragment B

Visual and UV-VIS microscopy

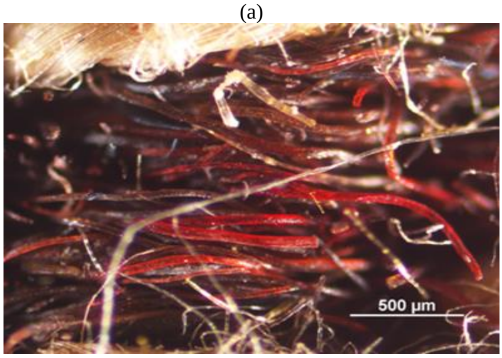
It is a fragment of a wall hanging textile from the Coptic period. As previously, the investigation of the fibres using visual and UV-VIS microscopy showed that the textile fragment consists of many types of weaving structures. The main base of the fabric was weaved with the uncoloured warp, cellulosic fibres with tabby weave 1/1, and Z-twisted threads. Then comes, the floral/geometric motifs were applied artistically in undyed and reddish-purple fibres (Fig. 4a), Z-twisted threads. The fabric piece was woven according to the method of tapestry, "Kabaty", which is one of the main decoration methods of the Coptic textile. The tapestry weave based on the weft threads used that do not extend via the loom [29]. The Coptic artist modified artefacts considerably in the early time, that influenced Coptic textiles, principally tapestries. This might be due to religious and artistic philosophy or because of the artistic features of that time [30].

It is worth observing by UV-VIS microscopy that the dyeing technique of the reddish-purple fibres could be a double dyeing of red and blue woad or other Indigofera species, which results in purple colour (Fig. 4b and c). According to [31], the purple colour obtained from mollusc species has often been examined by scholars. Being a scarce and priceless colour, it has a specific attraction, which can also be observed from specific insect dyes.

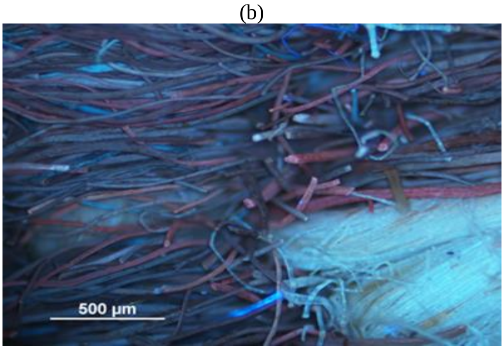
However, the bulk of analysed textiles, show the use of plant dyestuffs, commonly a mixture of red with blue dyes. This dyeing technique was used not only in the double-dyeing of the fibres but also in spinning blue and red dyed fibres to obtain purple. In practical terms, to control the darkness and ambiguity of the colour, it is simpler in the first step to dye red and blue in the second.



(a)



(b)



(c)

Fig. 4. UV-VIS microscope images of the textile fragment B: (a) Show a weave structure is tapestry weave, (b, c) Illustrate that the dyeing technique of the purple fibres is double dyeing with red and blue

Multiband Imaging (MBI)

It is observed from (Fig. 5) that the decoration of fragment B consists of dark red or reddish-purple weft threads, as well as the original beige of undyed base fibres.

The dark red/reddish-purple threads of the decorations mainly absorb UV radiation. High magnification shows few threads with a weak pink luminescence, already highlighted by the observation of the optical microscope image (Figs. 4c and 6).

In the UVL image are visible also some modern fibres with high blue luminescence trapped on the surface (Fig. 6). The undyed parts have a greenish/pale yellow luminescence that can be assigned to cellulosic-based fibres (Fig. 6). Here, undyed fibres show different luminescence compared to those of fragments A, highlighting possible differences in the degradation or manufacturing process.

