

Article

Characterization of the Biodeterioration Caused by the Fungus *Serpula lacrymans* in Lignocellulosic Materials of Building Envelopes

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Abstract

Serpula lacrymans is considered the most aggressive and harmful brown-rot fungus for wooden buildings worldwide, and it has led to substantial economic losses due to the deterioration of wood and wooden-base structures. This study aims to connect the loss of parallel compressive strength and mass loss caused by the fungus *Serpula lacrymans* in different lignocellulosic materials commonly used in building envelopes in Chile. Samples suspected to contain the fungus *Serpula lacrymans* were gathered from four Chilean localities. From these samples, the fungus under investigation was isolated and identified in the laboratory. It was used to inoculate wood samples of radiata pine, impregnated radiata pine with chromated copper and arsenate (CCA) salts, raulí (*Nothofagus alpina*), oriented strand board (OSB), and plywood to evaluate compressive strength at 0, 30, 60, and 90 days. As expected, the best mass loss results were obtained in impregnated pine and plywood, with values of 0.8% and 2.5%, respectively. However, significant parallel compression strength losses of 42% and 28%, respectively, were observed. This study provides valuable information for the structural diagnosis of wood elements attacked by the fungus *Serpula lacrymans*.

Keywords: brown-rot decay; wood and buildings; lignocellulosic materials; parallel compressive strength loss; structural diagnosis of wood elements



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1. Introduction

Biodeterioration is caused by microorganisms, such as bacteria and fungi, and is visible when materials undergo physical changes [1,2].

Fungi, bacteria, and insects are the main agents responsible for wood decomposition and are vital players in the life cycle of forest ecosystems [3–5]. However, some forest rot fungi have been introduced by humans into built environments, adapting their degradation mechanisms to colonize wooden buildings [6].

The basidiomycete fungi of brown rot are among the most aggressive xylophages in buildings [7,8]. These fungi significantly damage the internal structure of wood, thereby causing significant loss of mechanical strength and becoming an important issue for building structures [9–11].

Serpula lacrymans is known as the most important brown-rot fungus worldwide, due to the significant economic losses it causes through deterioration in buildings [12–14]. The distribution of the *lacrymans* variant is almost cosmopolitan in nature. It has been recorded in buildings in mild climates of Asia, Australia, New Zealand, Europe, and North and South America [15,16], where the highest number of occurrences of basidiomycetes in buildings are mainly *Serpula lacrymans* and *Caniophora puteana*, except in Norway, where the genus *Antrodia* is the most common [17–19].

These fungi mainly attack construction elements made of coniferous wood in contact with the natural ground, in wet places in basements, storerooms, and floors in contact with the ground, or that have been affected by accidental or environmental moisture [20,21]. First, they partially modify the lignin, thus weakening the binding structure, exposing the structure's cellulose and hemicellulose to enzymatic attack, and leaving the remains of the modified lignin as waste [22,23]. Consequently, wood contracts and cracks into cubic brown pieces, thus reducing its mechanical properties [24–26].

Despite the loss of their enzymatic systems, brown-rot fungi are still able to depolymerize holocellulose and extensively modify lignin, acquiring alternative lower-energy mechanisms to initiate fungal attack [27], thus becoming dominant over other species [28]. Studies have shown that the mechanisms of brown rot fungi in early stages are explained by a Fenton reaction, in which highly destructive OH hydroxyl radicals are released, pass through the cell wall, and decompose the lignocellulose matrix [29].

The incipient attack by these decomposition fungi in wood is challenging to detect externally. However, depolymerization processes of cellulose occur within the wood cellular structure, as demonstrated by low mass loss and rapid structural strength loss of the element [30].

In the advanced stages of decomposition, wood turns brown due to the accumulation of modified lignin waste and a lower fraction of holocellulose, and it becomes friable into cubic pieces [31].

At an international level, there is greater concern about wood biodeterioration due to rot fungi, which focuses on the preservation of unique historical and cultural heritage materials [32–35]. The development of new molecular biology techniques, electron microscopy, and chemical analysis methods has made it possible to perform an in-depth systems analysis of the degradation mechanisms of objects of cultural heritage [36]. However, classic culture plate methodologies are extremely advantageous, as they provide valuable data to assess the potential risks of the microorganism to materials. Furthermore, they offer a highly informative, quick, and cheap platform [37,38]. Assessing biodeterioration is also significant for modelling to reduce the risk of fungal decomposition of wooden building structures during their lifespans, which is mainly expressed as material mass loss over time [39,40].

