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Effect of ionizing radiation on the color of featherwork.

Delgado Vieira[a] A.C., Kodama[b] Y., Otubo[b] L., Santos[b], P.S., Vásquez Salvador[b], P.A.

[a] Museum of Archeology and Ethnology
Universidade de São Paulo [University of São Paulo]
Av. Professor Almeida Prado, 1466
05508-070 São Paulo, SP, Brazil
ana.carolina.vieira@usp.br

[b] Instituto de Pesquisas Energéticas e Nucleares [Institute of Energy and Nuclear Research] (IPEN / CNEN - SP)
Av. Professor Lineu Prestes, 2242
05508-000 São Paulo, SP, Brazil
pavsalva@usp.br

ABSTRACT

Featherwork collections are usually stored and managed by ethnographic museums. Even though the featherwork manufacturing is still practiced by the indigenous communities, the offer of raw material and the contact with the surrounding society ended up reducing the production scale of such objects. Consequently, the preservation of the material culture is very important, particularly in museums. Biodegradation can affect featherworks mainly by xylophagous insects and moths' action. The tropical Brazilian weather contributes to the contamination and proliferation of insects and fungi making the preservation conditions difficult. The use of gamma radiation for the disinfection of cultural heritage objects has shown to be a safe process and an excellent alternative to traditional methods usually involving toxic chemical pesticides. In this work are presented the preliminary results of the ionizing radiation effects on the color and morphological properties of a featherwork from the Museum of Archeology and Ethnology of the University of São Paulo (MAE/USP). Samples of feathers were selected from the artifact and irradiated with gamma rays at the Multipurpose Gamma Irradiation Facility at IPEN, applying absorbed doses between 0.5 kGy to 200 kGy. The results shown had no significant changes on color and morphological properties within the disinfection absorbed dose range applied.

Keywords: **Gamma irradiation, Cultural Heritage, Conservation, Ethnographic Objects, Feathers.**

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1. INTRODUCTION

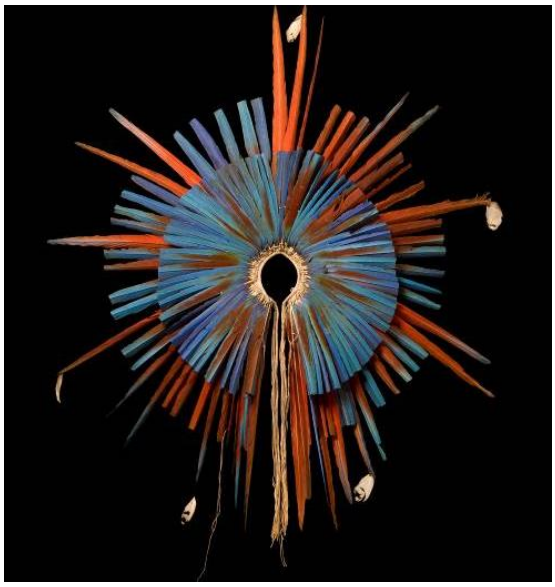
Featherworks are part of the most remarkable category of material culture produced by Brazilian indigenous groups because of its technicality and its aesthetic beauty standards. Weapons, baskets and musical instruments are frequently decorated with feathers. In addition, these materials are used in human body adornments that, in addition to esthetical purposes, carry the function of communicating information about the individual, its position within the group and cultural values that they wish to transmit [1].

For this, the craftsman carefully chooses the raw material with which he will build his adornment, exploring various chromatic combinations in the making of his object.

Samples of macaw feathers from a head ornament of the Kayapó indigenous group Xikrin who lives in villages in Pará, Brazil were used in this work. The samples were taken from an object belonging to the Museum of Archeology and Ethnology - MAE / USP.

The Kayapós Xikrin produce several artifacts, such as earrings, bracelets, diadems and pendants using colored feathers from birds such as scarlet macaw, red macaw and caninde macaw (Fig.1) [2]. These ornaments are usually made using organic materials such as vegetable fibers and cotton yarns that intertwine with feathers of varying colors [3]. In order to make these objects, the craftsman uses complex attachment techniques to hold the feathers, and, chooses shapes, sizes and colors with not only a decorative purpose, but also thinking of symbolic representations associated with rituals of birth, transition to adulthood and funerary rituals.

Figure 1: *Headdress Kayapó Xikrin.*



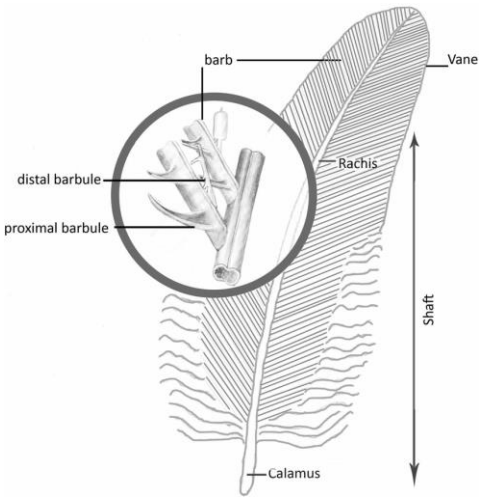
Source: Museu de Arqueologia e Etnologia – MAE/USP

Although plumage art is still practiced by indigenous societies, the supply of raw material and contact with the surrounding society has reduced the scale of production of these objects. For this reason, the preservation of cultural heritage that are in ethnographic museums is of great importance.

