Discovery of Vespasiano Bignami Paintings at The National Theater of Costa Rica Trough Technical Photography and UV-Vis Spectroscopy

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Discovery of Vespasiano Bignami paintings at the National Theater of Costa Rica trough technical photography and UV-Vis spectroscopy.

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Abstract

Paintings are one of the most striking means that human beings have used to share our history, learning, personal beliefs and thoughts. Paintings reflect the connection between the artist and its time, not only in the thematic and stylistic aspects, but in the availability of art materials such as pigments, vehicles and varnishes. Establishing and understanding these relations are key to provide accurate information about the artist's palette and developing conservation strategies.

The ceiling of the Foyer of the National Theater of Costa Rica is decorated with three large format paintings from the 19th century made by the Italian painter Vespasiano Bignami. The paintings are known as La Poesía, La Música and La Danza (The Poetry, the Music and The Dance) and have undergone restorations in the past. However, their state of conservation is unknown and thus demand accurate scientific examination in order to document their status and the extent of undocumented previous restoration work.

To overcome those issues, we propose the application of a combination of non-invasive and in-situ techniques to obtain information about the red pigment composition and actual state of conservation. We employed technical photography in the Visible (Vis) and Near Infrared (IR) regions, using panoramic stitching techniques in order to obtain high resolution images of the very large artworks. Several conservation problems were observed such as: detachment of pigments, cracks, stains, and sections with undocumented restorations. In the IR and in the False Color Infrared (IRFC) images we observed a very conspicuous behavior of the red pigment used in the three paintings. Particular areas with the red pigment were fluorescent, and through Ultraviolet fluorescence (UVF) imaging we identified the pigment as through its red-coral fluorescence as Madder Lake, by comparison to a historical pigments reference palette (Pigment Checker from Cultural Heritage Science Open Source).

Measurements in five different red pigmented zones using UV-Vis spectroscopy in La Musica show bands in the 550-650 nm region. A Lorentz Model nonlinear curve fit to the bands allowed us to correlated the fluorescent pigment in the paintings of Vespasiano Bignami with Madder Lake.

Keywords: Madder Lake, technical photography, Fluorescent, Costa Rica, UV radiation , spectroscopy

Introduction

Nature has always amazed us by the colors it generates, interpretation and use of color have been part of humankind since ancient times and until today, as said by Iqbal and Hao *"colour is an important and ubiquitous part or our everyday life and ever since pre-historic times, colours, be they inorganic or organic, have had profound anthropological, psychological, aesthetic, functional and economic impact on society"* [1], as an example, green pigments were used in the tomb of Tutankhamen in Egypt because was associated to abundance and growth [2].

In that manner the materials used by artists throughout history fortunately are strongly determined to the technology and trends of the epoch. For that reason, pigments can be of help associating the creation of a painting and further work done to it to a specific period of time. Hence, further investigation on pigments can be of great help to stablish an indicator in time.

Artists historically have found inspiration in the colors of Nature, and have made efforts to expand the color range of inorganic pigments by using plant dyes [2] . A good example is the important Carmine Red (from cochineal insect) dye which was produced in Perú and México in Pre-Hispanic times and was used as a dyestuff. When combined with several mordants and salts, it produces a variety of Lake pigments with different hues of red [3]. This red pigment, when found, can then be used as a marker associated with the Spanish conquest, regarding the fact it was commercially available in Europe since the sixteenth century when was started to be used in paintings [4,5] .

To understand the history around an artist's palette is necessary to identify the pigments used in the artwork, this also affords valuable scientific information for developing adequate conservation strategies worldwide. A pigment with a very strong connection between time and industry is Madder Lake. It was used first as dye for textiles when it was manufactured in the early sixteenth century B.C in Egypt [6] , then in book illustrations [6], in Rome ceramics and other archaeological objects [7–10], and later on a pigment in paintings [6,11,12]. In spite of its commercial success, the use of Madder Lake decayed when Alizarin, one of its main components, started being produced by synthetic means in 1869 by the chemists Graebe and Liebermann and becoming the first natural dye to be produced in the laboratory[13], as a consequence, caused a decrease in the use of natural Madder Lake.

