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Anoxic Treatment for the Eradication of Insects in the Choral Books of the Museo del Convento de los Descalzos, Lima, Peru

Ir a versión en español

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Javier Nakamatsu
Departamento de Ciencias, Sección Química, Pontificia Universidad Católica del Perú (PUCP), Peru
javier.nakamatsu@pucp.pe
ORCID: https://orcid.org/0000-0001-7721-7716

Jhonatan Arízaga
Departamento de Ciencias, Sección Química, Pontificia Universidad Católica del Perú (PUCP), Peru
jjarizagat@pucp.edu.pe
ORCID: https://orcid.org/0000-0001-5752-1032

Ivon Canseco
Escuela Nacional Superior Autónoma de Bellas Artes del Perú (Ensabap),
Museo de Arte Contemporáneo de Lima (MAC-Lima), Peru
imacava@gmail.com
ORCID: https://orcid.org/0000-0003-0181-3153

Patricia Gonzales
Departamento de Ciencias, Sección Química, Pontificia Universidad Católica del Perú (PUCP), Peru
pgonzales@pucp.pe
ORCID: https://orcid.org/0000-0003-0136-5813

Translated by Fernanda Andablo

ABSTRACT

One of the main causes of loss of historical heritage in museums is an insect attacks. At the *Museo del Convento de los Descalzos* in Lima, Peru, this is a severe problem, particularly in its choral books, which date from the 17th to 19th centuries, due to the materials used in their manufacture. Some disinfestation treatments for objects require compounds that either damage them or are toxic. A non-aggressive and effective alternative to disinfestation is anoxic treatment. In this case, the books were placed in laminated aluminum bags filled with nitrogen and an oxygen inhibitor. The treatment's efficiency was confirmed through X-ray images of the books. This inexpensive and easily adaptable disinfestation method, was successful and constitutes

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a noteworthy way to stop the deterioration caused by xylophagous infestation, both of choral books and other objects of artistic and historical value.

KEYWORDS

choir books, anoxia, disinfestation, inert atmosphere

INTRODUCTION

Choral books (also known as choir books or cantoral books, *libros de coro* o *cantorales* in Spanish) are those which contain the chants for the divine office and the Mass. Usually, they include both the text and the musical notation of the chants. Their large size is one of their distinguishing features since the singers had to read them from a distance, from a lectern placed in the center of the space intended for the choir spaces in the churches (Sierra, 2014, p. 43). Often the production of choral books coincided with the construction of monasteries, where the monks, assisted by scribes and illuminators, oversaw their creation. On other occasions, new monasteries acquired their choral books from the existing collections from another one (García, 2005, p. 152; Sierra, 2014, p. 52). The dimensions and quality of the books and their origin depended on the size of the choir and their lectern, and, mostly, on the resources available to the monastery (Estrela, 2015, p. 10).

In addition to the text and musical notation of the songs, choral books feature different types of illuminations, including illustrations and metallic applications: such as full-page decorations, borders, ornate capital letters, among others. These books were in use from the 15th century through the first half of the 20th century (with production declining from the 17th century onwards), and although their content was always the same (Catholic Church chants), the style of their illuminations evolved over the time (Sierra, 2014, p. 48). Due to the elements that comprise these books, such as text, music, and illuminations, they are of significance across disciplines from history to musicology.

For their production, a wide variety of materials were used, such as tanned leather, wood, nails, and brooches for the covers, as well as hemp and linen threads for the seams. Initially, parchment was used for writing, later replaced by paper. Inks were used for writing, pigments of mineral and vegetable origin for the illustrations, binders for the pigments and inks, and metallic applications for the illuminations (Crespo, 2014, p. 91). The presence of this diversity of heterogeneous material and the interactions between them can

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become a starting point for the deterioration of choral books (Bueno-Vargas, 2006, p. 44; Crespo, 2014, p. 105).