In Europe, the natural durability of wood in contact with the ground is determined by the European standard EN 252 [41], and the EN 113-2 [42] standard evaluates, in the laboratory, the degradation of wooden structures affected by the attack of rot fungi of the basidiomycete type. The test described by UNE-EN 113-3 [43] is Durability of wood and wood-based products—Test method against wood destroying basidiomycetes—Part 3: Assessment of durability of wood-based panels. To define mass loss, it is applied to assess the attack of basidiomycetes on pure culture of rigid and uncoated wooden boards [44]. This test is classified according to UNE EN 350 [45], Durability of wood and wood-based products—Testing and classification of the durability to biological agents of wood and wood-based materials, which sets the use of *Serpula lacrymans* as an alternative. The standard establishes methods for determining and classifying the durability of wood and

wood-based materials, in contrast to biological degradation agents, including xylophagous fungi such as basidiomycetes and soft-rot fungi.

In Chile, the standard NCh789/1 [46] Wood—Part 1: Wood durability establishes a research methodology based on laboratory tests to determine the durability of both wood and its derivatives. Methods are outlined to determine and classify the durability of wood and its derivatives in contrast to the action of degradation by biotic agents. This standard includes natural wood, thermally treated wood, impregnated wood, wood treated with superficial products, and modified wood. Intrinsic or improved durability defines the useful life of a component and the building to which it belongs [47].

On the other hand, the existing literature and standards for determining the durability of wooden and wood-based materials focus on fungal-rot-induced degradation, measured by mass loss, without relating it to reductions in mechanical performance [48].

The biodeterioration of materials is an essential component of the resilient design of wooden structures and the selection of wood-based materials for building envelopes that may be affected by fungal microorganism attacks [49].

The quantitative evaluation of the loss of mechanical resistance due to the attack of the rot fungus in different wood materials used in buildings allows us to determine their structural susceptibility over time and therefore define more stable and durable envelope designs.

This study becomes even more critical when total wooden housing construction in Chile, that is, the sum of homes and apartments with wooden envelopes, represents 17%, ranking third behind reinforced concrete (45.7%) and ceramic brick masonry (33.5%) [50].

Therefore, this research seeks to characterize the biodeterioration caused by the fungus *Serpula lacrymans* on different lignocellulosic materials currently used in building envelopes in Chile, with the objective of providing background information to engineers, architects, and builders on the long-term structural safety of wood-based elements affected by this rot fungus.

2. Materials and Methods

The biodeterioration of *Serpula lacrymans* was assessed in the primary wooden and wood-based materials commonly used, which are the structural components of building solutions recommended for envelopes by Chile's prevention and/or atmospheric decontamination plans (PPDA) [51].

Dry radiata pine sapwood without protective treatment, dry impregnated radiata pine sapwood using a chromated copper arsenate (CCA) salt treatment of 4 kg CCA/m³ according to NCh819 [52], raulí sapwood (*Nothofagus alpina*) without treatment, an 11.1 mm thick oriented strand board (OSB), and a 15 mm thick structural plywood were considered.

The test was divided into two stages: first, the biodeterioration capacity of the rot fungus strains taken from the cities of Viña del Mar, Nacimiento, Valdivia, and Puerto Varas was reviewed. The fungal samples were inoculated for several traditional materials used in building envelope elements in Chile; second, the influence of the biodeterioration capacity of *Serpula lacrymans* on the mechanical properties of the materials defined by the test was assessed at 0, 30, 60, and 90 days.

2.1. Sampling and Treatment

Samples of brown-rot fungi were collected from four affected dwellings in Viña del Mar, Nacimiento, Valdivia, and Puerto Varas. Figure 1 shows the sectors of the homes affected by the rot fungus and their sampling locations throughout Chile.