One of the most useful properties of Madder Lake is its fluorescence under ultraviolet light (UV). Its fluorescence allows the identification of Madder Lake in paintings by using non-invasive methods, such as UV-Visible spectroscopy. There are interferences from the fluorescence of binding media [14] and the possible low intensity bands of other components of the painting. Nevertheless, an advantage is that this technique is non-invasive and low-cost in comparison with chromatographic techniques and surface enhanced Raman spectroscopy (SERS) that require extraction of samples or more expensive equipment [15]. UV- induced visible fluorescence can be then used as a low cost technique for preliminary examination thanks to the particular red-orange fluorescent color of Madder Lake, this pigment has been detected in many cultural heritage objects [12,14].

Another important non-invasive, preliminary diagnostic technique is the use of technical photography to create high resolution images in the visible (Vis) and Near Infrared (IR) region of the electromagnetic spectrum. The photographs can be taken by using a digital camera in which the sensor’s low-pass filter is removed and replaced with a material transparent to UV, Vis and IR light. With images from the Vis and IR region, it is possible to create an infrared false color image (IRFC) to make a preliminary assignment of the pigment composition of a painting such as the case of Madder lake. An additional benefit of this technique is that is also possible to discover previous restorations attempts. The images can be used for establishing a timeline and follow the state of conservation of the artwork [16].

The aim of this study is to provide an experimental framework based on non-invasive techniques, due to the fact that most recent publications related to the identification of Madder Lake involves a combination of invasive and non-invasive techniques [17–21]. This paper examines the application of low-cost, non-invasive and in-situ techniques using UV-Vis spectroscopy and technical photography for examination of three large nineteen-century paintings of Vespasiano Bignami, located at the National Theater of Costa Rica. An important consideration while examining these works, is that the art imported into Latin America was not designed to withstand the effects of the climate and humidity of the tropics. This research also evaluates the state of conservation of the three paintings created by this artist, known as *La Poesía, La Música,* and *La Danza (The Poetry, The Music, and The Dance)*.

In the next sections we present a brief history of Vespasiano Bignami and his paintings, followed by the application of our experimental set up to the examination of the paintings. We continue with our main results and discussion regarding the state of conservation and the identification of Madder lake. We finish with concluding remarks and detailed experimental methods and data.

Vespasiano Bignami

One of the most important aspects of studying the work of an artist is that art is always linked both to the artist's personal history and also to the history of a country and its society: It is a reflection of a specific moment in time. Studying Vespasiano Bignami is taking a look into Costa-Rican society and history, regarding the fact that Bignami was in charge of the three largest paintings for one of the most important cultural buildings of the 19th century in Costa Rica.

Vespasiano Bignami was an Italian painter, cartoonish, and illustrator who was born in Cremona in 1841, and passed away in Milano in 1929. He studied under the guidance of Enrico Scuri at Carrara Academy in Bergamo, and later moved to Milan where he started his professional development as an artist [22]. He was part of the convulse period of history that surrounded the independence of Italy, a process known as the “Risorgimento” that ended in 1861 with the creation of the Kingdom of Italy. This political process lead to three artistic movements in literature, music, and art, that went directly against the academic rules imposed by nearby countries. These artistic movements arose in different regions of Italy, and in general were known as : *Macchiaioli* (appeared in Florence), *Scapigliatura* (appeared in Milan)*,* and *Divisionism* [23]. These movements affected painting in several ways and were transitions from Neoclassicism, Romanticism, Verism, and Realism. Therefore, all these transitions and changes were strongly linked to the historic movements of each region of Italy [24].

Bignami was involved in the *Scapigliatura* movement where the most important painters were T. Cremona (1837-1878), and D. Ranzoni (1843-1889) [25]. Most of the works of Vespasiano were oil paintings and some watercolors, most of which are nowadays conserved in Italy. His most iconic oil paintings are mentioned in Table 1 [26–30]. These oil paintings as far as we know, have not been studied by scientific means, for that reason, is not possible to establish similarities in technique and materials with those located at the National Theater of Costa Rica.

Table 1. Oil paintings of Vespasiano Bignami located in Italy.

Painting Name	Current location	Date
Philosopher	Picture Gallery of Carrara Academy	1862
Botanic Lesson	G. Verdi Conservatory	Post 1869
Portrait of Ignazio Peregalli	Art Collection of Major Hospital	Post 1884
Portrait of Francesco Osculate	Art Collection of Major Hospital	Post 1891
Portrait of Achille Nebuloni	Art Collection of Major Hospital	Post 1911

The three paintings by Vespasiano Bignami which correspond to the artworks studied here, cover the entirety of the ceiling of the Foyer at the National Theater of Costa Rica. The Foyer is a large area (roughly 176 m^2) above the entrance lobby where people used to meet before a performance. Today, the Foyer is used for protocolary acts of the government, artistic presentations, and is also a tourist attraction. The National Theater is then a building of great importance for the Costa Rican culture, society and economy.

