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LOW TEMPERATURE TREATMENT OF PEST INFECTED PAPER DOCUMENTS

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Abstract

The eradication of pest insects which are pernicious for books and paper documents is an important problem. The existing chemical treatments are toxic and relatively dangerous for the preservation of paper supports. The exposure to freezing temperatures during a period of time offers a new alternative for chemical treatments. The utilization of extreme temperatures (-80°C) may reduce the time for the treatments of volumes of books from several days to several hours. Also this treatment can assure a complete mortality of species for all development stages.

Keywords: pest control, paper documents, low temperatures, preservation

1. Introduction

Nowadays, over 70 species of insects are known to cause significant damages in the libraries and archives [1]. There are several insects that can be frequently find in old books collections from Moldova, among them, *Stegobium paniceum* şi *Xestobium rufovillosum* (Coleoptera: *Anobiidae*) are the most dangerous species (Figure 1). These species induce significant damage in book when appear [2].

Stegobium paniceum is a cosmopolitan pest that may infest almost any dry animal or plant product. Only the larval stage of this species feeds. Within museums it has been known to attack a wide variety of materials including botanical and entomological specimens as well as anthropological artifacts.

Xestobium rufovillosum (commonly known as woodworms) is a xylophagous specie whose larval form attack and destroy wood and cellulose materials: textile, paper, cardboard, etc.

The deteriorations produced by insects are the following:

- physico-mechanical deteriorations (irreversible) of the paper: holes, galleries and cracks, rubbings and scrapes, and even perforations;
- the decrease of paper resistance determined by the consume of sizing agent;

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- the decrease of paper pH and its weakness caused by the introduction of different metabolic products;
- chromatic alterations of paper due to the accumulation of excrements.

The information data regarding the pest control treatment are offering a series of solutions to eradicate pest insects. The problems which appear are determined by the necessity to use chemicals in order to stop the biologic attack on paper supports. All along the time, scientists have demonstrated different noxious effects induced by the chemical substances used for the pest control; in this way modifying the paper composition and being toxic for the restorers [3].

Taking in consideration the aforementioned effects, the utilization of low temperature is highly recommended by the specialist for the pest control of the museum collections and archival holdings. This method is considered to be an economic and ecologic alternative to the chemical treatments usually used in museums for the annihilation of biologic pests.

The potential lethal effects can be explained by dehydration effects, osmotic swelling, changes in enzyme reaction rates, and ice crystal formation [4].

The pest control of books can be accomplished by the exposure and holding of infected paper samples in special conditions with low temperature (around -20 ÷ -29°C) during 72 hours 72h [5]. In 1984, Nesheim [5] had tried even lower temperatures for the pest control of books attacked by *Gastrallus* sp., the utilized temperature was -40 °C, during 72 hours of treatment.

Though, the researches [5, 6] have noticed that several species are very resistant even at temperatures beyond -15 °C. Fields mentions in his works that the adaptability of these insects brings in a survival possibility for weeks and months at -5 ÷ -10°C temperature, but at -25, °C the insects are frozen in 15 minutes [6].

According to Gilberg and Brokerhof [7] a direct exposure of the insects at specific conditions of -20°C and 75-85 % relative humidity (RH) for 2 hours, ensures a complete death rate at all developing stages: egg, larva, pup and adult.

The abundance of information about the eradication of insects in laboratory conditions still cannot cover the problem of insects that are infesting paper materials and lead to huge damages in archival holdings and museum documents. There are few studies concerning the low temperature eradication of pest insects inside books or volumes of documents. The only recommendations are the direct exposure at -30 °C during 72 hours [5] and repeated cycles of freeze-thaw at -20 ° during 48h [4].

Based on the existing data regarding pest eradication, the aim of the experiments described in this work are to investigate the effects of the treatment at -80°C applied to the books infested with *Stegobium paniceum* and *Xestobium rufovillosum* and to identify the secondary effects which appear during cyclic processes of freeze-thaw applied to the paper supports.