Additionally, since the books would be used permanently in Catholic rituals, their constant manipulation contributed to their wear and tear, apart from the fact that in many cases they underwent modifications over time; including addition of pages, scrapings, corrections, and patches (Bueno-Vargas, 2006, pp. 51-54; Crespo, 2014, p. 105; Sierra, 2014, p. 55). Finally, environmental conditions, such as lighting, temperature and relative humidity (RH) fluctuations, and biological factors (fungi and insects) also contribuited to their deterioration (Bueno-Vargas, 2006, pp. 44-45; Crespo, 2014, p. 97).

The *Museo del Convento de los Descalzos* (at Rimac district, Lima, Peru) has a collection of nearly 14,000 ancient books, among which 30 choral books dating from the 17th to 19th centuries stand out. The smallest one measures 53 cm x 46.7 cm, while the largest one measures 63 cm x 45.5 cm. They are crafted from parchment and paper, with wooden covers bound in leather, and are sewn with hemp fiber. Written in Gothic script and square musical notation, they feature black ink on staves with lines in red ink. In some of them, the capitulars are decorated while others also present polychrome floral designs and lacework (Figure 1). The books are located in the Choral Book Room in the San Francisco Cloister. This is a non-air-conditioned room, with limited lighting and ventilation; nonetheless, it is subject to the moderate temperatures and high humidity typical of Lima. Although the access to this room is restricted to avoid excessive exposure of the books to light and other factors that could accelerate their deterioration, these environmental conditions provide a climate conducive to the development of xylophagous insects.

One of the main threats to the collection are the termites *Cryptotermes brevis*. They feed primarily on cellulose, particularly wood, and produce a characteristic excrement, in the form of very small spheres, which helps to evidence their presence. These termites, unlike their subterranean counterparts, do not need to be in contact with moist soil. As long as the environmental humidity is high enough to provide them with the necessary water, they can inhabit the wood they have infested, without needing to leave it (Trematerra & Pinniger, 2018, p. 229).

Other insects commonly found in infested book collections include silverfish, which belong to the species *Lepisma saccharina*. These wingless insects, that are generally silver in color (hence their name), prefer to live away from light sources and in humid en-

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FIGURE 1. Illustrations and writing inside the choral books (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

vironments. They feed on various organic materials, such as paper, cardboard, and wood, and, mainly, those that contain polysaccharides, like starch or its derivatives. Their excrements can stain cardboard or paper surfaces. Silverfish—along with as some other insects—can remain inactive for months due to lack of food, a characteristic that makes their elimination difficult (Querner, 2015, p. 601).

Methods for addresing insect infestations can be divided into two categories: *chemical methods* (involving compounds toxic to insects) and *non-chemical methods*. In the first category there are various types of treatments to disinfest historical objects. One of them involves the use of toxic compounds (pesticides). These can be divided into groups based on their application method. For instance, they can be applied in powder form (such as para-dichlorobenzene or naphthalene), as liquids (biological agents such as pyrethroids and growth hormones), via aerosols or gases (such as methyl bromide), or by controlled release (such as 2, 2-dichlorovinyldimethyl phosphate) (Linnie & Keatinge, 2000, pp. 1 -2; Querner, 2015, p. 597).

In general, the problem with this type of treatments is that they are not effective in destroying insect eggs. Additionally, they expose people to toxic substances not only during their application, but also afterwards, since these compounds eventually become impregnated in the material of the books. Furthermore, the books can be damaged due to reactions with these compounds. In this way, stains or discolorations can occur during these treatments, especially if they contain organic solvents, as in most cases (Querner,

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2015, p. 597; Selwitz & Maekawa, 1998, p. xi). Finally, some of the mentioned compounds are persistent, so they also affect the environment in the long term.

On the other hand, there are non-chemical methods for eliminating insects in museum pieces; some of these methods are the thermal treatment, which involves the application of both cold and heat, the exposure to microwave radiation, treatment with oxygen-free atmospheres (anoxic), and electrocution (with high voltages and low electrical currents). In practice, most of these methods are not applicable to every insect infested object.

