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Myco-surface model for *Fusarium solani* growth and non-thermal plasma decontamination on building materials

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Keywords:

Fusarium solani, plasterboard, wood fiberboard, growth modeling, non-thermal plasma, cold air plasma, inhibition of mold growth

Highlights:

- Myco-surface model effectively describes *F. solani* growth on building materials
- Non-thermal plasma is suitable for inhibiting mold growth on building materials
- Surface barrier discharge completely inhibits *F. solani* growth on fiberboard
- Corona discharge is less efficient but more accessible and easier to use

Abstract

Controlling fungal growth on building materials is essential for preserving indoor air quality and structural integrity. This study aims to (i) adapt the Myco-surface growth model for *Fusarium solani* colonization on plasterboard and wood fiberboard, and (ii) evaluate the antifungal efficacy of non-thermal plasma (NTP) treatments on these substrates. Fungal growth was monitored over a temperature range of 5–40 °C and modeled using the sigmoid-based Myco-surface model. Two NTP sources, a high-power diffuse coplanar surface barrier discharge (DCSBD) and a low-power negative corona discharge, were applied at various stages of fungal development. The Myco-surface model successfully captured the growth dynamics on both materials, with plasterboard supporting faster colonization than fiberboard. NTP treatments significantly inhibited fungal growth: the DCSBD source achieved complete inhibition on fiberboard, while the corona discharge had partial efficacy. These findings confirm the predictive capability of the Myco-surface model on complex building substrates and highlight NTP as a promising, non-destructive technology for fungal control in construction materials.

1. Introduction

Fungi are ubiquitous microorganisms that play a vital role in ecosystems by contributing to nutrient cycling, biodegradation and symbiotic relationships. They also offer numerous beneficial applications in medicine, agriculture and biotechnology[1,2]. However, fungi can also be harmful, causing significant damage to crop and infrastructure and posing a risk to humans and animals[3,4]. In particular, filamentous fungi can decompose various building materials, both indoors and outdoors.

This affects their aesthetic appearance, compromises structural integrity, and impairs functionality. Moreover, indoor mold proliferation poses significant risks to human health. Therefore, effective monitoring and modelling of fungal growth, as well as its removal following sanitation procedures, are required. In the study by Lindemann et al.[5], over 50 mold-infested building samples (e.g., wallpaper, plaster, wood, polystyrene, glass wool) were analyzed, revealing 15 fungal genera. Among the most common were *Penicillium*, *Aspergillus*, *Acremonium*, and *Fusarium*.

Usually, construction materials are typically resistant to the growth of common fungi when properly integrated into a building's structure. This resistance depends on their chemical composition and physical properties, mainly the material’s pH. Most fungi grow in environments with a pH between 3 and 8[6], and tolerate low humidity[6-10].

The most commonly used materials that suffer from fungal infections in construction include plasterboard and wood fiber boards.

Plasterboard, also known as gypsum board, is a versatile building material consisting of a gypsum plaster core, made from a naturally occurring mineral, sandwiched between layers of thick paper, and provides a smooth finish. It is valued for being durable, cost-effective and easy to install. The second material, the wood fiberboard, is made from wood fibers and natural binders and is widely used in constructions for insulation, sheathing and soundproofing purposes. It provides excellent thermal resistance, helping to maintain comfortable indoor temperatures and reduce energy consumption. Both materials are vapor-permeable what allows interior spaces to breathe and helps to regulate humidity and prevent issues such as water condensation leading to the fungi growth[11].

Nevertheless, as mentioned previously, this resistance can be significantly broken or reduced when building materials are exposed to environmental conditions outside their design specifications, e.g. they are not properly integrated into the structure or are damaged by water leaks. Common issues often include elevated indoor humidity, particularly in areas such as bathrooms and kitchens, condensation of water vapor due to temperature gradients, or high concentrations of airborne fungi spores near the structure.

In these cases, it is necessary to look for ways to suppress fungal growth. In the case of permanently unsatisfactory conditions, a structural solution is usually necessary. In the case of sudden incidents, such as water leakage as a result of an accident, a one-time intervention is often sufficient to temporarily limit fungal growth. Typically, various disinfectants can be used.

In recent years, the potent microbicidal properties of non-thermal plasma (NTP) has gained significant popularity (e.g., recent review[12]). NTP is an ionized gas in which the ion and neutral gas temperatures remain much lower than the electron temperature. One of its key features is the generation of highly reactive species, which play a primary role in its antimicrobial activity. The composition and concentration of the reactive species depend heavily on the conditions under which the plasma is generated, particularly the working gases, the type of electric discharge, and its specific characteristics[13]. Unlike traditional chemical disinfectants, NTP does not leave behind harmful residues or contaminate treated surfaces, making it a promising and environmentally friendly alternative for a wide range of applications[14-16]. Notably, its potential to eradicate fungi from building materials represents a particularly promising application that this research aims to assess.