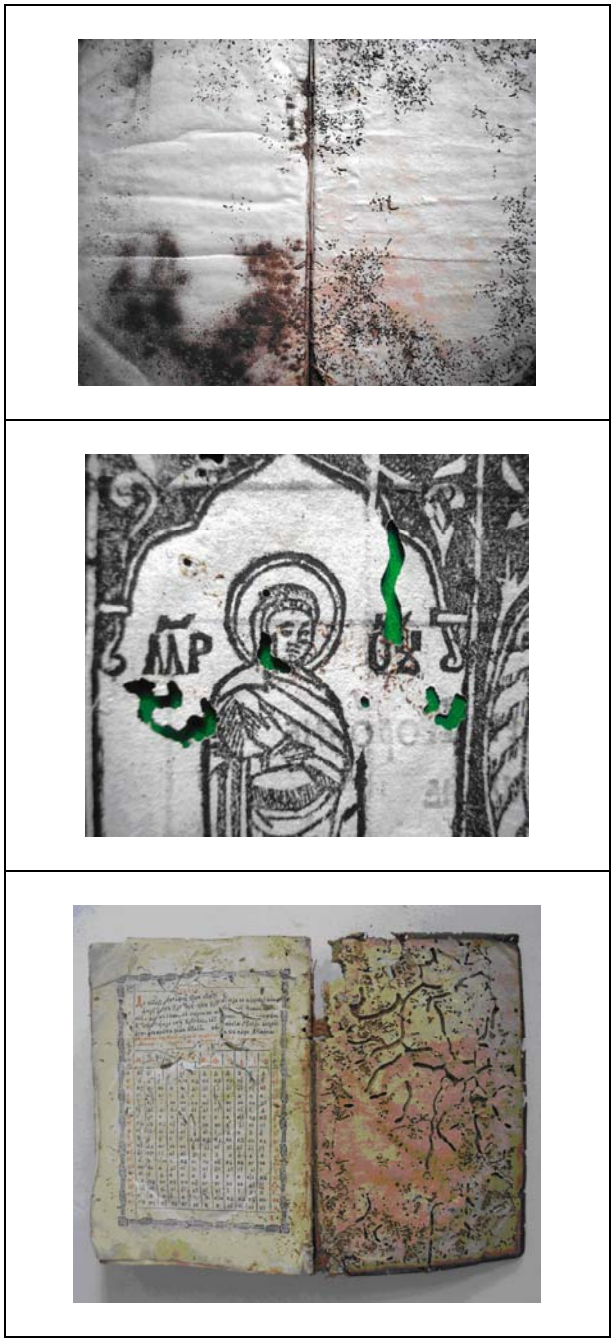


Figure 1. Books deteriorated by insects: (a) *Stegobium paniceum* and (b, c) *Xestobium rufovillosum*.

2. Experimental

2.1. Materials

2.1.1. Insects

Stegobium paniceum larvae were used for the experiment; all larvae (40 pieces) were grown at 19°C and 55 % RH, using dried bread. Also, *Xestobium rufovillosum* larvae were used for a comparative investigation.

2.1.2. Paper samples

The investigated supports were comprised of five industrially manufactured books having no patrimonial value.

For the destructive analysis two types of paper without patrimonial value have been used. The first type was similar with the paper which undergone infestation and pest control treatments, and the second type was hand made paper because the majority of books from the monasteries collections are based on the same paper support. The characteristics of papers are presented in Table 1.

Table 1. Paper materials utilized for the experiments.

Paper Type	Age	Fiber composition	Sizing agent	Filling agent	Basis weight (g/m^2)	Thickness, mm
Hand made paper	100 years	100% Textile fibers, hemp	Gelatin	$CaCO_3$	120±1	0.14±0.01
Machine made paper	35 year	Mechanical pulp	Colophonium	$CaCO_3$	65±1	0.1±0.01

2.2. Methods

2.2.1. Pest control treatment applied to the books

- Preliminary treatment

For the investigation, ten larvae have been introduced in four different volumes of book (2 cm thickness). The fifth book was used for the introduction of *Xestobium rufovillosum* with 6 mm length.