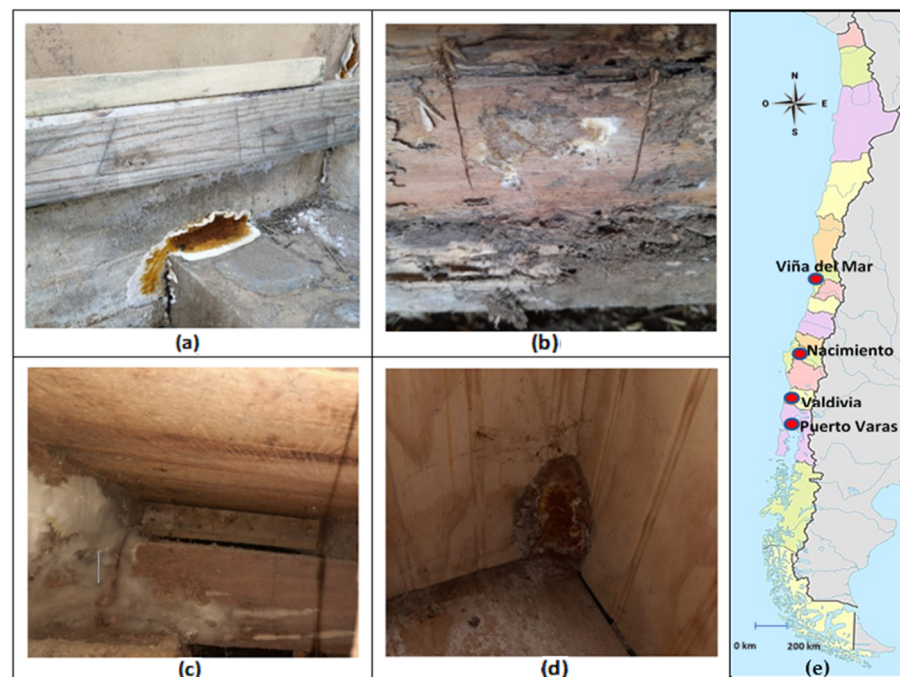


Figure 1. Dwellings affected by rot fungus. (a) Fruiting body in a joint between the staircase and the foundation in Viña del Mar; (b) fruiting body of a radiata pine wood trunk, with rot fungus mycelium in the dwelling in Nacimiento; (c) mycelium under ventilated floor in a dwelling in Valdivia; (d) fruiting body at the lower joint of grooved plywood cladding walls, and mycelium development on ventilated floor plywood plate in Puerto Varas; and (e) location of the cities where the fungus was sampled.

The fungal samples were isolated in Petri dishes and successively sub-cultured on dextrose–potato agar for the growth of basidiomycete fungi: 4 gL^{-1} potato extract, 20 gL^{-1} dextrose, and 15 gL^{-1} agar. The fungal mycelium was isolated and placed in a slanted agar tube in a Benlate medium (60 mgL^{-1}) and lactic acid (0.2%), with no antibiotics, and kept in Thermo Scientific laboratory incubators at 4°C .

2.2. Identification of Strains Through PCR

The pure strains of the isolated fungi were transferred to liquid culture media, which were prepared with 1.5% malt extract, 0.4% yeast extract, and streptomycin (10 mgL^{-1}). The pure mycelia were inoculated into 10 mL of liquid media, which were contained in 50 mL flasks and kept between 20 and 24°C at room temperature without shaking. Afterwards, from 10 to 15 days of incubation, they were filtered and washed with ultrapure water and frozen and sprayed with liquid nitrogen for DNA extraction. The lyophilized mycelia were extracted using the WIZARD® Promega kit (Promega Corporation, Madison, WI, USA) for genomic DNA extraction. A total of 40 mg of mycelium was used for the procedure. The integrity of the DNA molecules obtained was verified by performing electrophoresis in agarose gels, which were prepared at 1% of the polymer. Likewise, the intercalating stain used was GEL RED® from BIOTIUM (Biotium, Inc., Fremont, CA, USA).

PCR reactions were performed targeting the LSU region of the ribosomal DNA. LROR/LR5 were the two primers used for basidiomycetes [53]. The reaction mixture was prepared with a final volume of 50 μL . It contained Taq DNA polymerase (Sigma-Aldrich Co. LLC., St. Louis, MO, USA), its $10\times$ reaction buffer (with MgCl_2), a final concentration of 0.4 mM dNTPs, 12 μM of each primer, and 5 μL of DNA from each isolate.

The amplification reaction was performed as follows: pre-denaturation at 95°C for 2 min, 95°C for 20 s, 35 denaturation cycles for alignment at 54°C for 20 s, an extension at

72 °C for 30 s, and a final extension at 72 °C for 5 min. Finally, purified PCR fragments or products were sequenced by Macrogen INC. (Seoul, Republic of Korea), and the sequences were analyzed using BLAST in the NCBI GenBank database (<https://blast.ncbi.nlm.nih.gov/Blast.cgi>, accessed on 28 November 2025).