The National Theater of Costa Rica opened to public on October 21st, 1897. Subsequently it was declared National Monument in 1965 and more recently, in 2018 National Symbol according to Costa Rican Law # 9521. Inside the Theater, ornamentation was commissioned to contractors Molinari & Riatti [31,32], whom subcontracted the work to several Italian artists such as Carlo Ferrario, Roberto Fontana, Aleardo Villa, Antonio Rovescalli [33], and also to Vespasiano Bignami.

The three paintings created by Vespasiano are the largest in the Theater and are representations or allegories of art -*The Music*, *The Dance*, and *The Poetry*-. Each painting was made in the Sforza Castle in Milan, and then sent to Costa Rica [34,35] . The three paintings have in common their very large size as well as a similar color palette. The lateral panels *La Danza* and *La Poesía* can be observed in Figure 1.

Figure 1. Paintings *La Danza* (9.83m length x 5.13 m wide) and *La Poesía* (9.83m length x 5.13 m wie) located at the National Theater of Costa Rica.

In spite of their preponderance inside the building, these three paintings have not been subjected to a scientific examination in order to determine their state of conservation, or to document their pigment composition, and to correlate its use of pigments with Vespasiano Bignami's technique.

Methodology

Experimental set-up

We employed a combination of non-invasive techniques such as technical photography, inspection with UV (ultraviolet) radiation, and UV-Vis (visible) spectroscopy, in order to determine the stage of conservation of each painting and to detect conservation problems. Analysis of technical photographs in the Vis, and IR regions, as well as IRFC (infrared false color) images allowed us to carry out a preliminary determination of the pigment composition. Finally, in situ UV-Vis spectroscopy and fluorescence induced by UV radiation completed the identification of the pigments.

Technical photography and state of conservation

Technical photography has become one of the most important tools to assess the state of conservation throughout a painting. This procedure was employed for *La Poesía, La Danza and La Música* to obtain high resolution images in the Vis and IR regions of the electromagnetic spectrum. The channels of IRFC were constructed using the luminosity channel of the infrared (IR) image and doing the usual channel substitution of the Vis image R, G, B channels into IR, R, G.

Photographs were acquired with a Nikon D7200 camera, modified for technical photography by Life Pixel, equipped with a AF-D Nikkor 50 mm f/1.8 objective. Images were captured in the visible spectral range (Vis) -400 to 780 nm- by using a XNiteCC1 M52 filter and for the infrared range (IR) -780 to 1000nm- with a Heliopan RG1000 filter. For both ranges we used a exposure time of 4 s, aperture at f /11, ISO 200, using two halogen lamps of approximately 150 W for illumination.

Prior to the photo shooting which was done by night to avoid as much as possible the city lights, it was necessary to cover six windows of the Foyer as the Theater is located downtown in Costa Rica's capital city. We also employed a 4 m tall scaffold for examining the artworks in the ceiling. The image stitching process required that we kept the camera's sensor perfectly aligned with the ceiling while the camera was displaced horizontally on a tripod. We marked a grid on the floor to position the camera so there was enough image overlap for covering properly the whole painting and at the same time making sure we could mask out the "hot spot" of the IR region during the stitching.

Before starting the shooting of the Vis images a white balance calibration was made with an AIC target. The calibration and exposure remained unchanged for the IR images. The camera was manually focused and operated remotely using the tethering software Camera Control Pro 2 from Nikon. Images were stored directly into the computer's hard disk in RAW format for further processing. In order to obtain image registration to the pixel level, both the Vis and IR images were obtained at each position on the grid, and the camera was carefully refocused each time that a filter was changed for the Vis and IR photos. A total of 48 photograph pairs were acquired for the each of the two lateral paintings, *La Poesía* and *La Danza* and 202 photograph pairs for *La Música* in Vis and IR.

We used the following editing process for the Vis and IR RAW data (as .NEF) files. For the Vis images we created a color-correction profile using a X-Rite Color Passport Checker® reference and the ColorChecker Camera Calibration v1.1.1 software and applied it, together with the proper lens parameters profile, in Adobe Lightroom Classic®. For the IR region the photos were exported from Lightroom and converted into grayscale files (the IR images) from which we used only the red channel for the IRFC images. This procedure was done in Adobe Photoshop®.