Fig. 5. Results of MBI. Visible reflected (VIS), Ultraviolet induced visible luminescence (UVL), near-infrared reflected (NIR) and Infrared reflected false-colour (IRFC) images of textile fragment B (Wall hanging from Coptic period, Cairo Egyptian Museum)

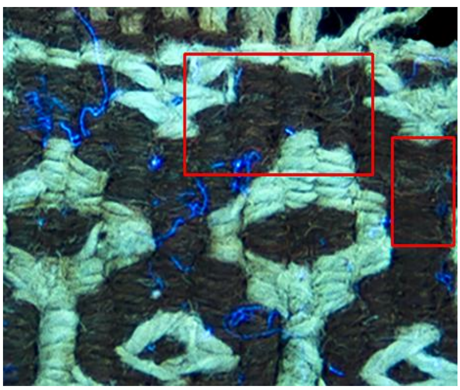


Fig. 6. Details of UVL image showing the threads with weak pink luminescence, highlighted with the red squares, and modern fibres with blue luminescence

As previously noted for textile fragment A, also the materials that constituting textile fragment B are predominantly transparent to NIR, even in the darker parts.

Despite the presence of the double dyeing thread with blue and red, the area with dark red/reddish purple mainly appears in a reddish-slightly orange in IRRFC (Fig. 5).

The image compared with the UVL show the high predominance of the blue dye behaviour, although a difference in the IRRFC can be recognized compared with the pure blue dyes.

Textile fragment C

Visual and UV-VIS microscopy

This loose fragment is a piece of a carpet from the Islamic period.

Visually, it is observed that the textile piece consists of loose undyed warp ground, cellulosic threads, and wool weft threads coloured with more intense black and green dyes (Fig. 7) thus, it was difficult to recognise the weave structure of this textile piece. By comparison of the fibres using UV-VIS investigation with magnification 500x highlighted the differences in the green threads, as appearing two tones of the green colour, dark and light (Fig. 7c and d) as well as the black colour, appears intense blue as shown in figure 7b.

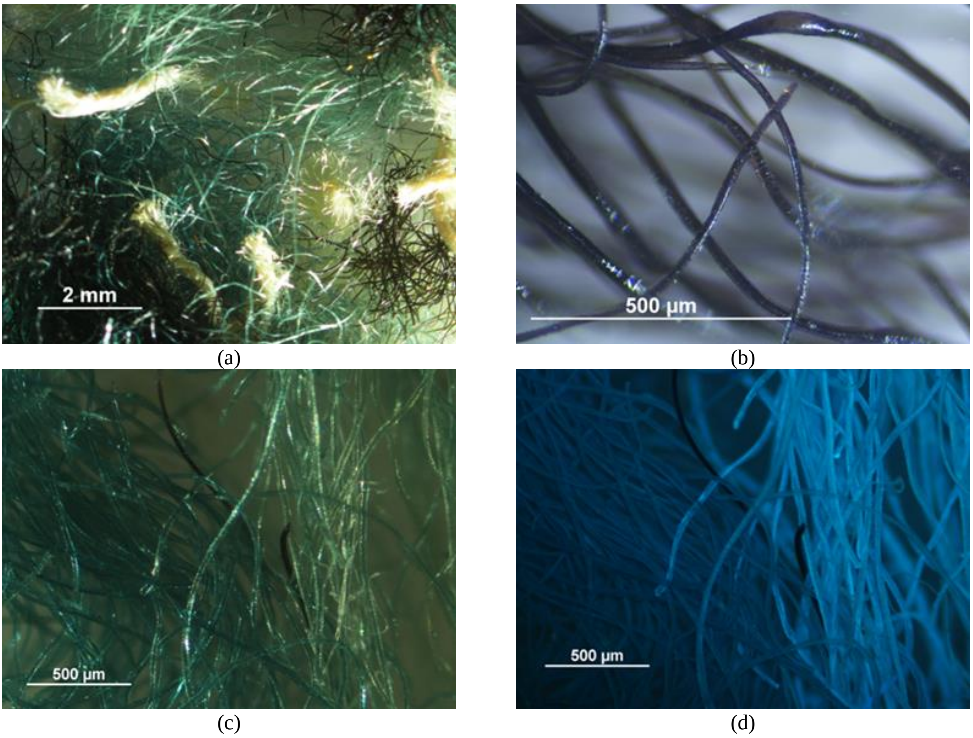


Fig. 7. UV-VIS microscope images of the textile fragment C: (a) Shows that the fibres are dyeing with green and black colours; (b) black dyed fibres appear intense dark blue; (c, d) VIS and UV images 500x clarify that there are 2 tones green coloured fibre, light and dark

Multi-Spectral Imaging (MBI)

The observation under visible light of fragment C (Fig. 8) show coloured weft threads composed of light green, dark green and black threads, as well as the original beige colour of the undyed warp fibres.