2.3. Sample Biodeterioration per City at 90 Days

The strains of the sampled and purified fungi from Viña del Mar, Nacimiento, Valdivia, and Puerto Varas were inoculated into three sterilized test samples with dimensions of 27 mm × 27 mm × 27 mm for dry pine radiata pine, impregnated with CCA dry radiata pine, and raulí, and three sterilized test samples of 27 mm × 27 mm for a 11 mm thick OSB board and a 12 mm thick structural plywood board manufactured using phenolic adhesive. The samples were placed under aseptic conditions in sterilized 500 mL glass bottles. For the characteristics of the soil, such as pH and water retention capacity, 145 g of a black leaf base was used, which was passed through a 1 mm diameter sieve with 65 mL of distilled water, then poplar wood feeder strips measuring 35 mm × 28 mm × 4 mm were added, which were conditioned at an ambient temperature of 21 °C and a relative humidity of ±65% during the study period. The biodeterioration capacity of each strain was assessed for 90 days. Figure 2 shows the sealed bottles containing the inoculated wood samples.



Figure 2. Sealed and conditioned bottles containing the wood samples inoculated for 90 days using the strains taken from Viña del Mar, Nacimiento, Valdivia, and Puerto Varas.

The samples were evaluated for 90 days according to the standard E10-22 [54] Laboratory method for evaluating the decay resistance of wood-based materials against pure basidiomycete cultures: soil/block test. The mass reduction was determined according to the following equation:

$$\text{Mass loss} = \frac{(m_0 - m_1)}{m_0} \times 100\% \quad (1)$$

where m_0 and m_1 are the masses (g) before and after exposure to the fungus, respectively.

2.4. Mechanical Strength Tests

Parallel compression tests were performed according to the Chilean standard NCh 973 [55] Wood—Determination of Mechanical Properties—Compression Parallel to Grain. For this purpose, a universal mechanical test machine, an Instron Model 4468 with a capacity of 50 kN, was used.

The methodology explained above was applied to evaluate biodeterioration. For this purpose, the cryopreserved strain of *Serpula lacrymans*, code VM-SL1, from the Bioprocesses and Biodeterioration Laboratory of the University of Bío-Bío in Viña del Mar, was used. The test was sequenced by the Macrogen Korea Laboratory and identified through the National Center for Biotechnology Information library, with 100% certainty (GenBank: AM946629.1).

The experiment evaluated 3 uninoculated samples and 3 inoculated with the rot fungus for each material: dry radiata pine, impregnated radiata pine (CCA), and raulí. Mass loss and compressive strength were evaluated at 30, 60, and 90 days.

2.5. Statistical Analysis

A multifactorial statistical analysis was applied to the results to assess the validity of the experiment using Design-Expert software version 2024 (<https://www.statease.com/software/design-expert/>, accessed on 28 November 2025). Two experiments were applied: the first of two factors (mass loss—localities) related to the results of mass loss (response variable) due to biodeterioration of the fungus in the material samples from the different localities, and the second of a factor (material) associated with the mass loss due to biodeterioration of the fungus and the compressive strength over time (response variables).

3. Results and Discussion

This section presents the results of the biodeterioration and mechanical compression properties of the samples exposed to *Serpula lacrymans*.

3.1. Sample Biodeterioration per Locality at 90 Days

Radiata pine samples without treatment developed the fungus the most and also showed the greatest mass loss percentages of between 13% and 37% (Figure 3). NCh789 [46] classifies this type of wood as non-durable to the rot fungus action. This category defines a natural durability of less than 5 years. These values are four times greater than those found by Ortiz et al. [30] with *Pinus radiata* inoculated by *Serpula lacrymans*, but they coincide with the definition given by UNE EN 350 [45] for this type of wood, classifying it between little durable and non-durable, i.e., with mass losses between 15% and 30%, and greater than 30%, respectively. As for location, the highest loss percentage was observed in the fungus sampled in Viña del Mar (37%), and the lowest was observed in the strains from Valdivia (13%), with a standard deviation of 9.6%. It was observed that the Valdivia strain obtained the lowest biodeterioration value, even though its high aggressiveness is evident under ventilated flooring, a situation the literature attributes to optimal growth conditions in these spaces [56,57].