To create the IRFC images for the three paintings, each photo pair from the Vis and IR was aligned in Adobe Photoshop®**.** After the alignment the exchange of the RGB channels between the Vis an IR was applied as described. Each individual Vis, IR and the new IRFC image for each painting was exported in .TIFF format, and they were used to create a high-resolution panorama of the whole painting using PT Gui Pro® software.

If we now turn to observe the extent of previous restoration efforts, we used a UV lamp to inspect each painting at close range using the scaffold at 8 m height and allowing us to define the artwork's state of conservation. The lamp's source spectrum had two maxima: λ_1 at 370 nm with a power of about 2.45 mW, and λ_2 at 436 nm with a power of roughly 1.69 mW. The spectrum of the lamp is shown in the supplementary information. At these emission wavelengths, the lamp's radiation does not interfere with observing the fluorescence of varnishes, resins, or fluorescent pigments.

UV-Vis spectroscopy

Thanks to the inspection made with the UV radiation we observed several sections on the three paintings with a reddish-orange fluorescence. For that reason, we carried out measurements of UV-Vis spectroscopy induced by UV radiation for *La Música* on five different reddish-orange fluorescent sections, and in a reference zone were no fluorescent was observed (see Figure 2). We made these measurements only in this painting because has the most intense fluorescent zones of the three.

Figure 2. A) Panorama of *La Música* (9.51 m length x 8.84 m wide), B) Section of *La Música* showing the measurement points as M1 to M5, and the reference zone were the UV-Vis spectra were taken.

To carry out the UV-Vis induced fluorescence measurements an Avantes Model AvaSpec-2048 spectrometer with a grating set for 184-746 nm, coupled to an optical fiber was used. The measurement conditions were an integration time of 70 ms with an average of 30 scans to have a good signal to noise ratio and to avoid saturation on the optical fiber due to the UV radiation. The experimental design consisted on a set of three replicas per measurement.

To achieve an identification of the fluorescent pigment we did data analysis from each spectra: First, a nonlinear curve fit (Lorentz Model) was applied to the band around 550-650 nm. It was done to obtain information regarding the wavelength of the signal observed and also about the band's Full Width at Half Maximum (FWHM). The fitting was done by using the Origin Pro® software in accordance with the next formula:

$$y = y_0 + \frac{2A}{\pi}\frac{w}{4\,(x-x_c)^2 + w^2} \quad (1)\,,$$

$$\text{where } y_0 \text{ is the offset with respect to } y\,, x_c \text{ corresponds to the center of the curve,}$$

$$w \text{ denotes the FWHM, and } A \text{ is the total area of the curve.}$$

To validate our results for the identification of the fluorescent pigment, measurements on a fluorescent pigment (Madder lake) from the Pigment Checker from Cultural Heritage Science Open Source (CHSOS) [36] were done in the same conditions used for the five zones on the painting. The same fitting for the spectral band was applied and the data obtained were plotted as a box plot for making comparisons using the RStudio® software.

Results and Discussion

The history around a painting is a very important issue for a conservation proposal and to unveil possible relationships between pigments and artists. The paintings made by Vespasiano Bignami are only 122 years old; nevertheless, there is very little information regarding the conservation procedures applied to them since they were first displayed on the National Theater. For that reason obtaining that kind of information is key to create a timeline among the artist, the pigments and possible restorations.

There are records of at least four main interventions; nonetheless, no technical sheet of the materials and zones of intervention was documented for any of them. The first one was done in 1934 by the restorer Antolin Chinchilla, who made some retouches at oleo [37] . The second, in 1965, was in charge of the Instituto Nacional de Bellas Artes of Mexico, and was mostly related to conservation procedures on wood and cracks by using beeswax to avoid problems of humidity and leaks of water. The procedure was unsuccessful [37] due to the high ambient temperatures. The last two, which together took around ten years, started in 1970. A first stage was done by the Instituto Central de Conservación y Restauración de Obra de Arte of Spain [38], and later some additional works were done by the restorer Carmen del Valle [39–41]. To contribute to establishing the state of conservation of the three paintings, and create the first scientific documentation about these monumental works of art, we first employed detailed technical photography.

Photographs in the Visible (Vis) region made for *La Poesía*, *La Danza* and *La Música*, allow us to differentiate the original painting from the restorations. We were able to determine and document issues related to cracks, retouching with different types of strokes, stains, variation in color, detachment of pigments, as well as marks from the wood boards, to which is attached the painting substrate. All these features are more evident in the IR images. These photographs correspond to the first experimental realization of high-resolution images and hence support us to establish an initial mark in time regarding their state of conservation.