Trying to preserve ethnographic objects becomes challenging, since the biological cycle to which its organic substances is exposed inevitably brings variable stages of deterioration and disintegration of these materials. In addition to their use trajectory and their biography, these collected objects are exposed to a new environmental condition when they are brought to the storage areas of the museums, where they must have their prolonged existence.

The flying feathers of birds are keratinous attachments intended for maximum performance with a minimum weight drawback, that comprises creative combinations of components that optimize lift, stiffness, aerodynamics, and damage resistance [4,5]. The feathers are part of the epidermal structure that forms the outer coating of the birds. As shown in Fig. 2, the feathers are complex keratin protein structures with a three-dimensional structure formed by hydrogen bonds and disulfide covalent bonds (-SS-) called cysteic bonds [6].

Figure 2: *Feather structure [5]*



Pigmentation is rarely uniform and combinations of multiple biopigments such as carotenoids, melanin, psitacofulvin and porphyrins may occur. The carotenoid pigments are responsible for the colors red, yellow and orange. The loss of this pigment occurs through the process of cyanism, where only melanin becomes evident, through blue colors. Melanin is responsible for the brown, black, yellow and reddish brown coloration on the feathers. The psitacofulvins produce the red, orange and yellow from the Psittaciformes group, which includes macaws. Finally, the porphyrins produce rosy, brown, red and green colors [5,7].

A very common cause of damage to feather artifacts is the fading of colors through exposure to light.

All biopigments that are present in the keratin matrix can degrade by oxidation or isomerization. The effects of light can also induce auto-oxidation, causing the double-bonded carotenoids to be broken and the color to fade [7].

Comprised of organic raw materials, these objects are also victims of xylophagous insects and moths, among other biological threats. The tropical climate of Brazil aggravates the conditions of preservation because it favors the contamination and proliferation of these pests.

The use of gamma radiation for disinfestation of museum objects is a very safe process and has been proved a great alternative to traditional disinfestation methods involving pesticides of high persistence and toxicity [8,9,10].

The Cobalt-60 Multipurpose Irradiator from the Nuclear and Energy Research Institute (IPEN-CNEN/SP), located within the University of São Paulo (USP) campus, has irradiated diverse bibliographical collections, paintings and museum objects since 2004. Several studies have been conducted to determine the optimal dose to eliminate contamination by biological agents in organic materials such as leather, furs and feathers. A maximum dose of 10kGy is recommended for these artifacts in order to avoid affecting the physical and chemical properties of these materials [11].

In this work, we present the results of the effects of ionizing radiation on the colors of a feather ornament belonging to the Museum of Archeology and Ethnology (MAE / USP).

2. MATERIALS AND METHODS

2.1. Samples selection and methodology

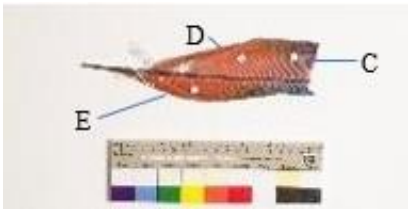
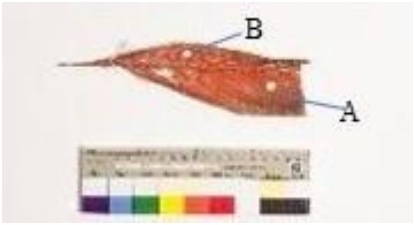
Two feathers were selected and removed from the feather adornment (SN 0371) shown in Fig. 3. The numbering of the samples indicates the order in which the feather was attached to the ornament. The results of the analysis of two feather samples named Feather 5 and Feather 31 (Table 1) are presented in this work.

Figure 3: *Original featherwork before sample removal.*

Colorimetric determinations were made with a PCE-CSM 8 equipment using the CIELAB 1976 color coordinate system and SQC8 Color Management Control System (0°/45° geometry; 58 mm diameter aperture) connected to a computer (Fig. 4). Each sample was read twice, before and 48 hours after each radiation absorbed dose. Measurement was done by positioning the point to be analyzed at the center of one white tile as a reference. White and black spectra was recorded using calibrated reference standards before every measuring process. Ten measurement points were chosen among the samples according to the colors of the feathers. Photographs were taken before and after the irradiation with gamma rays in order to follow possible chromatic changes in the feathers.