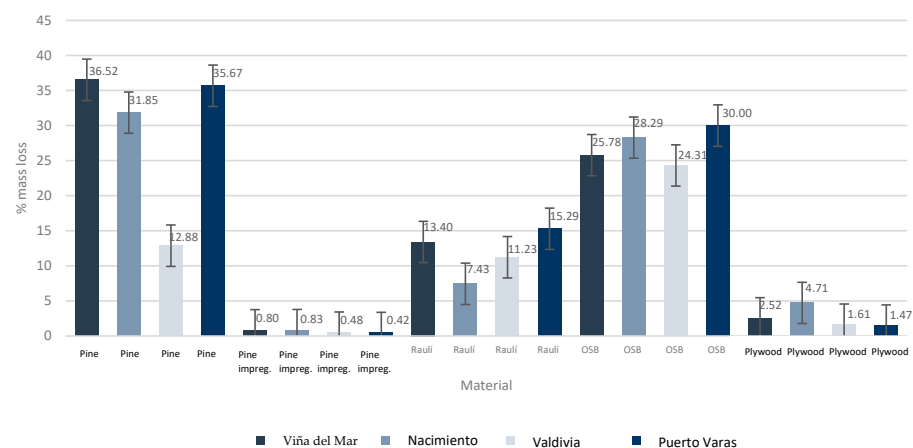


Figure 3. Mass loss percentage of the various materials tested according to the fungus sampled per locality.

The samples of the OSB board showed mass losses of between 24% and 30%, coincident with the results for brown rot fungi in OSB board substrates with no thermal treatment and with low phenol formaldehyde emission [58,59], which have similar characteristics to those made in Chile [60]. Other studies on brown-rot fungus degradation for different OSB boards have reported loss percentages of between 20% and 45% at 8 weeks [61,62]. As for location, the most significant mass loss percentages were obtained for Puerto Varas (30%), and the lowest for Valdivia (24%), with a standard deviation of 2.19%.

Raúl presented mass losses between 7% and 15%. According to NCh789 [46], this type of wood is considered durable. On the other hand, these values were comparable with those defined by UNE EN 350 [45] as non-durable, with losses of between 15% and 30% at 16 weeks. As for location, the most significant mass loss percentages were obtained for Puerto Varas (15%), and the lowest for Nacimiento (7%), with a standard deviation of 2.9%.

The samples of structural plywood had mass losses of between 2% and 5%, a result considered by UNE EN 350 [45] as very durable, which is a concept defined for mass losses lower than 5% evaluated at 16 weeks. These results were compared with a study of plywood panels made from okoume, birch, and poplar woods measuring 15 mm, which showed mass losses of 4%, 8%, and 15%, respectively, evaluated for fungal action at 14 weeks [63].

The samples of radiata pine impregnated with CCA salts showed the best behavior against fungal attack, with mass losses of between 0.4% and 0.8% and a standard deviation of 0.19%. According to UNE EN 350 [45], which defines values lower than 5% after 16 weeks of exposure to fungal biodeterioration, the results obtained classified this wood as very durable.

3.2. Statistical Analysis per Locality at 90 Days

Design Expert version 2024 was used to perform a statistical analysis and determine that the experimental model of biodeterioration due to mass loss was significant. The terms related to location (A), material (B), and their interaction were not significant. However, the most significant parameter in the results was Material (B) (Figure 4a). This can be observed by comparing the results obtained: untreated pine reached mass losses of up to 37%, whereas the same pine with CCA salt treatment reached mass losses of 0.4%. Likewise, Figure 4b shows a point of the standard run 25 number 42, which is located at the lower limit of the residual model, corresponding to one of the values obtained for the degradation of untreated radiata pine in Nacimiento (25.41%), a value considered as normal within the behavior of this type of species.