An alternative that has been used for some time is the thermal shock treatment. This requires subjecting the infested object to temperatures to which most insects are not normally exposed to, such as the range of 15 to 25° C —or 59 to 77° F— (Valentín, 1998, p. 18). Thermal treatments have been used to disinfest museum objects, both raising and lowering the temperature. In general, it is possible to use high temperatures, but, since this accelerates the degradation reactions of the materials and their dehydration, its application is limited to certain types of materials and is carried out only for short periods. For example, exposure of infested pieces for four hours at 52° C —125° F— has been reported (Museums & Galleries of NSW, 2011), or at higher temperatures for about thirty minutes (Lewis & Haverty, 1996, pp. 928-929).

Another possibility, which has recently been proposed and is currently being studied, is a heating treatment using microwave radiation. It has been reported that short periods of microwave exposure (around two minutes) of infested wooden objects may be sufficient to exterminate the insects without dehydrating or damaging the wood (Chidichimo, Dalena, Rizza, & Beneduci, 2017 p. 5). In contrast, the English Heritage charity in the United Kingdom has designed procedures for cold treatment, recommending temperatures of –18 to –20° — or C 0 to -4° F— for fourteen days, or three days at –30° C —-22° F— (Lauder & Pinniger, 2019, p. 1). However, this technique becomes complicated for the treatment of objects sensitive to these temperatures or due to the physical capacity of the treatment chamber, which is recommended to be able to quickly lower the temperature to guarantee its effectiveness (Zhang, 2012, p. 335). The use of freezing-and-unfreezing cycles has also been reported in order to make disinfestation more effective, which requires more technically demanding equipment.

As for anoxia, it consists in exposing the infested object to an oxygen-deficient atmosphere, in such a way as to cause permanent damage to the pest (this kind of treatment reports one hundred

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percent of mortality in all life stages). One way to perform anoxic treatment is to place the infested material in a vacuum chamber and remove the air. With this idea, Chidichimo and company exposed wood samples with *Hylotrupes bajolus* larvae to pressures of 10^{-2} Ba from 8 to 144 hours, causing their death due to dehydration between 10 and 25 days after said treatment (Chidichimo, Dalena, & Beneduci, 2015, p. 271).

This type of treatment can also be carried out using chambers that allow the air to be replaced with an inert gas, usually nitrogen or argon, although carbon dioxide has also been used. These gases are preferred due to safety concerns regarding their handling and due to their low potential for damaging the treated object. Furthermore, this process can be carried out under controlled humidity and temperature conditions, which, compared to the application of vacuum, reduces the possibility of damaging to the treated object. In the case of insects, Chidichimo and company explain that the mechanism that causes death is desiccation. The spiracles (holes —or openings— through which oxygen enters the trachea of the insects) are sensitive to the concentration of oxygen in the air, so when it is lower, they open wider and more frequently, which dehydrates the insect. Generally, a loss of 20 to 30% of the insect's weight causes its death (Chidichimo, Dalena, & Beneduci, 2015, p. 271).

Anoxic conditions also have additional advantages: not only do they stop the development of insects and fungi, but they also prevent the oxidation of materials and delay the color fading in manuscripts due to the oxidation of pigments (Hanlon, Daniel, Ravenel, & Maekawa, 1993, p. 1; Rust & Kennedy 1993, p. 4; Selwitz & Maekawa, 1998, p. xi; Valentín, 1998, p. 19). Besides selecting the gas to be used, the treatment time is also an extremely important factor. This depends both on the type of insect and its stage of development, and on the temperature and residual oxygen content. Given what was explained above, a higher temperature and a lower amount of oxygen require a shorter treatment time since these conditions would favor the desiccation of the insect. Supporting this information is data that has been reported for different species, ranging from one to just over twenty days of treatment (Selwitz & Maekawa, 1998, p. 46). However, the determination of this time also depends on the materials and the structure of the object to be treated since the gases are required to penetrate the entire material until they reach the insects.