Figure 4: *Colorimeter and feather measurement setup.*

Table 1: Feather Samples description

Samples	Side		Sampling points and predominant colors	Notes
Feather 5	Front		C: Blue D: Grayish E: Blue	D: Loss area
	Back		A: Red B: Red	B: Loss area
Feather 31	Front		C: Blue D: Red E: Red	E: Loss area
	Back		A: Red B: Red	B: Loss area

2.2. Irradiation by gamma rays from cobalt-60 sources

The samples were irradiated at the Multipurpose Gamma Irradiation Facility of the Nuclear and Energy Research Institute – IPEN/CNEN/SP (Fig. 5). This facility is a panoramic wet storage source compact irradiator (IAEA - Category IV and group 1, according to CNEN), meaning that a panoramic wet source storage irradiator is a controlled human access irradiator in which the radioactive source is stored and fully shielded in a pool of 7m depth of deionized water [12].

The facility uses cobalt-60 source pencils where the radioactive material is encapsulated in corrosion resistant stainless steel. The source pencils were loaded into predetermined positions in source modules and these modules were distributed over the source racks. The racks are the structures that house all the source pencils enabling the movement of the source system from the bottom of the pool to the irradiation level. In 2015 the installed activity of the facility was around 11.1PBq (300kCi) [13,14]. According to information obtained through a technical visit guided by Paulo Santos, nowadays the Multipurpose Gamma Facility has around 14,8PBq (400kCi).

Figure 5: *Multipurpose Gamma Irradiation Facility – IPEN/CNEN*

The absorbed dose, D, is the amount of energy absorbed per unit mass of irradiated matter at a point in the region of interest. It is defined as the mean energy, $d\bar{\varepsilon}$, imparted by ionizing radiation to the matter in a volume element divided by the mass, dm, of that volume element:

$$D = \frac{d\bar{\varepsilon}}{dm} \tag{1}$$

The SI derived unit of absorbed dose is the gray (Gy), which replaced the earlier unit of absorbed dose, the rad, 1 Gy = 1 J/kg = 100 rad. The PMMA-Harwell dosimetry system was used to calculate the absorbed dose in the irradiated samples [15].

In this study, samples were irradiated by gamma rays with absorbed doses of 0.5, 1.0, 2.5, 6, 10, 15, 25, 50, 75, 100 and 200 kGy, and, the dose rate was 5-6kGy/h.

2.3. Colorimetry

Several systems to measure the color already exist. The CIELAB system, published in 1976 by the Commission Internationale d'Eclairage (CIE), has become the universally accepted colorimetric reference system for quantifying and communicating color.

Color differences can be computed as the relative distance between two reference points within a color space. This difference is typically expressed as delta E (ΔE) and is calculated by comparing reference and sample L*a*b* (L* = Lightness, a* = red to green, b* = yellow to blue) values to pinpoint how far apart two colors reside within a color space. The ΔE calculations will quantify the magnitude of a color difference but do not necessarily indicate the direction of the difference [16,17].

The ΔECIELAB 1976 utilizes a formula to calculate the distance between two points of color. In addition, this parameter is known as total color.

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (2)$$

2.4. Scanning Electron Microscopy (SEM) and Scanning Electron Microscopy Energy Dispersive Spectrometry (SEM–EDS)

Surface topography and elemental analysis of the feathers were analyzed by scanning electron microscopy (FEGSEM), using a Jeol JSM-6701F electron microscope with a field emission gun operating at 2kV and 3kV with a coupled Thermo EDS detector. A piece of each sample was cut and fixed with a double sided conducting carbon tape. The images were taken with the "raw" samples at an accelerating voltage of 2kV, but for EDS analysis, the samples were previously coated with carbon to avoid damage using 8kV of accelerating voltage. For semi-quantification of elements, it was chosen a general scan for the elements distributions of the samples and a single point individual analyses, which means selecting many points to reach the composition of a selected

region of the micrographs. For quantification of elements, it was chosen C-K / O-K / Mg-K/ Al-K / Si-K / S-K / Cl-K / Ca-K.