Some differences arise in the luminescence behaviour of threads, compared with the two fragments analysed above.

The green threads are especially highlighted in the UVL image, appearing bluish. This luminescence can be associated rather than the dye to their origins from proteinaceous fibres like wool [32]. The close observation of the undyed warp threads shows a greenish/pale yellow luminescence which may be attributed to cellulosic materials, such as flax, hemp, jute or cotton.

NIR image of green threads are quite transparent to infrared radiation and appear as light grey areas (Fig. 8). Compared with undyed threads, the green parts absorb a small quantity of infrared radiation. The black threads absorb infrared radiation in a greater amount compared with the green and undyed threads, but despite all, not as expected from such a dark pigment (Fig. 8).

Fig. 8. Visible reflected (VIS); ultraviolet induced visible luminescence (UVL); near-infrared reflected (NIR) Infrared reflected false colour (IRRFC) images of the textile fragment (C) of an Islamic carpet, Cairo Egyptian Museum

Despite the green and dark threads appear to be dyed with different colourants; it is clear from the image in IRRFC (Fig. 9) that they are just various tones of the same mixtures of colourants.

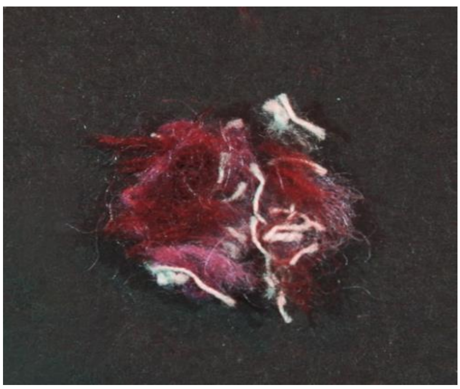


Fig. 9. Details of fragment C in IRRF

Different shades of pink and red are visible in the IRRFC image and this result indicating that the green threads were dyed with a mixture of indigo and yellow dyes.

A possible explanation for the differences of the green tones may lie in the dyeing technique used, since it is proposed that dark green fibres may be double-dyed consecutively, with indigo probably in high concentration, or dyed with various dye baths first, and yellow dye in the second.

Of particular note are the black threads that appear with an intense black in the visible image (Fig. 8), but in the IRRFC image (Fig. 9) appear in red, indicating the presence of indigo/woad dye.

From the data gained, it is not possible to say whether this colouration was done through dyeing in a single high-concentration vat dye or through various dye baths.

The undyed threads show similar behaviour to the undyed threads in sample B, even if the loose threads of the surrounding make them look redder (Fig. 9).

Conclusions

This work has illustrated the capability of the MBI approach for investigating the dyes and material properties of the ancient textiles presented, together with a first visual indication of their state of conservation.

The MBI technique can easily and quickly provide the first set of information using affordable instrumentation. The results of these techniques on the three selected Egyptian textile fragments demonstrated that the dyes, although they seem to be multiple, were obtained from somewhat limited dye sources, such as indigotin, madder and yellow dye, probably weld, along with their mixtures. Variations and resemblance of shades between and within the coloured fibres of the studied textiles were also identified.

The photographic techniques reported are the principal precursors to punctual analysis and micro-sampling that could be required for the full identification of the chemical composition and nature of the dyes used on colouring ancient textiles. The MBI could be used as tools to guide further supplementary non-invasive analyses, such as FORS and portable ATR-FTIR, choosing a set of more specific areas of measure, based on the differences arising from the images. Thereby, instead of taking samples randomly from the decomposable and precious ancient material, selective, well-informed sampling with these techniques could reduce the damage of artefact whereas maximising the information offered for supplementary scientific analysis.

The techniques can also provide quick viewing of the results obtained, necessary for conservators, especially when large collections were investigated. The visual nature of the results, through images, are helpful in the perspective of virtual dissemination through museums, projects and collection web pages.

The study has also highlighted limitations of the MBI techniques, such as the differentiation of mixture components or the identification between indigo and woad.

Besides, the characteristic variability of such natural materials, further uncertainties and difficulties in comparison are added with modern mock-ups that cannot be always compared with the sample.

For this reason, full collaboration and continued dialogue between conservators and scientists are necessary to achieve the best level of knowledge about the investigated artefacts.

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