In 2013, the *Museo del Convento de los Descalzos* began the preventive conservation work on the choral books. That same year, the museum organized the *Segunda Jornada de Arte* which had

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as its main theme *The Book Is Art: Preventive Conservation in Libraries*. Within the frame of this occasion, a conservation and restoration specialist from the *Biblioteca Nacional de España* (BNE, National Library of Spain) not only participated in the event, but also trained two people who could then be in charge of the conservation of the collection.

After that first training, the books that were found to have active xylophagous pests (termites, *Cryptotermes brevis*) were isolated and treated with Prematek, which is a water-insoluble liquid product, manufactured by *Tecnoquimica, S.A., Peru*. This product contains an organometallic compound of tin at a concentration of 1% in an aliphatic hydrocarbon. It is also commonly used for the elimination of both moths and wood fungal rot, but causes irritation upon contact with the skin and eyes. Since their Prematek treatment, the books have been kept dust-free, wrapped in Sontara[1] and placed on wooden shelves. From this point on, a permanent record of the temperature and relative humidity conditions of the choral book room is also kept.

The conservation of choral books is a constant concern for the *Museo del Convento de los Descalzos*. As mentioned previously, the weather conditions in Lima favor a high incidence of xylophagous infestation, and this poses a threat to the integrity of the collection. Thus, it is required to have a system that can be used periodically as a treatment for any possible infestation of choral books. For this system to be sustainable over time, it must be low-cost and account both for the health of the museum staff and, to the extent possible, also be applicable to other objects in the collection. Therefore, it was decided to design an anoxia disinfestation system using laminated aluminum bags. This document presents, as an example, the results obtained with the treatment of one of the choral books and the comparison with another book that did not undergo any treatment.

MATERIALS AND METHODS

In total, nine books were worked on, which underwent an anoxic treatment with gaseous nitrogen and oxygen inhibitor, although some only with inhibitor (Figure 2). The treatment protocol was suggested by Dr. Nieves Valentín, a microbiology specialist who had recently retired from the *Instituto del Patrimonio Cultural Es-*

[1] Sontara is a multi-layer non-woven cloth, highly absorbent and with excellent mechanical resistance, which does not contain binders or chemical adhesives, and which is also used for cleaning surfaces, as it does not leave lint.

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pañol (IPCE, Spanish Cultural Heritage Institute). This was done in a second training stage at the museum.

Book[a]	Type and time of treatment	Comments[b]
15	**No treatment (control)**	**X-Rays: 173-day interval**
18	No treatment (control)	
1	Anoxic: O_2 inhibitor only, 22 days	
4	Anoxic: O_2 inhibitor only, 22 days	
7	Anoxic: O_2 inhibitor only, 22 days	
3	Anoxic: N_2 + O_2 inhibitor, 25 days	
9	Anoxic: N_2 + O_2 inhibitor, 22 days	
13	Anoxic: N_2 + O_2 inhibitor, 22 days	
23	**Anoxic: N_2 + O_2 inhibitor, 22 days**	**Sensor: T, HR y O_2** **X-Ray: 230-day interval**
26	Anoxic: N_2 + O_2 inhibitor, 22 days	
30	Anoxic: N_2 + O_2 inhibitor, 25 days	Sensor: T, HR y O_2

[a]: book codes belong to the Museo del Convento de los Descalzos.

[b]: T: temperature; RH: relative humidity.

FIGURE 2: Table of the choral books included in the study (those that were evaluated are highlighted). (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

At the time of the treatment of the books, they were in poor conditions and with an active termite infestation (*Cryptotermes brevis*), located mainly in the covers (Figure 3), despite their Prematek treatment five years earlier. Book 23, which serves as an example in this report, had tears in the cover and missing supports in the corners. Although the wood of the lids appeared to be strong and intact, the cover presented some holes from insect attack and detritus (residues from decomposition of the material). The end papers were attached with fabric and organic adhesives, which could have served as food for xylophages.