3. RESULTS AND DISCUSSION

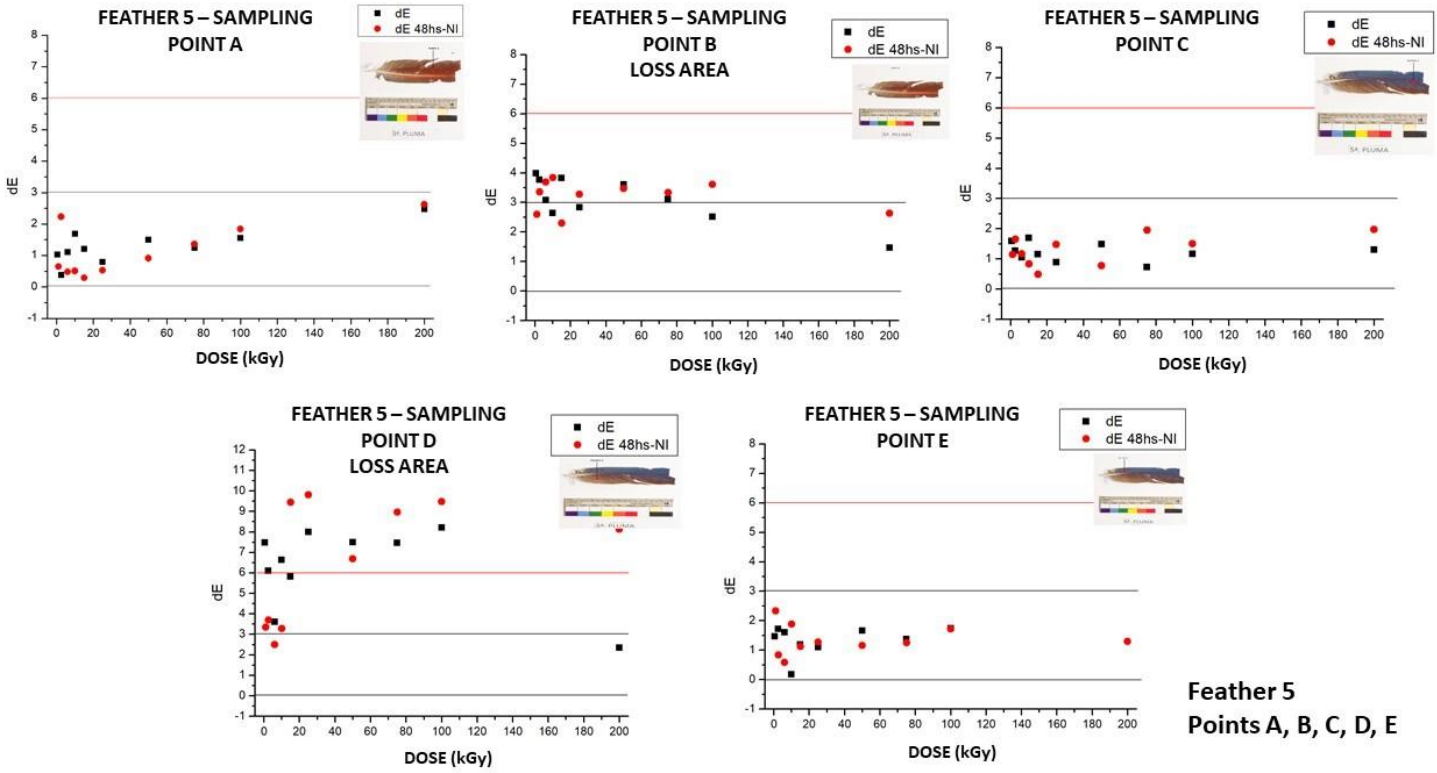
3.1. Colorimetry

In this study, approximately 232 measurements were considered according to feathers 5 and 31. Color fading was estimated by determining ΔE CIELAB and considering the criterion proposed by Hardeberg [16] about the relationship between ΔE and the perception of color change (Table 2).

Table 2: ΔE and the perception of color change.

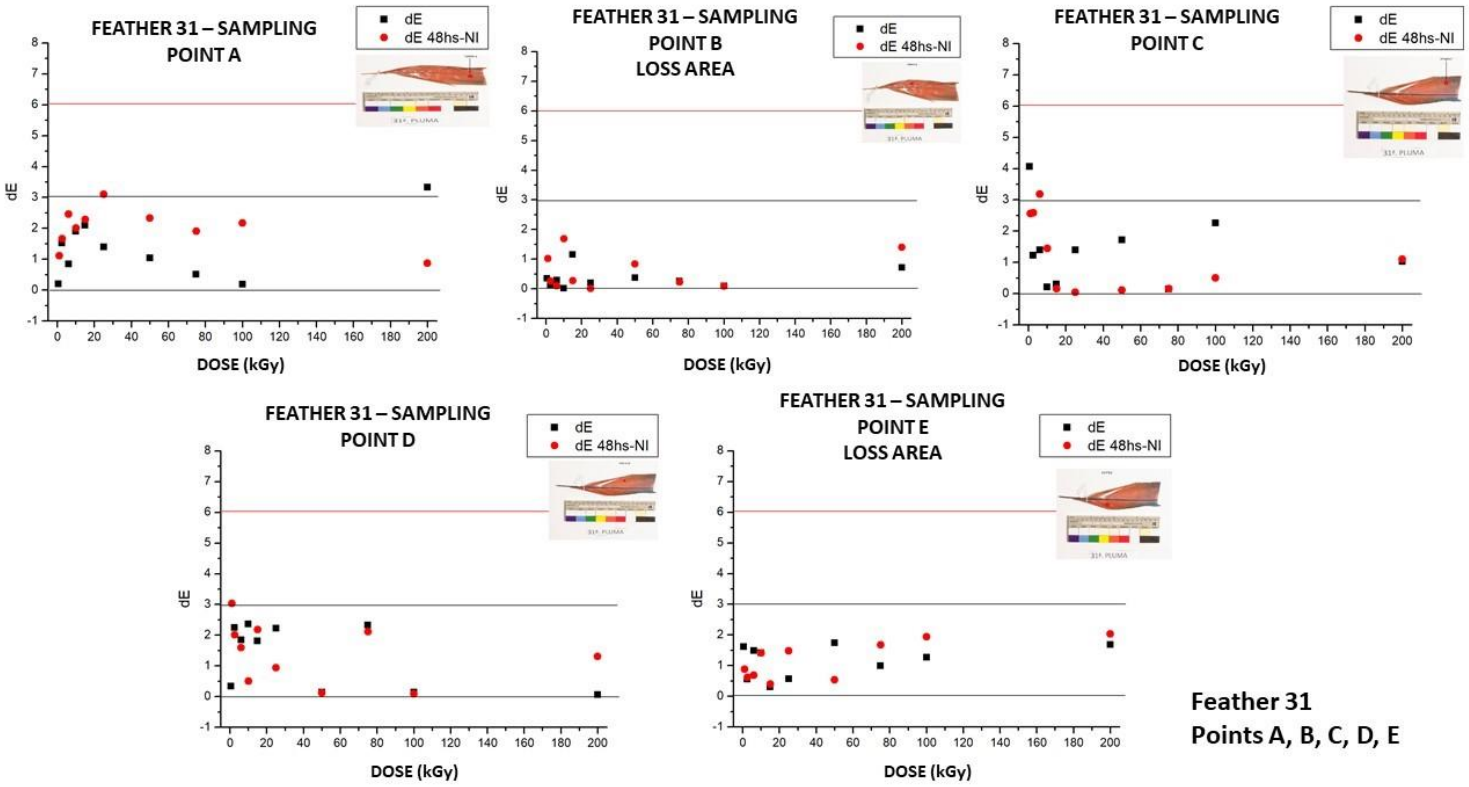
ΔE	**Effect**
< 3	Hardly perceptible
3 < 6	Perceptible, but acceptable
> 6	Not acceptable