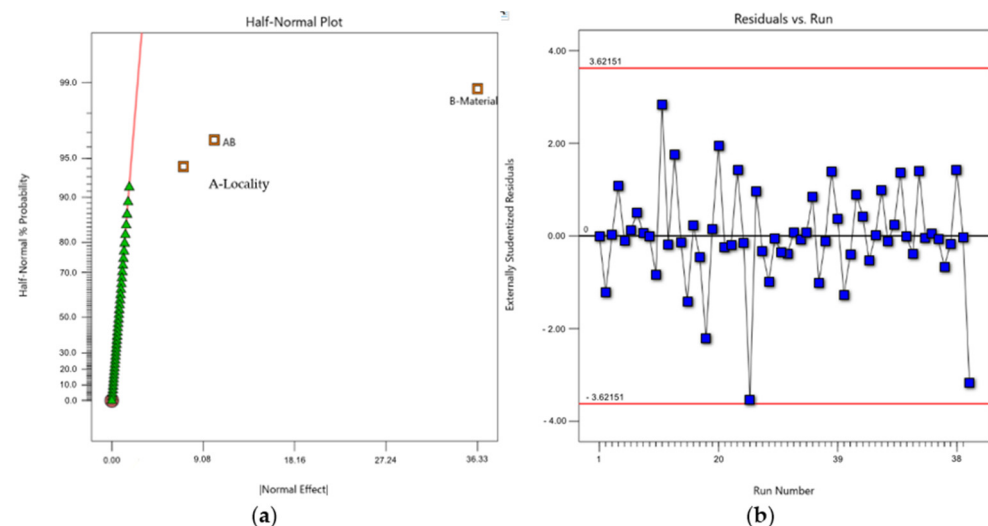


Figure 4. Statistical analysis: (a) graph of the normal effect of the results; and (b) graph of residuals versus runs.

3.3. Results of Mass Loss Related to Compression Strength Loss

As for the tests on the material biodeterioration caused by *Serpula lacrymans* in relation to compression strength loss, the untreated pine obtained an initial mass loss of 0.8% at 30 days and a parallel compression strength loss of 9% (Figure 5). A mass loss of 4.3% was obtained at 60 days, equivalent to a strength loss of about 35.7%. A 36.5% mass loss

was observed at 90 days, along with a 51.4% mechanical strength loss. Other studies have shown that the biodeterioration of *Serpula lacrymans* on this wood resulted in a mass loss of 6% at 12 weeks, as well as a decrease in parallel compression strength of 33% [30].

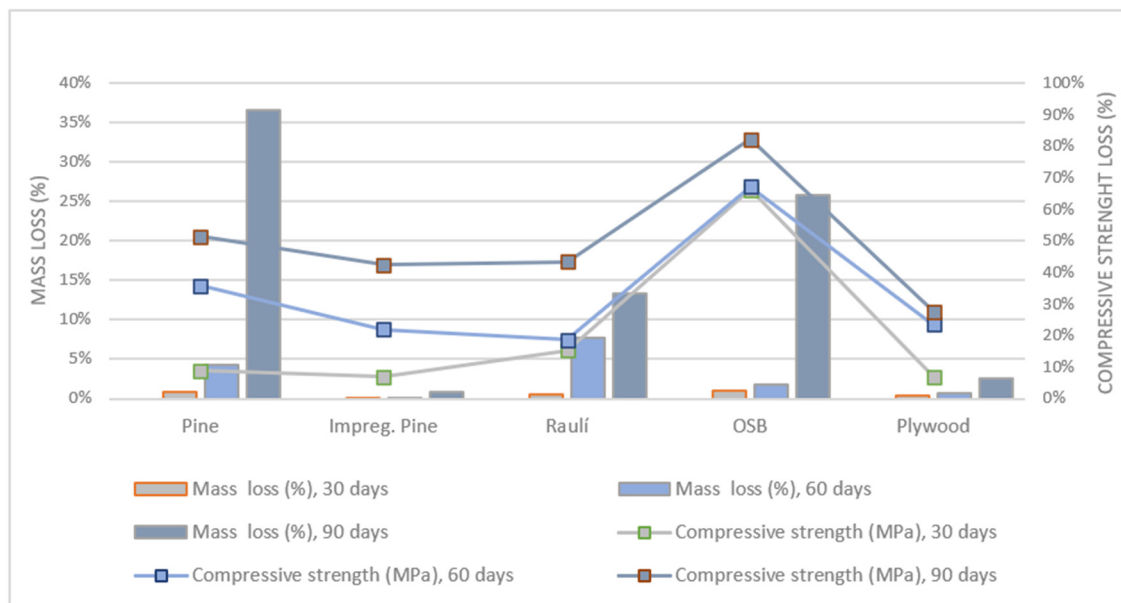


Figure 5. Mass loss related to loss of compressive strength of wood materials inoculated by *Serpula lacrymans* strains.

On the other hand, Ref. [10] studied the relationship of mass loss and compression strength of wild pine (*Pinus sylvestris*) attacked by the brown-rot fungus *Caniophora puteana*, obtaining a compression strength loss of 50% for a mass loss of 20%. Moreover, the effect of deterioration of southern yellow pine (*Pinus echinata*) exposed to the brown-rot fungus *Gloeophyllum trabeum* for 72 days was studied with respect to mechanical properties, and a relationship between strength loss and mass loss of 4/1 [64] was established.