- Pest control treatment

The pest control treatment has been accomplished using Sanyo MDF-U5386S freezer, the working temperature has been set at -80°C. The time-period of the treatment has been assigned for one hour and two hours. When the freezing treatment was completed, the books were conditioned at 20°C and 55% RH.

The larvae from books number 1, 2 and 4 had been left inside books; the larvae from books number 3 and 5 had been removed and transferred to Petri dishes with dried bread, in this way reverting to the conditions before the treatment.

2.2.2. Paper treatment applied for the evaluation of the effects of low temperature

Paper samples had been conditioned at 20°C and 55 % RH. After that, each sample was packed in filter paper and introduced into a polyethylene bag with the air being partially removed according to the literature [8].

The samples of hand made paper had been maintained in the freezer for 1h, 3h, 7h and 14h; after that, these samples were brought back to room temperature (20°C).

The investigated properties were the following:

- physical-mechanical properties (bursting strength, tensile length) were measured for paper sheets using an Instron device, according to T494;
- sizing degree was determined according to $Cobb_{60}$/T441 om-90.

In order to evaluate the structural modifications, the paper samples were investigated using scan electron microscope (SEM) TESCAN Vega II SBH after covering with silver.

3. Results and discussion

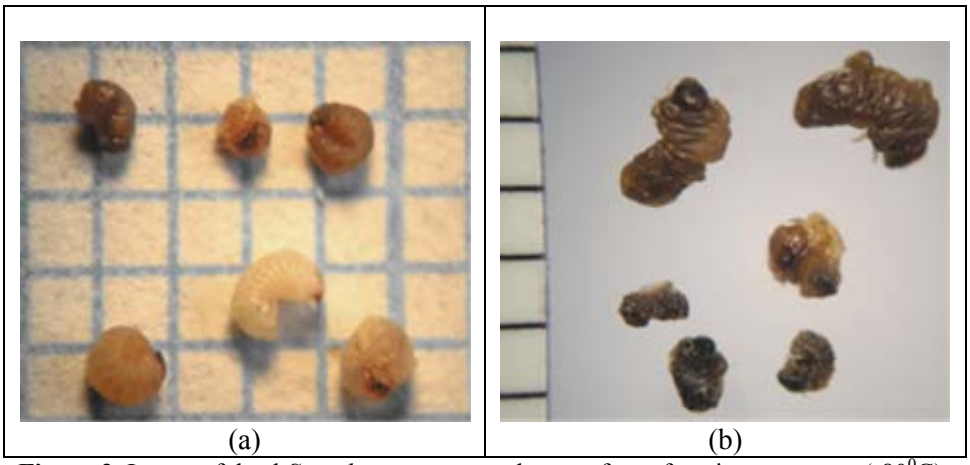
3.1. Effect of pest control treatment applied to papers

The pest control treatment proved to be highly efficient, the majority of larva utilized in the experiment have died after two hours of treatment (Table 2). After the exposure of the volume of books at -80°C for 1h and 2h, the *S. paniceum* şi *X. rufovillosum* larvae were motionless (Figure 2). The mortality rate in the case of *X. rufovillosum* proved to be no less than 100% just after 1h of freezing in the books of 2 cm thickness. The same result was obtained in the case of *S. paniceum* larvae which had been maintained in the same conditions (-80°C in books of 2 cm thickness), but the time-duration was longer, the freezing time was 2h. The sudden transfer of larvae from freezing temperature (-80°C) to the conditions of room temperature induces tissue necrosis.

The differences between the mortality rates of larvae have been determined mainly by the type of its preservation after freezing. Even though one hour of freezing treatment with sudden transfer to room temperature proved to be lethal to all larvae, the larvae bearing were different in the case of *S. paniceum* frozen during one hour and then kept forwardly inside the same books – not all larvae died. After 5 days treatment, during verification, it could be observed that from the total number of 10 larvae (*S. paniceum*) just 5 larvae were dead and the other 5 were alive, active and with a normal colour of tegument (Figure 3).