Figure 6: *Values of ΔE in relation to the doses of gamma rays - Feather 5 - Points A, B, C, D, E*



As shown in Fig. 6, the points A, C and E measured in feather 5 are within the limit of $\Delta E < 3$, thus implying a hardly perceptible color change. The points B and D presented variable results, since they were areas of losses that could have their readings affected by the material fragility of these points. In addition, these two points were close to the central stem of the feather (calamus), which may have made it difficult to read at these points. We can say that there is a tendency to increase the value of ΔE from doses above 50 kGy. However, even the high doses (up to 200 kGy) were within the limiting range of the color change, which was difficult to perceive, with $\Delta E < 3$.

Figure 7: *Values of ΔE in relation to the doses of gamma rays - Feather 31 - Points A, B, C, D, E*



As shown in Fig. 7, most of the measured points of feather 31 are within the limit of $\Delta E < 3$, thus implying a hardly perceptible color change. Some measurements show $\Delta E > 3$ and we conclude that these may be only errors at the time of the reading caused by a different positioning at the sampling point. Again, we have proof that doses up to 200 kGy are safe to avoid causing significant chromatic changes in the feathers.

3.2. SEM analysis

The images show different morphological structures and small dust particles in the two samples at different resolutions. No effect of the irradiation on the structure of the samples can be noted on the SEM images of non-irradiated and gamma irradiated samples as shown in Figure 8 and 9.

SEM images of feather samples studied here are similar to the ones observed by Sullivan et al [4] attributed to barbs and barbules of feather.

Figure 8: *SEM micrographs of the non–irradiated (0kGy) and irradiated samples (15kGy) - Feather 5.*