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FIGURE 3. 19th Century choral book (Book 23) damaged by termites (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

Given the dimensions of Book 23 (42.5 x 59.5 x 17.8 cm), it was placed in a 1 x 1 m laminated aluminum bag (FlexiArt®). Once the book was inserted, the bag was first partially sealed with heat, and most of the air was removed from the inside with the help of a vacuum cleaner. Subsequently, previously humidified nitrogen gas was introduced, passing the gas through a volume of water. Then, the gas was removed from the inside of the bag for a second time, and it was refilled with nitrogen to further reduce the oxygen content. This operation was repeated once more and then a 0.5 kg package of a Hanwell® oxygen inhibitor, which in its composition contains around 50% by mass of elemental iron, was introduced before completely sealing the bag. Along with the book, a temperature and humidity recorder and a remote oxygen sensor (AnoxiBug, from Hanwell®) were also placed inside the bag to monitor the treatment conditions. The book remained under the anoxic atmosphere for 22 days. X-ray plates were taken of the book covers before the procedure, and 208 days after the treatment.

When handling nitrogen gas, it should be done with caution: managing pressure gauge and appropriate connectors, securing the cylinder to prevent it from falling, and ventilating the environ-

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ment in case of a leak, since it is a high-pressure gas. Once the system bag is sealed, there is no danger, because the gas is confined inside. Additionally, the oxygen inhibitor always has a resistant protective cover that facilitates its handling and protects the operator.

RESULTS AND DISCUSSION

Book 23 was subjected to an anoxic atmosphere for 22 days, in a room at ambient temperature. Figure 4 shows the process that was followed for its treatment: placing it in the bag, sealing it, and recording the temperature and relative humidity inside the bag throughout the treatment. During that period the bag did not change in volume. This means that there was no loss of gas from inside: the material was suitable for its purpose. At the same time, the effectiveness of heat sealing was demonstrated. The temperature inside the bag varied between 17 and 19° C —62 to 66° F—, depending on the environmental conditions of the room, which lacked a controlled temperature system, and the relative humidity ranged from 57 to 60 percent.

It is important to maintain a certain degree of humidity in the bag since very low relative humidity can cause some materials to become rigid or inflexible (desiccation). This mainly happens to materials that tend to absorb water, such as the object of this study. Additionally, humidity excess favors the growth of microorganisms when the treatment continues for a long time. In short periods of time, high humidity can increase the flexibility of some materials and favor their deformation; for example, when accompanied by changes in temperature, this can result in the curling of papers and cardboard. However, in this study process no change of this type was observed. The oxygen content measured inside the bag was less than 0.2% (the Hanwell® AnoxiBug sensor alerts if this limit is exceeded). This demonstrates that the system, which consisted on the type of bag used and the Hanwell® oxygen inhibitor, as well as the methodology proposed and carried out, was able to maintain the anoxic conditions inside throughout the treatment.

The efficiency of disinfestation is difficult to verify and evaluate. In samples specifically designed to facilitate the collection of cellulosic material processed by insects, Chidichimo and company verified the cessation of their activity by weighing said material after its treatment (Chidichimo, Dalena, & Beneduci, 2015, p. 270). In this case, to verify the effectiveness of the treatment, it was decided to compare the X-ray plates taken from Book 15 (control

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FIGURE 4. Anoxic treatment of Book 23: heat sealing of a nitrogen-filled bag, humidity and temperature monitoring during treatment (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

book, not subject to anoxic treatment), with an interval of 173 days between the analyses. As can be seen in Figure 5, in the period of just under six months between taking the X-ray plates, the damage caused by termites increased in the covers of the control book, where the cavities extended and branched.