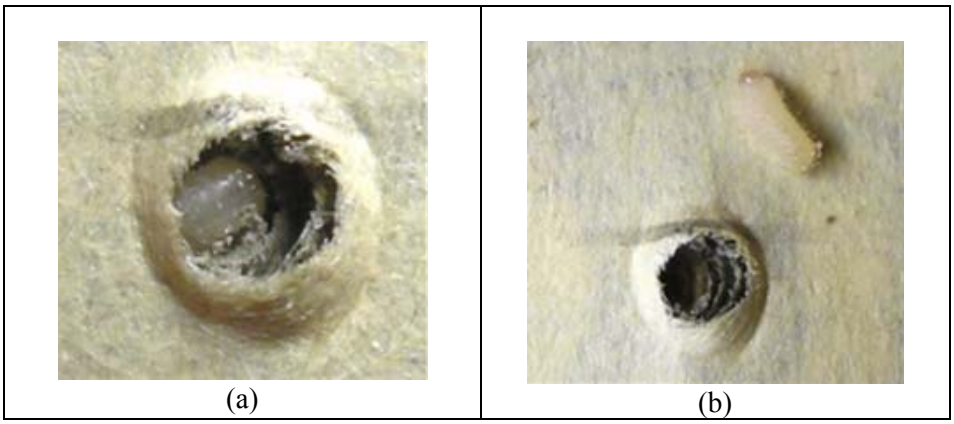
Table 2. Larvae mortality after the freezing treatment.

Book's number	Pest insects used for the investigation	Treatment time	Place for the maintaining of larvae after the freezing treatment		Mortality
			Inside the book	Outside the book (20^0C)	
1	*Xestobium rufovillosum*	1h	+	-	100%
2	*Stegobium paniceum*	1h	+	-	50%
3		1h	-	+	100%
4		2h	+	-	100%
5		2h	-	+	100%



(a) (b)

Figure 2. Image of dead *Stegobium paniceum* larvae after a freezing treatment (-80^0C) applied for: (a) 1 hour (b) and 2 hours.



(a) (b)

Figure 3. Image of *Stegobium paniceum* larvae which survived after the freezing treatment inside the books (a) and at light stimulus became active (b).

The survival of these larvae could be explained by the protection created by the books thickness, and also by the adapting capacity of the insects. All larvae that managed to survive were in the middle of the books volume, in this way, they were much more protected from freezing in comparison with the other larvae. The other essential aspect is the keeping of the larvae in the book even after the freezing treatment – this offering the possibility to avoid sudden changes of the temperature and to adapt gradually to the modifying conditions.

The *Xestobium rufovillosum* larvae have proved to be much more sensitive to freezing treatment in comparison with *S. paniceum* larvae. Just one hour of freezing treatment was lethal to all larvae, even in the case of larvae left inside the books after the freezing treatment (Figure 4). It is possible that this phenomenon could appear because of the lager dimensions of *X. rufovillosum* larvae: the size is causing a higher expansion to aggressive factors of the environment.

Figure 4. Image of *Xestobium rufovillosum* larvae: (a) before and (b) after treatment.

3.2. Effect of low temperature upon paper characteristics

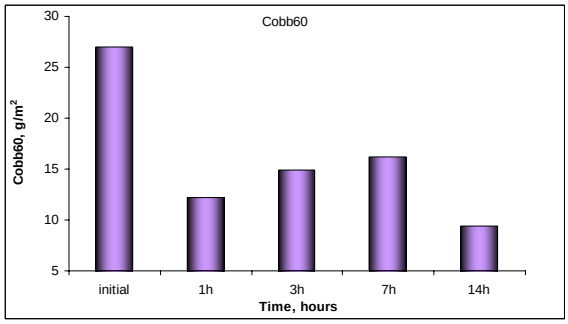
3.2.1. Cobb Number – Cobb60 (T441 om-90)

The sizing degree has been quantified according to the variation of Cobb values, which indicates the hydrophobicity of the paper (expressed as the amount of water retention per unit surface area of paper).