In our previous work[17], we investigated the growth of *Fusarium solani* on agar, applied our Myco-surface model to simulate its growth on this homogeneous, nutrient-rich medium, and

study its inactivation by the NTP. This approach appears to be very suitable for studying the possibility of suppressing contamination also on building materials, which would make it possible to quantify the inactivation effect and predict further growth and spread of the fungal infection. However, building materials do not represent an ideal nutrient-rich medium; rather, they are complex natural and human-made substrates. Growth can be significantly affected by nutrients, as well as by resistance to inactivation due to surface roughness, hydrophobicity/hydrophilicity, and a material's capacity for moisture sorption and desorption. This may play significant roles in fungi growth by promoting the retention of dust and moisture. The primary objective of this study was to experimentally investigate the growth of *Fusarium* on common building materials, specifically plasterboard and wood fiberboard, under varying temperature conditions. In addition, using our Myco-surface model, we aimed to quantitatively describe *Fusarium* growth on these materials, enabling its prediction at any given temperature. A secondary aim of the research was to assess the potential of NTP to inhibit *Fusarium* growth on these materials. To aim this, we tested two different NTP sources and applied suggested model to quantify the inactivation effect and to predict further growth of the fungal contamination.

2. Materials and methods

The *Fusarium solani* species complex DS253 strain used in the experiments was kindly provided from the DBM collection Prague[18]. This strain was isolated from a swab taken from a water pipe in a residential building and identified based on morphology and through DNA sequencing.

For the experiments, we prepared a stock aqueous suspension of *F. solani* with a drop of TWEEN 80 (HiMedia, Mumbai, Maharashtra, India) added as a surfactant. The concentration of *F. solani* spores in the stock suspension was determined by direct counting and serial decimal dilution. A working inoculum was then prepared by diluting the stock suspension with sterile water to achieve a final concentration of 50–100 colony-forming units per 100 µl[19]. Each sample was inoculated with 100 µl of the resulting inoculum. Illustrated more clearly in Figure 1.

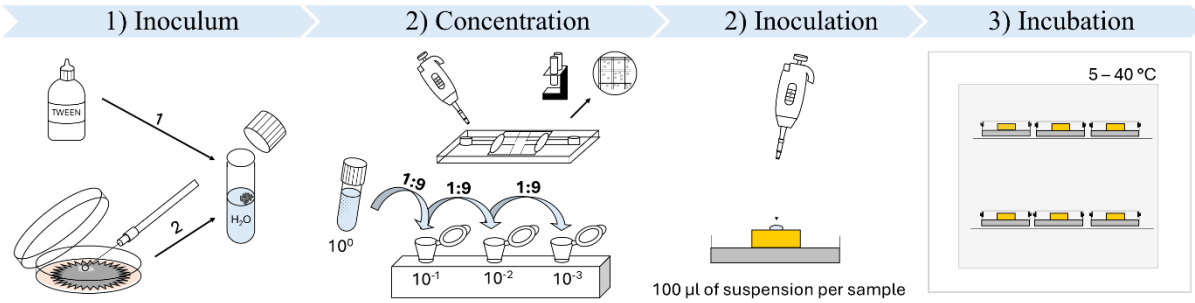

Figure 1. Schematic representation of the experimental procedure: 1 - inoculum preparation, 2 serial tenfold dilutions of the microbial suspension, 3 sample inoculation (100 µl), 4 incubations at controlled temperatures ranging from 5 to 40 °C.

The growth of *F. solani* was studied on plasterboard and wood fiberboard. The selected wood fiberboard (22 mm) is used in roofs and walls. It minimizes thermal bridges, insulates well in summer, is vapor-permeable, and recyclable[20]. The plasterboard (12.5 mm) is a lightweight, non-combustible panel for dry indoor use. It is renewable-based, easy to install, and unsuitable for wet areas[21]. The specific properties of these materials are presented in Table 1.

Table 1. Properties of the building materials used.

Property	unit	Wood fiberboard[20]	Plasterboard[21]
Board thickness	mm	22	12.5
Board format	mm × mm	2230 × 600	1000 × 1250
Nominal thermal conductivity value λ_D	W/(m·K)	0.048	0.21
Bulk density	kg/m³	approx. 270	approx. 640
Water vapor diffusion resistance factor **µ**	–	5	10
Diffusion-equivalent air layer thickness (s_d value)	m	0.11	0.06 – 0.10
Short-term water absorption	kg/m²	≤ 1.0	approx. ≤ 0.2
Specific heat capacity **c**	J/(kg·K)	2,100	approx. 1000 – 1090
Compressive stress at 10% deformation σ_{10}	N/mm²	0.20	-
Compressive strength	kPa	200	approx. > 500
Tensile strength	kPa	≥ 30	approx. > 30
Composition:	–	Wood fibers,	Solid gypsum core and

	aluminum sulfate, paraffin, layer bonding	paperboard surface

Plasterboard and wood fiberboard were cut into square samples with a side of 50 mm. Prior to experimentation, the samples were washed by immersion in distilled water and sterilized by autoclaving at 121 °C for 20 min. After autoclaving, the water was discarded, and the samples were allowed to cool for 1 h. The cooled samples were then placed onto the solidified surface of malt extract agar (MEA, Oxoid Limited, Hampshire, UK) in Petri dishes. The Petri dishes were 86.5 mm in diameter and 14.5 mm in height. To fit the height of the samples, all Petri dishes were equipped with 3D-printed PETG height extensions (Figure 2). The extensions were cleaned by immersion in chemical disinfectants.