Similarly, the effect was evaluated on Book 23, which was subjected to an anoxic atmosphere for 22 days. Figure 6 shows the X-ray plates taken from the front cover of the book before the treatment, as well as another plate which was taken 230 days after the first one (208 days after the end of the anoxic treatment). Unlike the control book, in this case there is no evidence of an increase in damage to the book once treated, even if the evaluation interval was almost two months longer than with the control. This indicates that the treatment stopped the destructive activity of the xylophages in the book. The other books treated were not subjected to X-rays, to reduce the risks associated with handling and transportation (the museum does not have access to adequate

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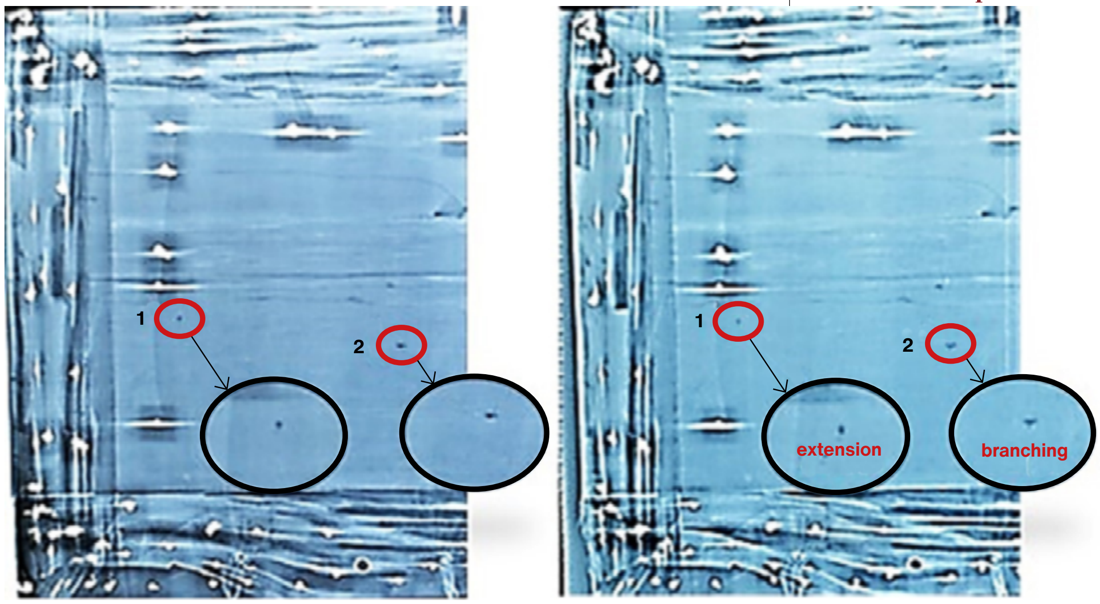

FIGURE 5. X-ray images of the front cover of Book 15 (control without anoxic treatment), showing termite activity. The plate on the right was taken 173 days after the one on the left (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

equipment for this; thus, both Book 23 and 15 were the only ones taken to a medical center for the X-ray analysis).

The protocol developed in this work made the anoxic treatment of large books effective, using normally available materials and equipment and without the need of a significant budget. To the extent possible, household appliances were used, such as a vacuum cleaner to remove the air inside the bag and an electric iron to seal it.

It is likely that the treatment conditions applied in this study are still not optimal, primarily in terms of the exposure time to the anoxic atmosphere. This is because the priority was put on the effectiveness of the treatment to disinfest the books, which were at very high risk of suffering further deterioration due to the infestation. More studies are needed to optimize both the treatment time and the amount of oxygen inhibitors needed.