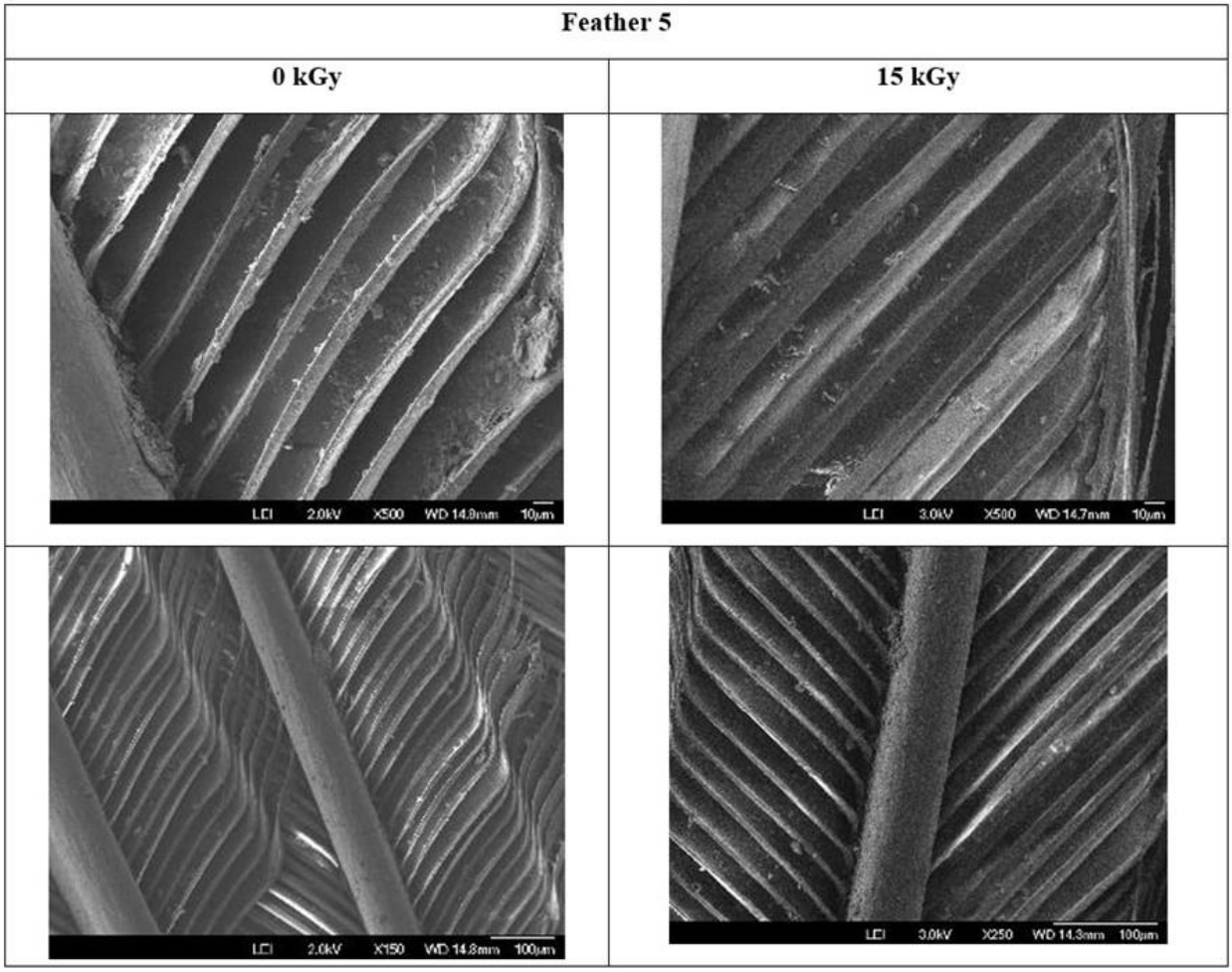
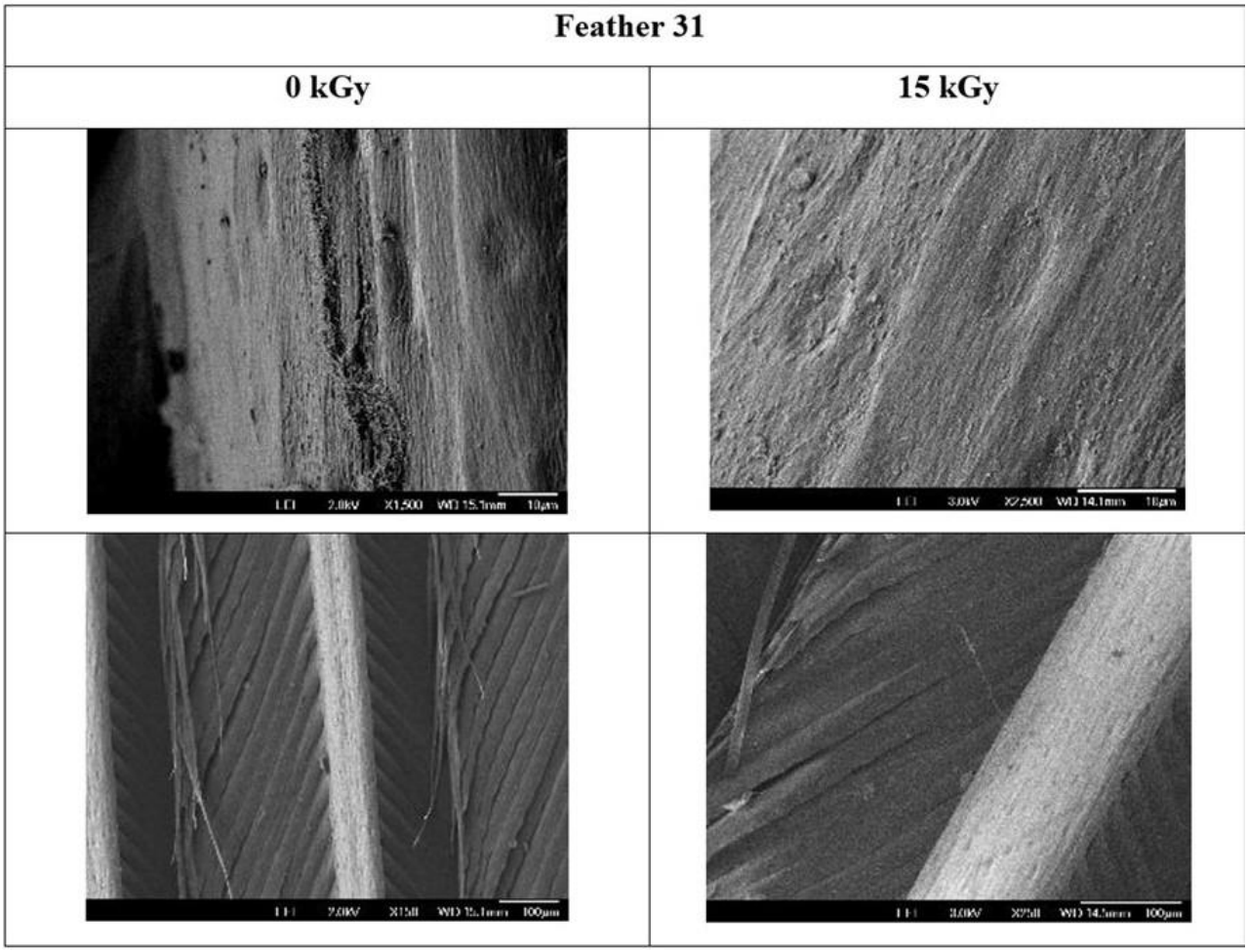