Figure 2. Sample of building material placed in a Petri dish: 1 – cultivation medium, 2 – material sample, 3 – base of the Petri dish, 4 – height extension, 5 – Petri dish lid.

The samples, enclosed in Petri dishes, were left at room temperature overnight in a fume hood. On the following day, 100 µl of the inoculum was pipetted onto the center of the upper surface of each material sample, and the dishes were transferred to incubators set to various temperatures ranging from 5 to 40 °C. The growth of *F. solani* was systematically monitored over a three-week period.

Image analysis was employed to quantify mold surface coverage on the samples, providing an accurate and non-invasive method for monitoring growth dynamics. Digital images of the mold-covered surfaces were captured at regular intervals (approximately every 24 h) throughout the experimental period using a Nikon D3500 camera. These images were processed in ImageJ using the FIJI distribution with the Trainable Weka Segmentation plugin[22]. This software enabled accurate segmentation of mold-covered areas and calculation of surface coverage percentages. The experimental approach allowed continuous tracking of mold growth over

time, providing detailed insights into its behavior under varying conditions such as temperature and substrate type.

The collected experimental data were further processed to enable the description of *F. solani* growth on plasterboard and wood fiberboard. For this purpose, we applied the Myco-surface model presented in our previous works[17,19]. In brief, the evolution of the mold-covered area for each sample was fitted using the following sigmoid function:

$$N(t) = \frac{100\%}{1+\exp(-r\cdot(t-\Delta))}. \quad (1)$$

Here, t represents time, $N(t)$ denotes the percentage of the sample surface area covered by *F. solani*, r is the growth rate, and Δ is the growth delay. Both growth parameters are clearly interpretable and effectively capture the key dynamics of mold development. Specifically, the growth rate (r) defines the steepness of the growth curve, while the growth delay (Δ) defines its horizontal shift over time. Note that the growth delay corresponds to the time required for *F. solani* to cover 50% of the sample surface area.

Fitting the experimental data to the growth function (1) enabled the evaluation of the growth rate and growth delay of *F. solani* depending on building material and temperature (T). Subsequently, the growth parameters were subjected to statistical analysis and fitted to the following mathematical models. The dependence of the growth rate on temperature was modeled with a biphasic Hill equation[23]:

$$r(T) = \frac{M}{\left(1+\left(\frac{G}{T}\right)^{a}\right)\cdot\left(1+\left(\frac{T}{H}\right)^{b}\right)}. \quad (2)$$

In this model, M defines the upper asymptote of the function, while G and H denote the temperatures at which the function reaches half of M on the rising and falling slopes, respectively. The shape of the temperature dependence is determined by the Hill coefficients a and b, which control the steepness of the rising and falling phases, respectively.

The dependence of the growth delay on temperature was modeled with a combination of decaying and growing exponential functions:

$$\Delta(T) = A_0 + A_1 \cdot \exp\left(\frac{-T}{B_1}\right) + A_2 \cdot \exp\left(\frac{T}{B_2}\right). \quad (3)$$

Here, A_0 represents the function's offset, A_1 denotes the amplitude of the decaying exponential, A_2 the amplitude of the growing exponential, $1/B_1$ defines the decay rate, and $1/B_2$ represents the growth rate in the respective exponential functions. The parameters A_0, A_1, A_2, B_1, and B_2, obtained by fitting the growth delay data with function (3), enable evaluation of the growth delay at any desired temperature.

After determining the set of ten parameters (M, G, H, a, b, A_0, A_1, A_2, B_1, B_2), these values can be used to model the growth of *F. solani* on plasterboard and wood fiberboard at any given temperature by substituting the computed growth rate from function (2) and growth delay from function (3) into the growth model described by function (1).

To explore the potential of NTP to inhibit the growth of *F. solani* on plasterboard and wood fiberboard, another set of experiments was conducted. For this purpose, material samples inoculated with *F. solani* were treated with two different NTP sources (Figure 3). The first NTP source, hereafter referred to as NTP1, was a commercial 300 W diffuse coplanar surface barrier discharge (DCSBD) system (RPS400; Roplass, Czech Republic)[24]. The second NTP source, referred to as NTP2, was a portable laboratory-made device[25] based on a 1 W direct current corona discharge in a point-to-ring electrode system[26]. In both cases, the treated samples were not in direct contact with the plasma.

The samples were exposed to either NTP1 or NTP2 for 10 min at 0, 24, 48, or 72 h after inoculation to assess the ability of each NTP source to inhibit *F. solani* at various stages of its development. In this set of experiments, all measurements were conducted at a constant cultivation temperature of 23 °C.