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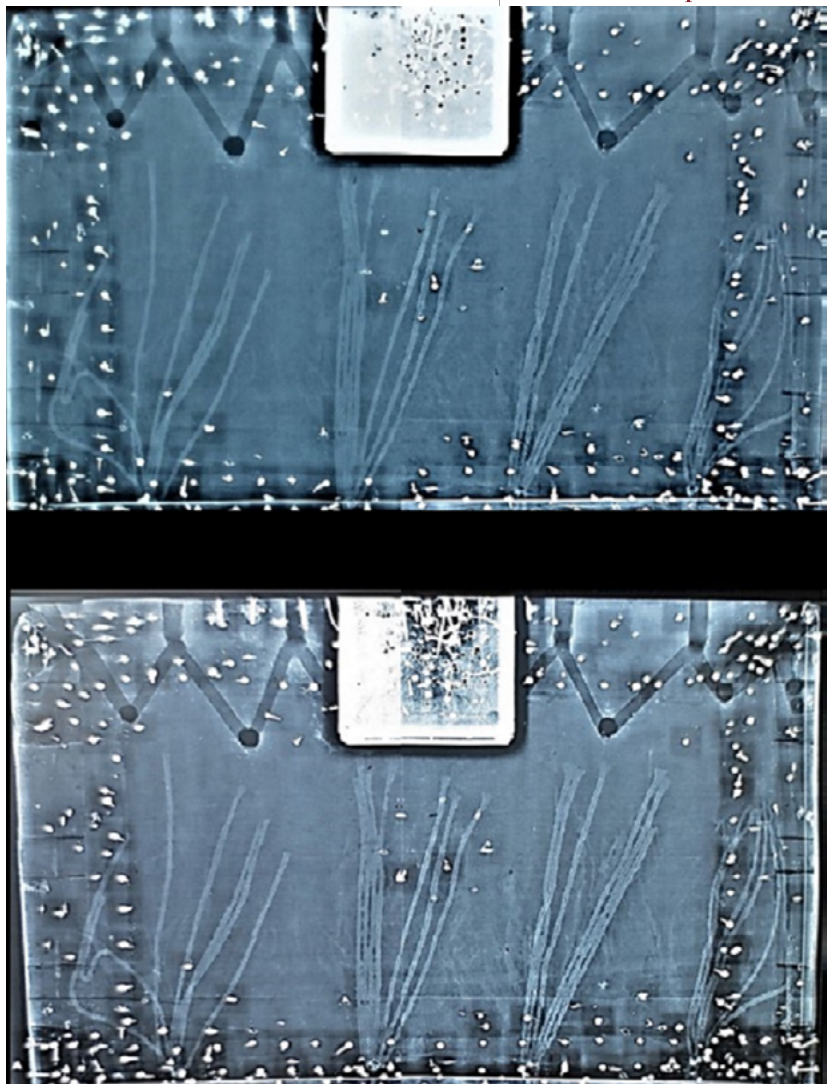

FIGURE 6. X-ray images (taken with an interval of almost 8 months) of the front cover of Book 23 subjected to anoxic treatment (above: before the treatment; below: 230 days after taking the first plate) (Photographs: Javier Nakamatsu, Jhonatan Arízaga, Ivon Canseco, and Patricia Gonzales; courtesy: *Museo del Convento de los Descalzos*).

CONCLUSIONS

Peru has a very rich and diverse tangible cultural heritage, whose conservation and valuing requires an interdisciplinary effort. Given the weather conditions of the city of Lima, infestation and damage by termites is one of the greatest risks faced by documentary heritage, and especially that made of wood. Anoxic treatment constitutes an interesting alternative to tackle this problem with easy-to-obtain materials and tools, and without using dangerous chemical compounds.

In this work, it has been demonstrated that it is possible to create and maintain an anoxic atmosphere in an effective and inexpensive manner for the safe treatment of infested materials. It is not necessary to have sophisticated and expensive equipment such as sealed chambers and vacuum pumps; but, rather, only laminated aluminum bags, gaseous nitrogen, and an oxygen inhibitor. Al-

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though the main difficulty and the bulk of the cost of the treatment used lies in the implementation of the source of pure nitrogen and the accessories for its proper management, this is only faced once. Low oxygen permeability bags and the oxygen inhibiting agent can be purchased as the need arises, and their cost is much lower. Additionally, with the proposed system, the amount of gas necessary for the procedure is limited, by selecting bags with sizes that fit the dimensions of the objects to be treated. For all these reasons, we consider that this methodology is useful for the treatment of books and other objects of interest infested by xylophages. Furthermore, it can also be applied periodically in a preventive manner.