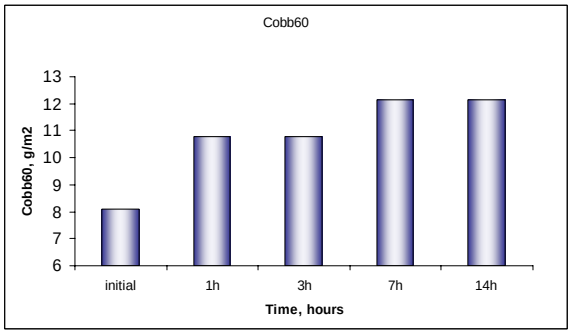
The variation of Cobb number in the case of hand made paper after the low temperature conditioning at different time-periods of treatment is presented in Figure 5a. A decrease of Cobb value can be noticed for all samples which undergone the treatment, indicating that the sizing degree is increased. It should be mentioned that after 14 hours of treatment Cobb number suffers a noticeable variation, reaching the value of 8.5 g/m^2.

The variation of Cobb number was also analyzed in the case of industrial paper (Figure 5b). The sizing degree decreases after the low temperatures treatment. The decrease is a gradual one (Cobb number increases from 8 to 12), the variation being related with the time-period of treatment.

The moisture variation is nearly the same in the case of hand made and industrial papers. The decrease in 1-2 units should not influence the strength of the paper.



(a)



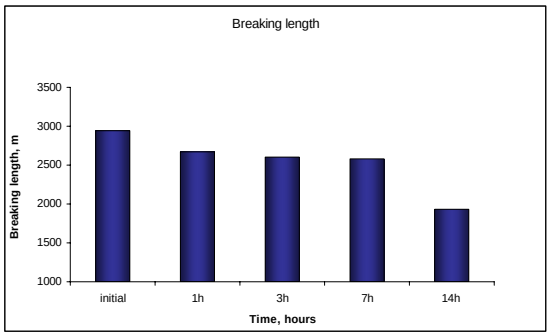
(b)

Figure 5. Cobb number variation after the low temperatures treatment: (a) hand made paper, (b) machine made paper.

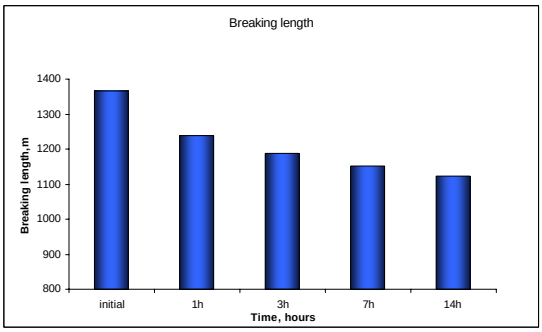
3.2.2. Tensile strength (T494)

Tensile strength (expressed as breaking length) modifications were analyzed before and after the freezing treatment for the two types of paper used for the experiment (Figure 6). The initial values of the breaking length differs, the value in the case of hand made paper is twice higher in comparison with the breaking length value of machine made paper. The graph representation shows that the variations are not significant if the time-period of treatment does not exceed 7h of treatment: 10 % decrease in the case of hand made paper and 16 % in the case of machine made paper. It shouldn't be neglect that after 14 h of

treatment the tensile strength suffers a significant decrease; that is why such a long time-period of treatment should not be recommended. Taking in consideration the importance of the historic documents containing hand made paper and the results obtained in the mentioned experiments, it is highly recommended to continue the studies with detailed experiments which should take in consideration the behaviour of paper with different initial moisture.



(a)



(b)

Figure 6. Breaking length after low temperature treatment: (a) hand made paper, (b) machine made paper.

3.2.3. SEM photomicrograph of paper

SEM analysis of the samples previously exposed to low temperatures does not reveal any major modifications of the aspect, for both hand made paper (Figure 7c-d) and machine made paper (Figure 8b-d), except the case of hand made paper maintained in freezer during one hour (Figure 7b). The micro fissures which are visible in paper structure could be determined by the thermal shock generated after sudden transfer of the sample from +20 °C to -80 °C, followed by the returning to +20 °C just in an hour. This treatment has produced irreversible alterations in paper structure.