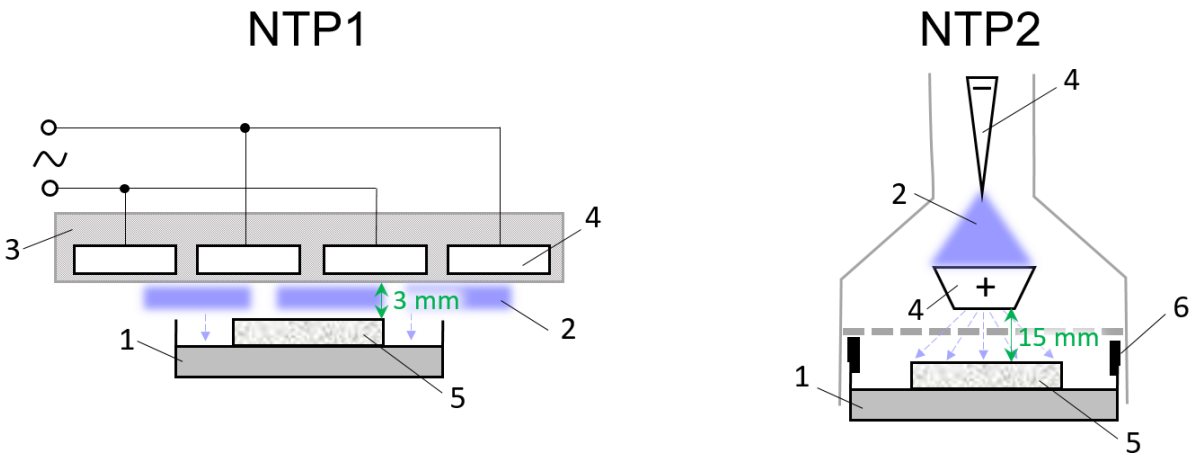

Figure 3. Illustration depicting the exposure of material samples to the NTP1 and NTP2: 1 – cultivation medium, 2 – NTP, 3 – dielectric, 4 – electrodes, 5 – sample of building material, 6 – height extension.

3. Results and Discussion

3.1 *F. solani* growth on fiberboard and plasterboard and its modeling

In the initial phase of the experiments, plasterboard and fiberboard samples were placed onto the surface of solidified Agar No. 1 (Oxoid Limited, Hampshire, UK) in Petri dishes (Figure 2). Agar No. 1 contains no nutrients to support mold growth but provides moisture to the samples. These experiments showed that *F. solani* barely grows on clean surfaces of building materials, even under conditions of high humidity. This suggests that building materials alone lack sufficient nutrients to sustain mold growth in the short term. Therefore, it can be concluded that *F. solani* is unlikely to proliferate in a perfectly clean building, even in the presence of high humidity. In real-world conditions, however, molds usually obtain nutrients from ubiquitous dust or polluted water[27,28].

To study the growth of *F. solani* on building materials, it is essential to provide the mold not only with moisture but also with an adequate supply of nutrients. For this purpose, we placed samples of fiberboard and plasterboard onto the surface of solidified MEA (Figure 2). Unlike Agar No. 1, which supplies only moisture, MEA is also rich in carbohydrates (primarily maltose and glucose), amino acids, vitamins, and other nutrients that promote fungal growth. In this approach, nutrients diffuse from the agar through the entire thickness of the sample, reaching the top surface where the mold growth is monitored. Providing molds with nutrients is a common practice in studies of mold growth on building materials (see, e.g.,[28,29]). Unlike dust or other natural contaminants, agar provides controlled growth conditions necessary for systematic and consistent experiments.

The growth of *F. solani* on samples of fiberboard and plasterboard placed on the MEA surface was experimentally investigated over a temperature range of 5 to 40 °C. Figure 4 shows the growth curves of the mold on both materials at different temperatures.

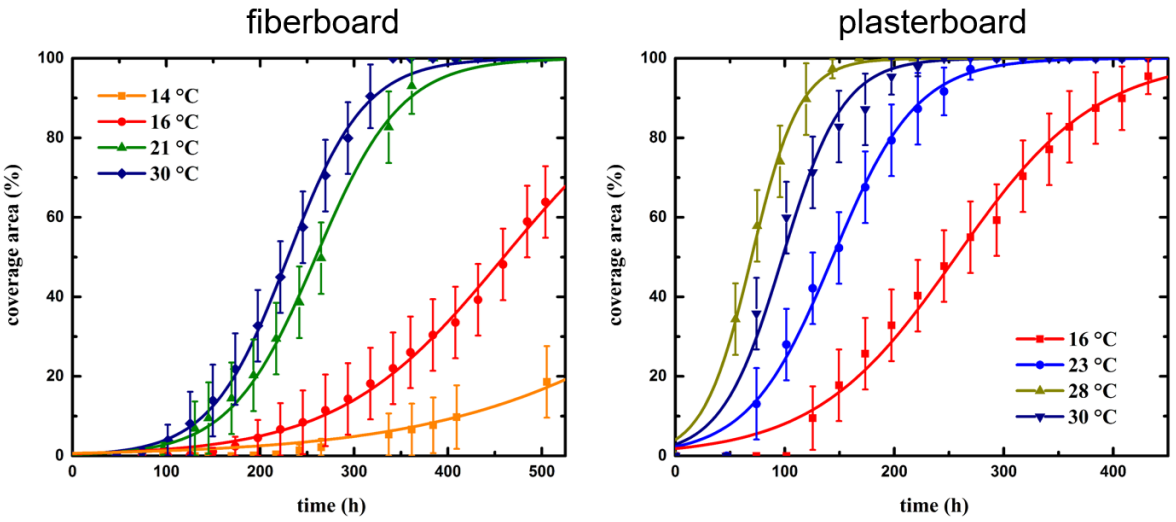

Figure 4. Selected growth curves of *F. solani* on fiberboard and plasterboard. Individual points represent measured values, while solid lines show their fit using growth function (1).