Likewise, the proposed methodology can also constitute a practical and safe way to store valuable objects in an anoxic atmosphere even in risky environments, i.e., an ambient with high humidity and exposed to infestation by insects or microorganisms. Lastly, it was demonstrated that taking X-rays constitutes an effective technique to detect the activity of xylophages in wood and, therefore, to evaluate the degree of success of its treatment. In addition, this process has proven its effectiveness, making the damage caused by termites visible.

Finally, it is important to consider that in Peru there are very few places that have X-ray equipment dedicated to cultural heritage objects. Therefore, it was key to demonstrate that the X-rays provided in medical centers work perfectly for the conservation of these assets and this proves that the exercise developed in here can be turned into a valuable and effective tool, that is of easy access to the conservators on our country.

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ABOUT THE AUTHORS

Javier Nakamatsu
Departamento de Ciencias, Sección Química,
Pontificia Universidad Católica de Perú (PUCP), Peru
javier.nakamatsu@pucp.pe
ORCID: https://orcid.org/0000-0001-7721-7716

Graduated in Chemistry from the *Pontificia Universidad Católica de Perú* (PUCP) and PhD in Chemistry from Louisiana State University, USA. He is a professor at the Department of Sciences at the PUCP, where he works as a teacher at both undergraduate and graduate levels. In addition, he investigates topics related to the chemical recycling of synthetic plastics, the obtaining, characterization, and applications of biopolymers, the formation of geopolymers from industrial waste, the stabilization of soils with fibers and polymeric materials, and, recently, the formulation of mixtures for 3D printing for construction. He is currently coordinator of the Materials Modification Research Group.

Jhonatan Arízaga
Departamento de Ciencias, Sección Química,
Pontificia Universidad Católica de Perú (PUCP), Peru
jjarizagat@pucp.edu.pe
ORCID: https://orcid.org/0000-0001-5752-1032

Graduated in Chemistry from the *Pontificia Universidad Católica de Perú* (PUCP) in 2018. He is currently pursuing a master's degree in Materials Sciences and Engineering, also at PUCP. He has experience assisting research projects on artistic and cultural heritage materials using several analytical techniques (XRF, Raman, GC-MS, FT-IR), and work experience in quality control of mineral and soil samples for the mining industry, in companies

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such as ALS *Perú y Cía: Minera Agregados Calcáreos, S.A*. The development of self-healing coatings for the prevention of corrosion in metallic materials is one of the topics among his interests.

Ivon Canseco
Escuela Nacional Superior Autónoma de Bellas Artes del Perú (ENSABAP),
Museo de Arte Contemporáneo de Lima (MAC-Lima), Peru
imacava@gmail.com
ORCID: https://orcid.org/0000-0003-0181-3153

Bachelor in Plastic and Visual Arts with a specialty in Conservation and Restoration from the *Escuela Nacional Superior Autónoma de Bellas Artes del Perú* (ENSABAP). She graduated from the Master's Degree in Higher Education from the *Universidad Nacional de Educación* (National University of Education) "Enrique Guzmán y Valle". Since June 2022, she has worked as a curator at the *Museo de Arte Contemporáneo de Lima* (MAC-Lima), and, since 2016, she has been teaching at ENSABAP. Between 2015 and 2017, she was coordinator of the Paper Conservation and Restoration Workshop of the Fundación Descalzos del Rímac, responsible for the project *Conservación Preventiva de la Colección de Libros Corales del Museo del Convento de los Descalzos* and curator of the Museo del Convento de los Descalzos.

Patricia Gonzales
Departamento de Ciencias, Sección Química,
Pontificia Universidad Católica de Perú (PUCP), Peru
pgonzales@pucp.pe
ORCID: https://orcid.org/0000-0003-0136-5813

Graduated in Chemistry from the *Pontificia Universidad Católica del Perú* (PUCP) and PhD in Biochemistry and Molecular Biophysics from the University of Pennsylvania (Philadelphia, USA). She is a professor in the Departamento de Ciencias at PUCP, where she works as a teacher and researcher. Her line of research focuses on the chemical analysis of archaeological and artistic objects, and she coordinates the Grupo de Análisis de Materiales de Patrimonio Cultural.