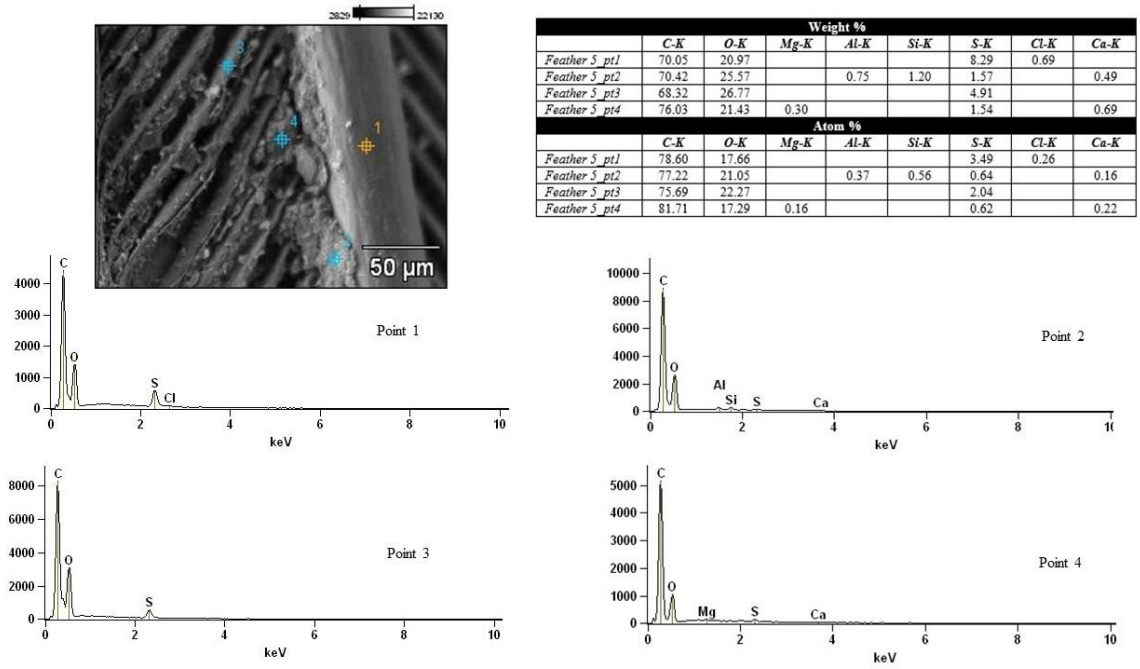
Figure 9: *SEM micrographs of the non–irradiated (0kGy) and irradiated samples (15kGy) - Feather 31.*