To quantitatively characterize the growth of *F. solani* on fiberboard and plasterboard, we determined its growth parameters. For this, all collected growth curves of *F. solani* on both materials were fitted using the growth function (1). The parameters of the growth rate and growth delay were then evaluated and statistically processed. Tables 2 summarizes the evaluated growth parameters of *F. solani* on fiberboard and plasterboard.

Table 2a. Evaluated values of the parameters describing the growth of *F. solani* on fiberboard.

Cultivation temperature: T (°C)	Growth rate: r ($\times 10^3$ h^{-1})	Maximum absolute growth rate: μ_{max} (cm^2·h^{-1})	Growth delay: Δ (h)
5	0	0	∞
14	6.8	0.043	737
16	11.4	0.071	459
21	22.0	0.138	259
23	24.3	0.152	244
29	23.6	0.148	199
30	25.9	0.162	236
33	15.2	0.095	354
35	0	0	∞

Table 2b. Evaluated values of the parameters describing the growth of *F. solani* on plasterboard.

Cultivation temperature: T (°C)	Growth rate: r ($\times 10^3$ h^{-1})	Maximum absolute growth rate: μ_{max} ($cm^2 \cdot h^{-1}$)	Growth delay: Δ (h)
5	0	0	∞
16	13.8	0.086	252
23	26.8	0.168	143
28	45.4	0.284	70
30	37.8	0.236	97
33	30.3	0.189	90
35	0	0	∞

As shown in Tables 2a, 2b, the growth rate is zero and the growth delay is infinite at temperatures below 5 °C and above 35 °C, indicating that *F. solani* did not grow on either material at these temperatures. Increasing the temperature above 5 °C caused a gradual increase in the growth rate and a decrease in the growth delay, suggesting improved conditions for mold growth on both materials. However, temperatures above approximately 30 °C led to a sharp deterioration in mold growth conditions on both materials, as the growth rate began to decrease and the growth delay increased rapidly.

Although the overall growth trends were similar, there were notable differences between the two materials in terms of growth rate and growth delay, highlighting the distinct dynamics of mold growth on each material. In particular, the growth rates of *F. solani* on plasterboard were significantly higher than those on fiberboard at the same temperatures. Additionally, the growth delays of *F. solani* on plasterboard were several times shorter compared to those on fiberboard. The higher growth rates and shorter growth delays indicate that *F. solani* grows much faster on plasterboard than on fiberboard.

The faster growth of *F. solani* on plasterboard is likely due to its ability to utilize several of the material's constituent components. These include cellulose-rich paper liners, which can serve as a nutrient source[30], starch-based additives[31], and certain mineral components[32]. *F. solani* is known to degrade cellulose and metabolize its breakdown products[33-35]. It produces cellulolytic enzymes such as endoglucanases, exoglucanases, and β-glucosidases, which hydrolyze cellulose into glucose, thereby providing vital nutrients for fungal growth[35,36].

Fiberboard, on the other hand, is made from wood fibers that are pressed and bonded with resins and, unlike plasterboard, has no paper facing. While paper consists mostly of cellulose, wood is a more complex material that also contains substantial amounts of hemicellulose and lignin. *F. solani* is known for its ability to degrade cellulose and hemicellulose, but lignin, due to its more complex structure, is more difficult to break down, making wood less favorable for the growth of *F. solani*. Some studies[37,38] show that medium-density fiberboard is generally more susceptible to fungal colonization by genera such as *Aspergillus* and *Penicillium*.

In addition, several studies (e.g.,[39]) show that *Fusarium* species exhibit optimal growth at neutral to slightly acidic pH levels (5.5–7.0), with significantly better development observed at pH 7.0 compared to more acidic conditions. Plasterboard typically has a core pH ranging from 7.10 to 7.82[32], creating an environment well-suited for *Fusarium* growth. In contrast, fiberboard often presents a more acidic microenvironment when moistened[40], making it less favorable for *Fusarium* proliferation. Specifically for *F. solani*, the combination of cellulose and starch-based additives with the neutral pH of plasterboard creates highly favorable conditions for growth. It is also worth noting that *F. solani* produces macroconidia and typically forms a fluffy or fibrous mycelium[41], which may promote colonization on flat surfaces.

To predict the spread of mold on building materials, it is highly beneficial to have the ability to mathematically describe its growth. Modeling mold growth can serve as a valuable tool in both research and practical applications, providing deeper insights into the dynamics of mold development and helping to identify more effective prevention and eradication strategies.