A remarkable aspect observed by comparison of the Vis and IR panoramic images was that in several areas the red tones “disappeared” when they were observed in the IR image. This aspect could be of help to make a preliminary identification of the pigment. The red color sections “disappear” as they look brighter in the IR region. They were more evident in details in areas with flowers, in accessories of the characters in the paintings, such as: bands in the hair, neckless, and in particular parts of the clothing. To examine closely the pigment behavior, we generated the IRFC images.

All of the sections that were brighter in the IR were also yellow in the IRFC. This is a first indication that the red pigment has the same composition on all of the three paintings. Features of the location of the pigments, and also the comparison among the Vis, IR and IRFC panoramas can be seen in the supplementary information section. The information gathered about the pigments distribution can be of help for future works, for conduct a sampling, and to design experiments without making measurements in a random way.

Because the information obtained with the IRFC is not conclusive regarding the pigments composition, we used UV induced visible fluorescence. This is a method often chosen to obtain more information about the pigment identity, and it can improve the data about the state of conservation [42,43]. At first, it was possible to observe zones in a darker color that are associated with retouches of color and are visible in all the three paintings. Futhermore, yellow-green fluorescence can be related to aged varnish, given that recent layers of resins and varnishes do not fluoresce. In those cases the material absorbed UV radiation, and it appears as a dark purple [14], such as was observed in the frames, also in a junction located in the center of *La Música*. With these inspections it became evident which sections had undergone restoration, and it will prove useful to identify conservation issues in each painting; information that was not previously available to our work.

In addition to the previous findings, the sections that were beforehand identified as brighter in the IR, and showed a yellow color in the IRFC, indeed show a particular behavior under the UV radiation as they exhibit a red-coral color fluorescence. Closer examination shows that these correspond only to some accented areas within a red-painted object such as flowers, ribbons, dresses, mouth, and a necklace. To have a more precise identification, the color observed was compared with a reference palette of pigments (Pigment Checker from CHOS [36]), which contains pigments from antiquity until early 1950.

Fluorescent pigments usually exhibit specific colors under UV light, so a visual comparison between the paintings and the reference palette (see Figure 3) is a first step in the analysis. The comparison allowed the identification of the fluorescent pigment as Madder lake (Kremer-372051). The pigment in the paintings was used to enhance the shadows or to represent movement on the figures and plants. Madder Lake was mainly a color accent taking into account that was a very expensive pigment [44]. For that cause its use was not so extensive in a painting, as was observed in Vespasiano Bignami paintings. A drawback to its confirmatory identification is that the color hue observed could be also affected by mixing with other pigments, its particle size, and the binders used [45]. For this reason, the use of UV-Vis spectroscopy could be of help to characterize more precisely the fluorescence observed.

Figure 3. Comparison between Vis and Fluorescent response under UV radiation in areas of A) *La Poesía*, B) *La Danza*, C) *La Música*, and D) Pigment Checker from CHOS, white rectangles show the Madder lake.

For the in situ measurements with the UV-Vis spectrometer five different zones on the painting *La Música* were selected, as was shown in Figure 2. This painting was selected over the other two, because it shows a specific zone where the fluorescence was more intense. A comparison was made with the Pigment Checker from CHOS where the Madder lake is present in two different zones, to determine if the preparation on the pigment could affect the measurements of the spectra and therefore the color observed.

For the UV-Vis measurements the center wavelength (x_c) was calculated through a Lorentz fitting between the wavelength range 500-700 nm (see Eq. (1)) . This range was selected because we observed a signal different from that of the source of irradiation (UV lamp). The average range for the five measurements zones goes from 582 nm to 602 nm, and as it was expected for the reference, no signal was observed within that range. Figure 4 shows the spectra obtained from UV-Vis measurements done in *La Música* and in the Pigment Checker as well as a box plot with a comparison from our experimental data, and six values reported in the literature for Madder lake identification samples [8,46–50].

Figure 4. A). Measurements of UV-Vis in painting *La Música* (M1 to M5) showing the center wavelength (x_c) and the measurements M6 and M7 for the Madder lake in the Pigment Checker, B) Box plot with x_c from painting *La Música* (M1-M5), Pigment Checker from CHOS (M6-M7), and reference from literature (M8). Black points corresponds to the experimental data.