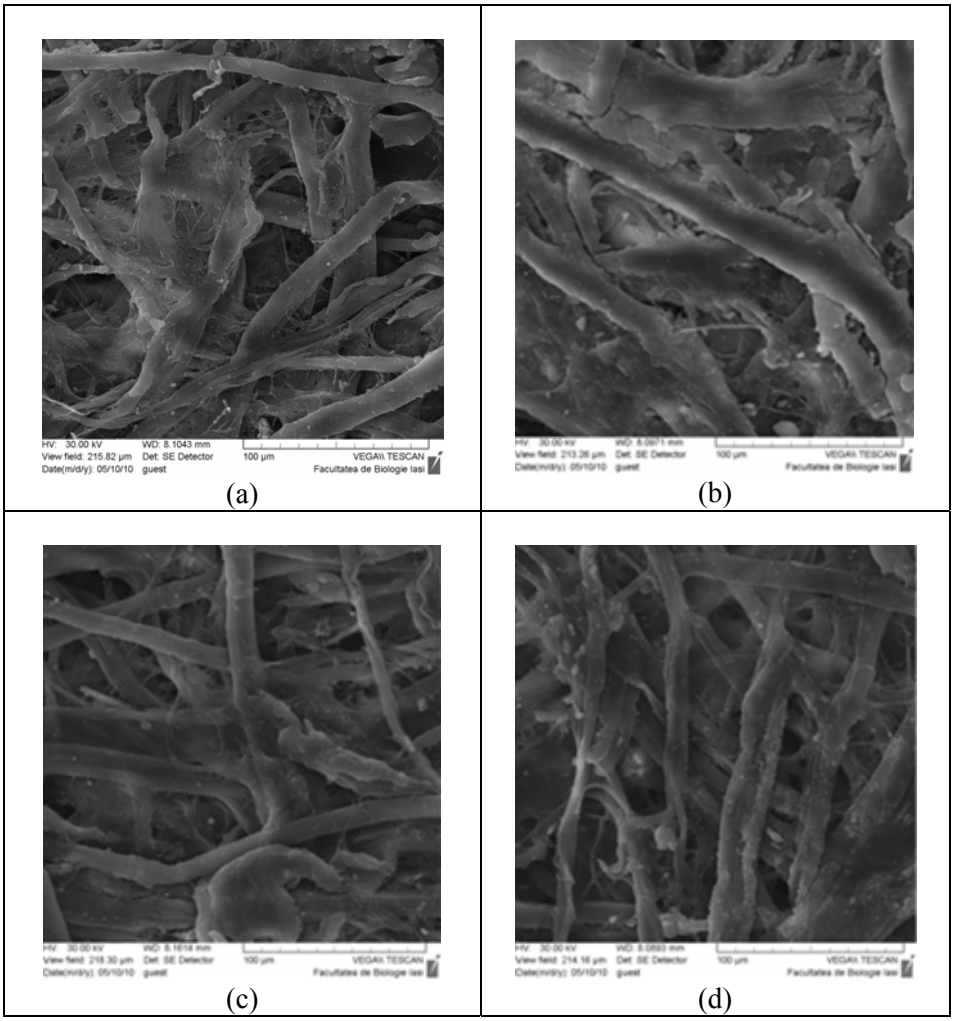


Figure 7. SEM photomicrograph of the hand made paper,: (a) before and after treatment for (b)1h, (c) 3h, (d) 14h.

4. Conclusions

The utilization of extreme low temperatures (-80 °C) ensures lethal effect for all investigated pest species. The effect does not depend on their development stage and does not allow the acclimatization of the insects.

The main benefit of the low temperature method is possibility to reduce to minimum the time of the treatment, especially in the case of bulky objects, containing different materials with low thermal conductivity (as wood and paper). In comparison with the general method of pest control by simple freezing, where the time-period of treatment is 2-3 days, when the pest control treatment at -80 °C is applied the time-period is reduced to 1-2 hours in the case of books.