The data presented in Table 2 were further processed to determine all the parameters incorporated into functions (2) and (3), which model the temperature dependence of the growth rate and growth delay, respectively. The resulting parameters are listed in Tables 3 and 4. These parameters, when applied to functions (2) and (3), allow for the calculation of growth rate and growth delay, which can then be substituted into function (1) to model the growth of *F. solani* on plasterboard and fiberboard at any desired temperature.

The temperature dependence of the growth rate and growth delay of *F. solani* on plasterboard and fiberboard is shown in Figure 5. These dependences enable the identification of optimal conditions for the growth of *F. solani* on each material. The determined optimal temperatures, along with the corresponding maximum absolute growth rates, are presented in Table 5, facilitating a direct comparison of *F. solani* growth performance across different substrates.

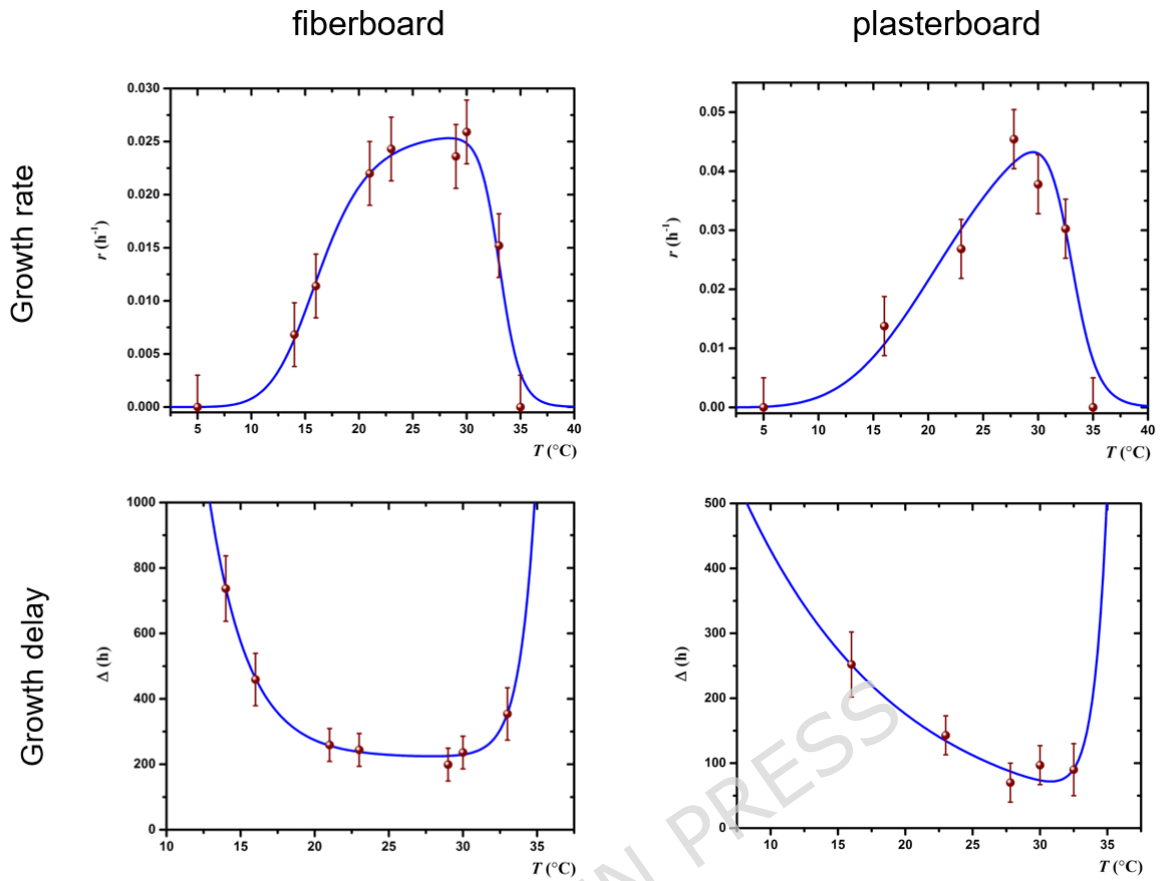

Figure 5. Temperature dependences of the growth rate and growth delay of *F. solani* on plasterboard and fiberboard. Individual points represent measured values, while solid lines depict the corresponding model fits.

Table 3. Values of the parameters used in function (2) to describe the dependence of the growth rate on temperature $r(T)$.

Parameter	Fiberboard	Plasterboard
M	0.026	0.061
G	16.4	23.1
H	33.1	33
a	6.96	4.2
b	35.2	29

Table 4. Values of the parameters used in function (3) to describe the dependence of the growth delay on temperature $\Delta(T)$.

Parameter	Fiberboard	Plasterboard
A_0	221	–3.5
A_1	$1.06 \cdot 10^5$	1037
A_2	$2.44 \cdot 10^{-12}$	$4.8 \cdot 10^{-14}$
B_1	2.63	11.4
B_2	1.043	0.95

Table 5. Parameters for comparing the growth of *F. solani* on plasterboard, fiberboard, and MEA.