The characteristic spectrum of a pigment usually correlates well with the observed color. In Figure 4A it is possible to observe variations among the measurements carried out on the painting (M1 to M5) in comparison with the measurements done on the Pigment Checker (M6 to

M7), and within the same sample. These variations could be related to the method of manufacture of the Madder lake moreover to extraction and recipes procedures [51], also to self-absorption of the molecule and scattering effects [52–54], and the application method of the artist.

The calculated value of x_c is sensitive to the mentioned factors, and the differences observed cannot be associated with just one them. Nevertheless, in Figure 4A the x_c range found among the measurements done on the painting (M1 to M5) is far larger than the measurements performed on the Pigment Checker (M6 to M7). The individual box plots show that our method is very precise as the individual x_c data for each site are clustered closely together and thus variation among sampling sites can be assigned to combination of factors that can affected the fluorescence response of the pigment.

The red dye in Madder is mainly a combination of the dyes alizarin (1,2-dihydroxyantraquinone), purpurin (1,2,4,-trihydroxyanthraquinone), and pseudopurpurin (1,2,4,-trihydroxyanthraquinone-3-carboxylic acid). Natural variation as well as the extraction method employed affects the proportions of these substances and thus the spectrum of a Madder sample [53], and therefore the observed color [55]. It has even been found that some Madder Lake pigment varieties do not even show fluorescence at wavelength of 254 nm (UVF254) [56], therefore fluorescence response could be related to manufacture of the pigment, and the proportions of alizarin, purpurin and pseudopurpurin found in an specific sample of Madder lake.

We also compared our Madder lake center wavelength (x_c) data to measurements found in the literature. The box plot was built with the x_c obtained with Lorentz fitting of three replicas for measurement points from M1 to M3, and M6 and M7. One exception is M5, for which only two of the three measurements allowed us to obtain a convergence for fitting. In our plot, M8 corresponds to experimental data collected from the literature. A striking aspect in Figure 4B is that when fluorescence data found in the literature are plotted together with our results, we notice that there is an even larger range of reported values, and our data are consistent with the different reported data [47–51]. This comparison also evidences the variability in the x_c of Madder lake, regarding the sample analyzed, the method of manufacture, and even the way in which the artist applies the pigment to the object.

An additional feature seen in Figure 4A is the presence of a broad signal around 450-500 nm in the spectra for *La Música* (M1 to M5). This band is not observed in the spectra of the UV lamp, but it is seen in the reference spectrum which was measured on an area of the painting that does not fluoresce due to absence of Madder lake. This band could be related to the varnish or resin used on the painting. The band may be shifted by aging, and be associated to oxidation processes that generate fluorescent molecules. It is possible that the recipe, and the type of varnish used could affected the signal observed [57]. Those signals could be related to previous restorations.

Forty years ago a restoration process applied a varnish retouch to *La Música.* This varnish could be the cause of the 450-500 nm signals on the painting, which are very different to the band observed in the same range for M6 and M7 that belong to the pigment checker from CHOS where the pigment is mixed with an acrylic resin. This varnish over the painting might also affect the color observed in the fluorescent areas, as the particle size of the bulk (pigment plus varnish) could affect the perception of color (scattering effect). An evaluation of the FWHM for measurements from M1 to M7 was done between 550-650 nm, in order to correlate the particle size and variations of the color observed. Table 2 shows the median of the three replicas for each point, with the exception of M5 where it was calculated with two replicas. The FWHM is obtained from the Lorentz fit previously mentioned (see the UV-Vis spectroscopy section).

Table 2. Mean of FWHM calculated for five measurements on *La Música* and in two samples of Madder lake from the pigment checker from CHOS.

Location of Measurement	**Median of FWHM ± standard deviation (nm)**
M1	70.8 ± 1.3
M2	70.1 ± 1.3
M3	70.2 ± 1.2
M4	66.5 ± 1.9
M5	42.7 ± 1.5
M6 (Madder Lake from Pigment Checker)	86.5 ± 2.3
M7 (Madder Lake from Pigment Checker)	73.1 ± 1.4

It is observed that in the measurements made on *La Música* (M1 to M5), there is a decrease in the FWHM that could be related to a small particle size, which in turn is correlated to a shorter wavelength observed in Figure 4B, and accounting for the variation in the observed color. Interestingly, the Madder lake samples from the Pigment Checker (M6 and M7), both have the same pigment composition mixed with an acrylic binder, nevertheless, there is a variation in the FWHM, which is an indication of how the preparation but also the scattering could affect the color and also the x_c associated with the identification of a pigment.