3.3. Energy-dispersive X-ray spectroscopy (EDS) analyses

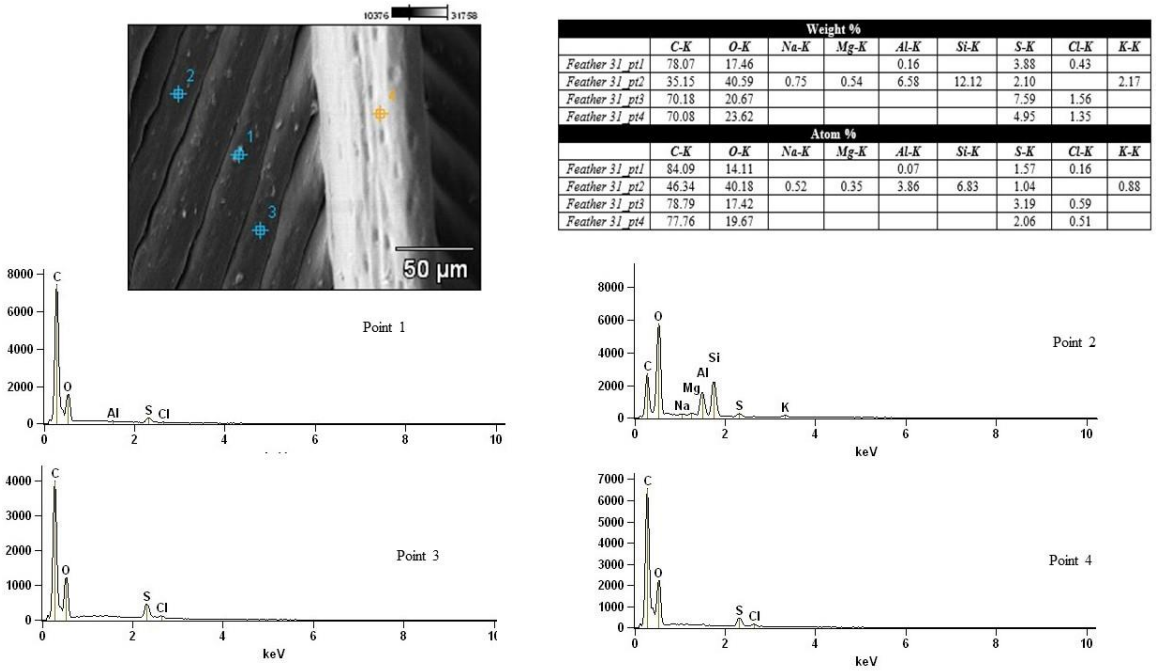
EDS was used for the chemical analysis of these samples. As shown in Fig. 10 and 11, the spectrum provides a fingerprint of the specific elements present in feathers 5 and 31. The selected points provide individual semi-quantitative analyses through mapping of elemental distribution on the sample surface. Presence of sulfur is in agreement with the feather composition [6].

Figure 10: *EDS semi-quantitative results for 4 selected points for Feather 5. Accelerating Voltage: 8.0 kV Magnification: 500.*



Weight %	C-K	O-K	Mg-K	Al-K	Si-K	S-K	Cl-K	Ca-K
Feather 5_pt1	70.05	20.97				8.29	0.69	
Feather 5_pt2	70.42	25.57		0.75	1.20	1.57		0.49
Feather 5_pt3	68.32	26.77				4.91		
Feather 5_pt4	76.03	21.43	0.30			1.54		0.69
Atom %								
	C-K	O-K	Mg-K	Al-K	Si-K	S-K	Cl-K	Ca-K
Feather 5_pt1	78.60	17.66				3.49	0.26	
Feather 5_pt2	77.22	21.05		0.37	0.56	0.64		0.16
Feather 5_pt3	75.69	22.27				2.04		
Feather 5_pt4	81.71	17.29	0.16			0.62		0.22

Figure 11: *EDS semi-quantitative results for 4 selected points for Feather 31. Accelerating Voltage: 8.0 kV Magnification: 500.*



Weight %	C-K	O-K	Na-K	Mg-K	Al-K	Si-K	S-K	Cl-K	K-K
Feather 31_pt1	78.07	17.46			0.16		3.88	0.43	
Feather 31_pt2	35.15	40.59	0.75	0.54	6.58	12.12	2.10		2.17
Feather 31_pt3	70.18	20.67					7.59	1.56	
Feather 31_pt4	70.08	23.62					4.95	1.35	
Atom %									
	C-K	O-K	Na-K	Mg-K	Al-K	Si-K	S-K	Cl-K	K-K
Feather 31_pt1	84.09	14.11			0.07		1.57	0.16	
Feather 31_pt2	46.34	40.18	0.52	0.35	3.86	6.83	1.04		0.88
Feather 31_pt3	78.79	17.42					3.19	0.59	
Feather 31_pt4	77.76	19.67					2.06	0.51	

4. CONCLUSION

The colorimetric analysis showed that there was no significant change in the irradiation range applied in this experiment ($\Delta E = < 3$). Although we have applied high doses like 200 kGy, the feathers did not undergo perceptible chromatic alterations. The colorimetric readings of feathers can be complex, since this material is translucent and has a very different color gamut on the front and back side. The areas of losses (caused by previous biological attacks and also natural fault bars) can offer misleading readings. In addition, the object's own geometry hinders the accuracy of the measurements. Areas near the central stem (calamus) with higher volume are difficult to measure because the positioning angle of the colorimeter may be compromised during readings. For future work, we recommend avoiding these areas as points of analysis. The SEM images also proves that up to 15 kGy radiation absorbed dose the samples did not present significant differences in their morphological topography. The EDS spectra present the protein chemical composition of the materials analyzed, confirming the presence of S chains responsible for constituting the feather keratin materials. These spectra also reveal other substances such as Si and Cl that can be part of the dirt present in the ethnographic object. The results indicate that feather artifacts can be subjected to gamma radiation without their colors being affected. Higher doses are not necessary for usual treatments against biological infestations.

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