Substrate	T_{opt} (°C)	μ_{max} ($cm^2 \cdot h^{-1}$)
MEA*	30 ± 2	0.50
fiberboard	27 ± 4	0.16
plasterboard	29 ± 4	0.28

* values taken from [19]

The fastest growth of *F. solani* on fiberboard was observed at a temperature of T_{opt} = (27 ± 4) °C, with a maximum absolute growth rate of μ_{max} = 0.16 $cm^2 \cdot h^{-1}$. On plasterboard, the mold exhibited a higher absolute growth rate of μ_{max} = 0.28 $cm^2 \cdot h^{-1}$, occurring at a temperature of T_{opt} = (29 ± 4) °C. Notably, the highest absolute growth rate was observed on MEA at a temperature of T_{opt} = (30 ± 2) °C, reaching a value of μ_{max} = 0.5 $cm^2 \cdot h^{-1}$ [19]. The optimal temperatures for the growth of *F. solani* across different substrates fall within overlapping uncertainty ranges, suggesting that substrate type likely has no significant effect on the optimal temperature for mold growth. This finding is consistent with other research. For instance, an optimal temperature of T_{opt} = 29.3 °C for the growth of *F. solani* on potato dextrose agar is reported in the study[42].

While mold growth on building materials is a widespread phenomenon, detailed studies specifically investigating *Fusarium* growth and its impact on building materials remain relatively scarce. Kazemian et al.[37] examined the spread of fungi on plasterboard in a university campus setting. Although *Fusarium* was less prevalent than genera such as *Aspergillus*, *Penicillium*, and *Cladosporium*, its presence, alongside other fungi, had a significant impact on material properties. The study revealed that *Fusarium* growth led to considerable deterioration in both the physical and mechanical properties of plasterboard. Notably, an increase in mold surface coverage correlated with a reduction in material integrity, with the tensile strength of

the paper backing decreasing by up to 86 % in heavily mold-infested samples[37]. Therefore, the proliferation of *Fusarium* represents a significant concern and necessitates effective eradication measures.

3.2 Impact of NTP on the growth of *F. solani* on fiberboard and plasterboard

Further experiments were devoted to investigating the impact of NTP on the growth of *F. solani* on fiberboard and plasterboard, with a particular focus on its potential to inhibit mold development on building materials, for example, in the event of water leaks. The study examined the effects of two distinct NTP sources on *F. solani* at various stages of its growth. Figures 6 and 7 present the growth rate and growth delay of *F. solani* exposed to the NTP1 and NTP2 for 10 min at 0, 24, 48, and 72 h of age, compared to untreated control samples.