Conclusion

The evidence from this study suggests an identification of the fluorescent pigment as Madder lake in three paintings of Vespasiano Bignami, with the aid of low cost and in situ equipment such as a modified commercial digital camera, UV radiation, and UV-Vis spectroscopy. This identification method on *La Música* could also be extended to *La Poesía* and *La Danza*, given the fact that comparable colored areas are very similar not only on the visible spectrum images, but also on their behavior in the IR and IRFC images. In addition, our most important finding was that our method for calculation of x_c gives very similar results to the reference and to previously studied samples with the same pigment.

In future investigations, it might be possible to use a different technique to improve the identification of Madder lake. Nevertheless, the information obtained is a first step to develop a technical data sheet about these paintings and about Vespasiano Bignami's techniques, and it allows to implement measurements and sampling to study the other pigments that are present in the paintings. To our knowledge, this is the first study that uses paintings from this artist, we therefore encourage further studies in paintings of Vespasiano Bignami located in Italy to create a full data base of this remarkable artist.

Abbreviations

AIC: American Institute for Conservation

CHSOS: Cultural Heritage Science Open Source

FWHM: Full Width at Half Maximum

IR: Near Infrared

IRFC: False Color Infrared

SERS: Surface Enhance Raman spectroscopy

UVF: Ultraviolet fluorescent

UV: ultraviolet

Vis: Visible

Availability of data and materials

The data will be available upon request.

Competing interests

The author(s) declare(s) that they have no competing interests

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Authors' contributions

GCB: Performed the experimental work for the technical photographs and UV-Vis spectroscopy measurements, CM: Help with the experimental set up in the National Theater of Costa Rica and with the research about Vespasiano Bignami, EL: Contributed with the experimental set up for technical photography and images processing. OAHS: designed the research, and contributed with all the experimental work. GCB: Write the first draft manuscript. All the authors contributed by interpretation and writing the paper. All authors read and approved the final manuscript.

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Figures

Figure 1

Paintings La Danza (9.83m length x 5.13 m wide) and La Poesía (9.83m length x 5.13 m wie) located at the National Theater of Costa Rica.

Figure 2

A) Panorama of La Música (9.51 m length x 8.84 m wide), B) Section of La Música showing the measurement points as M1 to M5, and the reference zone were the UV-Vis spectra were taken.

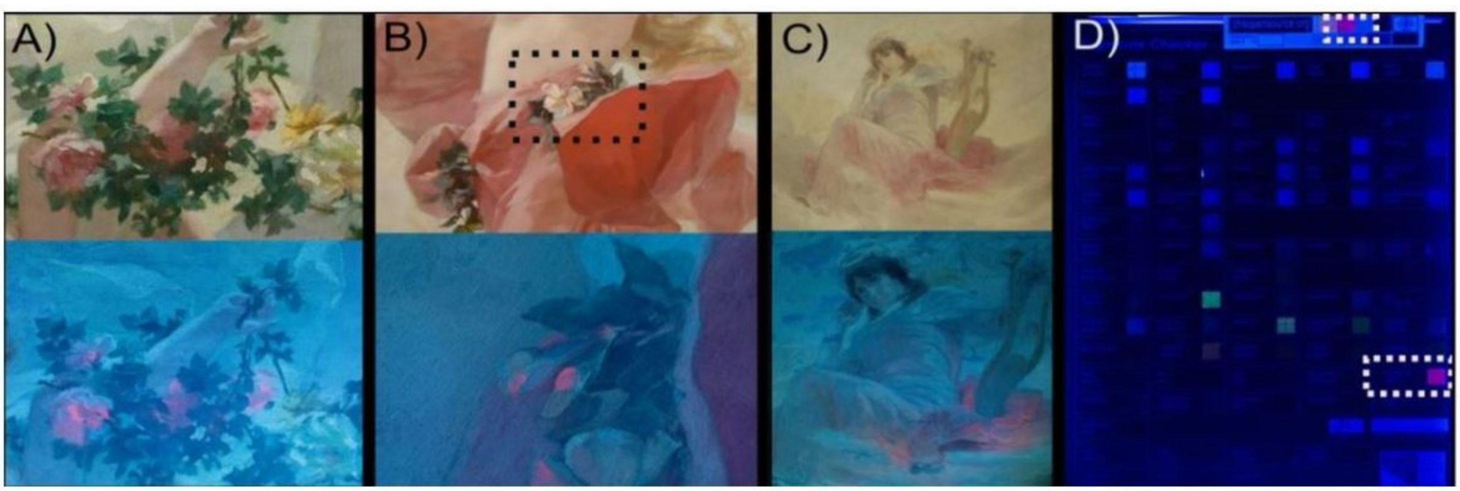

Figure 3

Comparison between Vis and Fluorescent response under UV radiation in areas of A) La Poesía, B) La Danza, C) La Música, and D) Pigment Checker from CHOS, white rectangles show the Madder lake.