These results could not be compared with those obtained, as no linear relationship was observed across the various periods evaluated. However, the most significant relationship was obtained with the incipient attack at 30 days, corresponding to a strength loss versus mass loss of 11/1, because brown rot degrades wood long before the point of hyphal growth at the cellular level and depolymerizes carbohydrates before they are used as nutrients. This produces drastic changes in the wood's properties, even though its visual appearance remains unchanged [21].

As for compression strength results, a particular behavior was recorded for each material. However, all gradually lost compressive strength over time after exposure to the rot fungus. The structural plywood was the material with the lowest compression strength loss, with an average value of 28.96 MPa at 0 days with no inoculation and of 20.98 MPa at 90 days, with a change relationship of -2.87 (Figure 5). The impregnated pine showed the most significant strength loss. At 0 days with no inoculation, an average compression strength of 61.67 MPa was obtained, and 35.55 MPa was obtained at 90 days of inoculation, with a change relationship during the evaluation of -8.75 .

As for the results obtained by the impregnated pine, mass loss was 0.0042%, 0.0043%, and 0.8033% at 30, 60, and 90 days, respectively. However, compression strength loss was 7.0%, 21.9%, and 42.4%, respectively. Impregnated wood obtained the lowest mass loss results. However, compression strength loss was significant, so it should be considered when defining the structural serviceability of wooden elements. These results show the tolerance of the *Serpula lacrymans* fungus to CCA treatment, as confirmed by other studies,

in which it is not completely inhibited, resulting in significant mechanical losses in the wood without a major decrease in mass [18].

Raulí obtained mass losses of 0.5%, 7.8%, and 13.4% at 30, 60, and 90 days, respectively. The compression strength loss was 15%, 19%, and 43%, respectively. Compared to untreated pine, raulí obtained a lower impact on compression strength because of the greater durability of the species, as defined by UNE EN 350 [45].

Likewise, OSB boards obtained a mass loss percentage of 0.9%, 1.8%, and 25.8% at 30, 60, and 90 days, respectively. Unlike the other samples, OSB boards presented the greatest losses in compression strength properties, particularly an abrupt mechanical behavior at the initial stage, with strength losses of 66% at 30 days due to biodeterioration by *Serpula lacrymans*. At 60 days, compression strength was reduced to 67%, only 1% greater than that of month 1. However, 82% was obtained at 90 days. The non-homogeneous distribution of the adhesive, as well as its susceptibility to leaching and volatilization of its residues, explain the significant deterioration of this material [65,66].

The structural plywood plates obtained mass losses of 0.4%, 0.6%, and 2.5%, corresponding to compressive strength losses of 7%, 24%, and 28%, respectively. This material obtained the lowest strength losses; however, its compressive strengths are usually significant from a structural serviceability point of view. Other studies measured the relationship between the degradation of *Serpula lacrymans* and the flexural strength of this type of plate, which showed a mass loss of 0.37% and a strength loss of 41.4% at 84 days.

As for the mass-loss test in relation to the biodeterioration of different strains of *Serpula lacrymans*, there was mycelial growth in all wood-based substrates. However, the growth of the fungus was partially inhibited in pine samples with CCA salt impregnation and in structural plywood samples with phenolic-based adhesives, with mean mass loss values between 0.8% and 2.5%, respectively. If the wood impregnation treatment is homogeneous and well distributed, it is a good strategy to inhibit fungal attack. However, the use of compounds derived from chromium and arsenic can be harmful to occupants' health and the environment once these parts reach the end of their life cycle. Therefore, these components have been internationally replaced by others less aggressive to the environment [18,67].

As for structural plywood plates, fungal growth was perpendicularly inhibited on wood veneers from the foundation of the poplar wood feeder sheet. The reason could be the effectiveness of the adhesive barrier that each substrate provided, thus resisting the advance of the mycelium in that direction [68].

As for compression strength evaluations, the best mechanical behaviors were consistent with the materials with treatment or effective protection against xylophagous microorganisms, such as impregnated pine and structural plywood boards. However, despite their fungal resistance at 90 days, there was a significant compressive strength loss of 42% for impregnated pine and 28% for the structural plywood plate. The OSB board was an exception. It also used phenolic-based adhesive to bind the panel flakes. However, the irregular distribution of the adhesive and the complex geometry of the flake resulted in numerous micropores and voids within the internal structure [69,70].

One of the limitations of this study was the failure to evaluate at a microscopic level the retention and penetration of CCA salts in radiata pine, as this would have helped to understand the relationship between the attack of the fungus and the quality of the treatment application. In the same way, the literature on the leaching and homogeneity phenomena in the application of adhesives and treatments to OSB and plywood boards was not evaluated, which offers the opportunity to develop exhaustive studies that explain these phenomena.