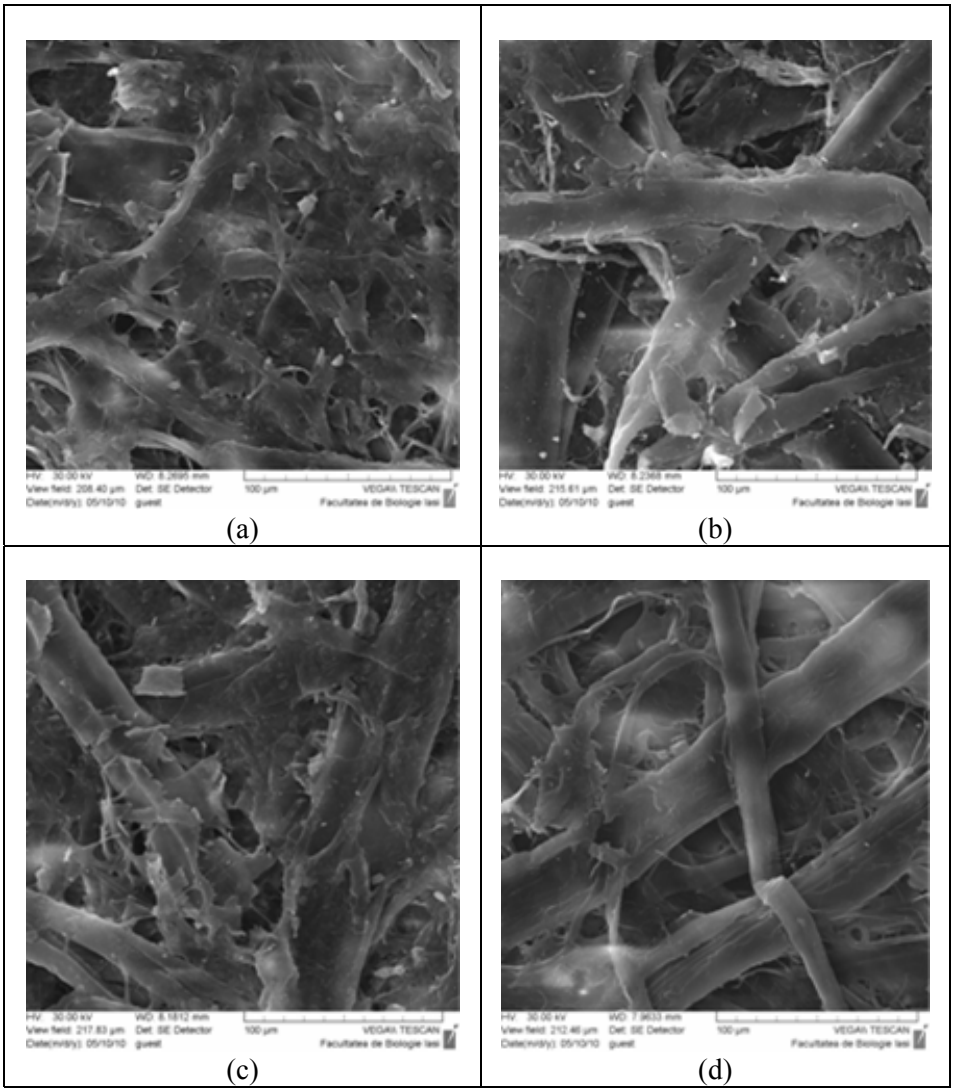


Figure 8. SEM photomicrograph of the hand made paper,: (a) before and after treatment for (b)1h, (c) 3h, (d) 14h.

The analysis of the physical properties and microscopic structure of the paper have demonstrated that the applied treatment does not introduce any significant changes in the structure and the properties are not diminished if the time-period of freezing does not exceed 7h of treatment. A longer period of treatment should not be recommended.

It is advisable to continue the research with detailed experiments and to investigate the behaviour of paper with different initial moisture content.

Even if the aforementioned treatment proved to be an efficient one, the existing negative effects should not be neglect, the freezing of moist paper is leading to physical degradations of fibres [9]. The same effect can be observed in the case of dried objects when these are entering into the freezer's area.

This study is offering basic information about a new method of protection against pest insects. It is still necessary to investigate the long-time effects of these treatments and to study the effects upon the other components of the books: leather, adhesives and inks.

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