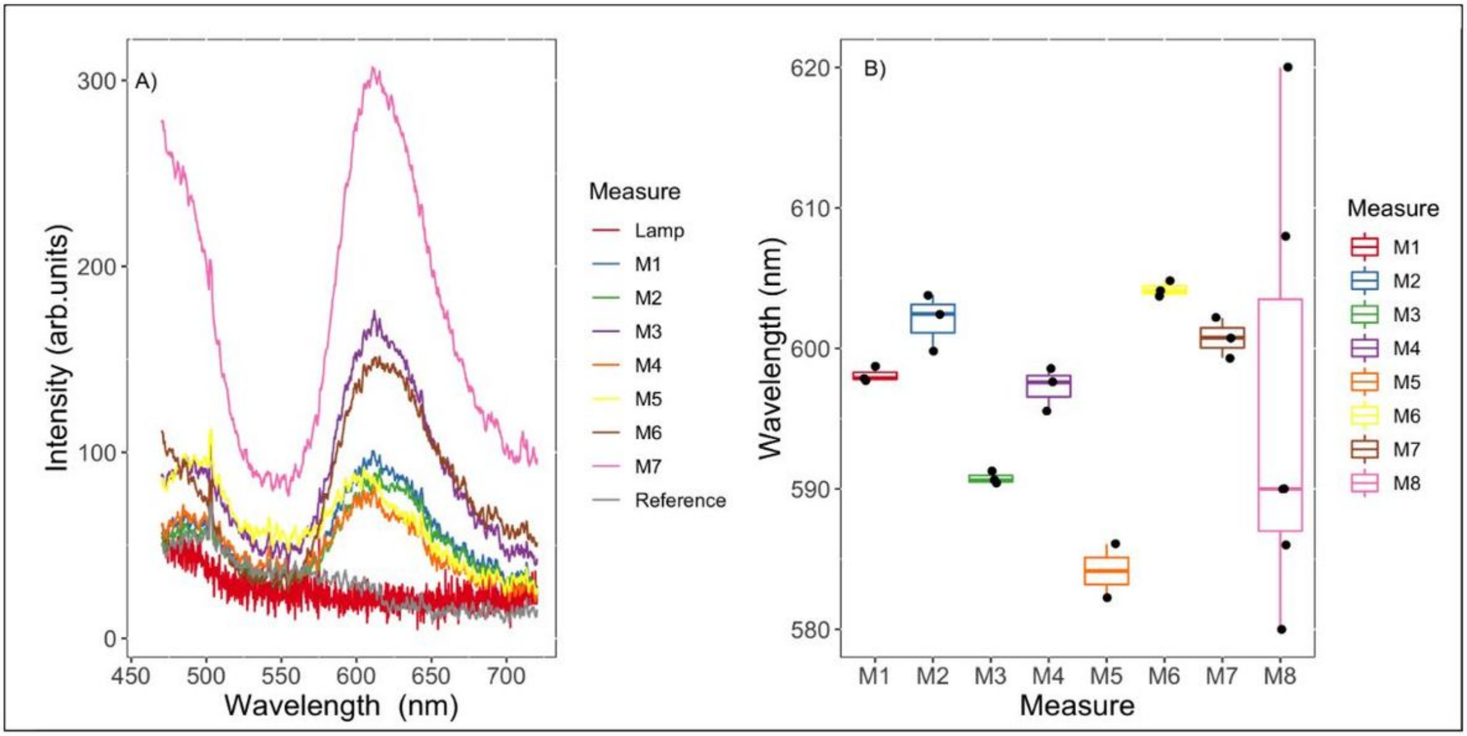

Figure 4

A). Measurements of UV-Vis in painting La Música (M1 to M5) showing the center wavelength (xc) and the measurements M6 and M7 for the Madder lake in the Pigment Checker, B) Box plot with xc from painting La Música (M1-M5), Pigment Checker from CHOS (M6-M7), and reference from literature (M8). Black points corresponds to the experimental data.

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