Finally, a significant limitation of this study is the comparison of different fungal strains to correlate them with the biodeterioration results, as, due to the scope of the study, it is not possible to explain all the phenomena.

3.4. Statistical Analysis of the Mass Loss Related to the Compression Strength Loss

As for the statistical analysis, the F value of the model was 127.22, which was significant, and the expected R^2 of 0.8766 matched the adjusted R^2 of 0.9002, i.e., the difference was lower than 0.2. The signal-to-noise ratio was 35.074, i.e., greater than 4, so it is an adequate signal. For the material analysis, the predicted R^2 of 0.9179 agrees reasonably with the adjusted R^2 of 0.9336; that is, the difference is less than 0.2. The graph in Figure 6a, corresponding to the average parallel compression strength of the materials, showed values close to the homogeneous mean, with the lowest means obtained by the OSB samples and the highest by the impregnated pine samples. However, the difference in mean treatment of pine and plywood was within the limit of no significance, with a value of 0.1038. Likewise, Figure 6b shows the residuals versus runs and indicates that all values were randomly distributed. No value exceeded the model limits.

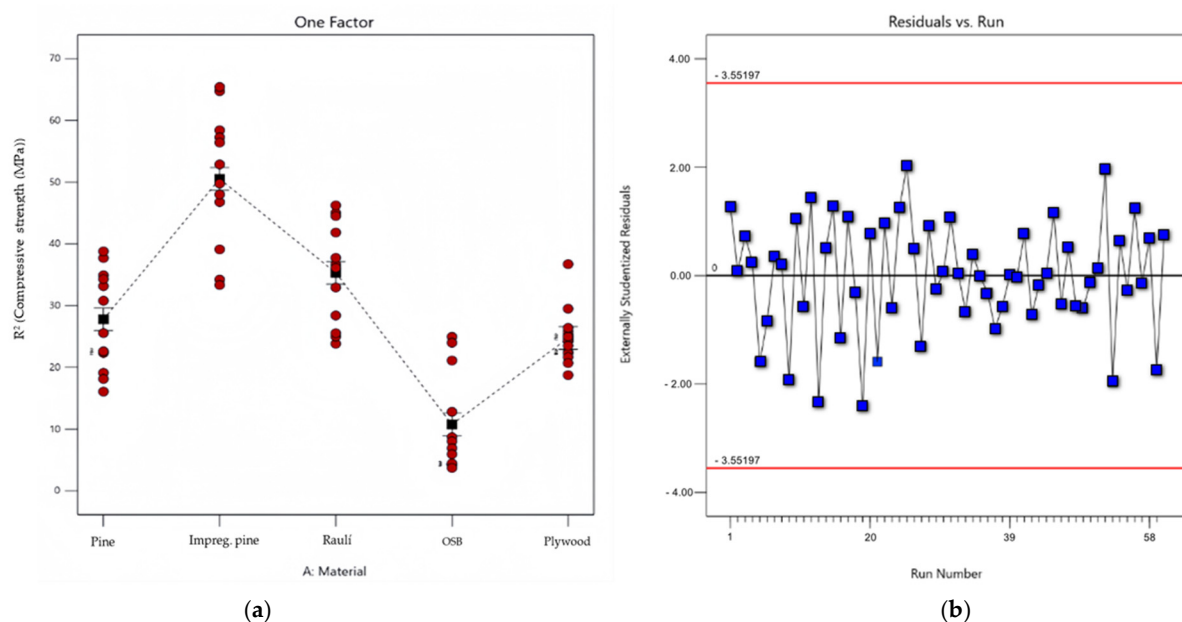


Figure 6. (a) Graph of the means of the parallel compressive strength results in megapascals, and (b) graph of residuals versus runs.

4. Conclusions

This study provides valuable information for the structural diagnosis of wood elements attacked by some strains of the fungus *Serpula lacrymans*. The results demonstrated that the evaluated strain of the *Serpula lacrymans* fungus is capable of efficiently degrading various woods and wood-based materials, exhibiting high tolerance, even in those containing preservatives. In the case of impregnated pine, no mass loss was observed up to 90 days; however, there was a gradual, significant loss of compressive strength in the early stages, which is explained by the degradation of the wood's internal structure. Consequently, this study highlights the opportunity to investigate other preservation methods that are more effective against the attack of this rot fungus.

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visualization, R.E.M.; supervision, C.R.-B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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