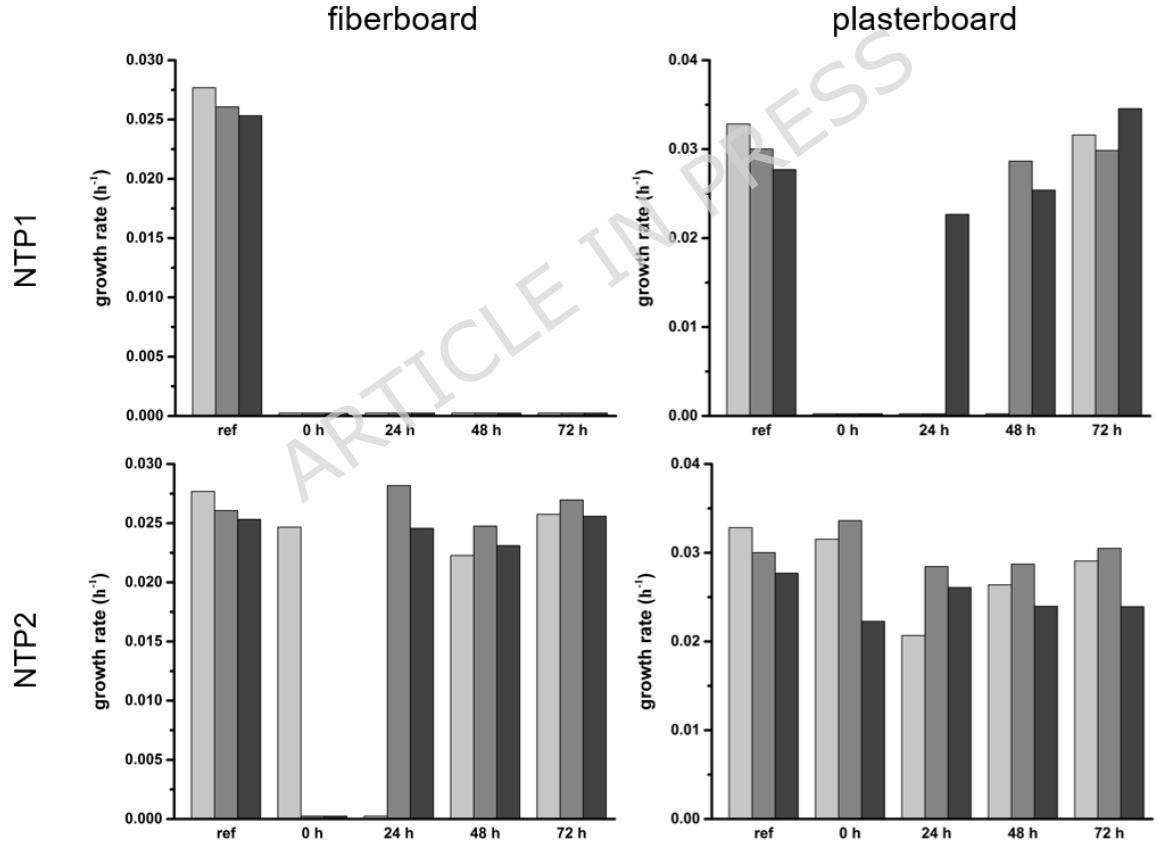

Figure 6. Growth rate of *F. solani* on fiberboard and plasterboard after exposure to the NTP1 and NTP2 for 10 min at 0, 24, 48, and 72 h post-inoculation, compared to the untreated reference samples. All samples were incubated at 23 °C. Each column represents an individual sample.

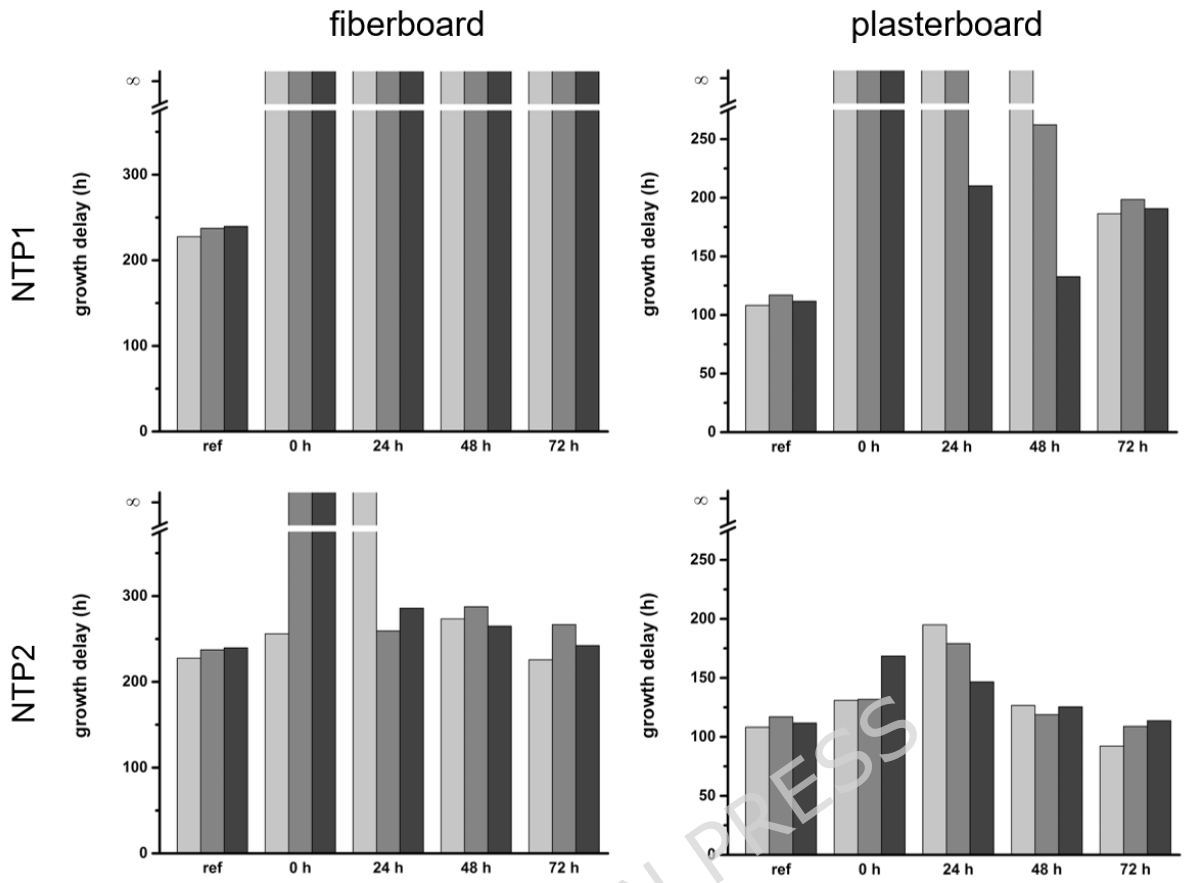

Figure 7. Growth delay of *F. solani* on fiberboard and plasterboard after exposure to the NTP1 and NTP2 for 10 min at 0, 24, 48, and 72 h post-inoculation, compared to the untreated reference samples. All samples were incubated at 23 °C. Each column represents an individual sample.

Figures 6 and 7 indicate that the NTP1 completely inhibited the growth of *F. solani* on wood fiberboard, from freshly inoculated up to three-day-old samples, as evidenced by a zero growth rate and an infinite growth delay. In contrast, the growth of *F. solani* on plasterboard was completely inhibited by the NTP1 only in the freshly inoculated samples. When applied to plasterboard samples with more developed fungal growth, the NTP1 treatment did not significantly decrease the growth rate of *F. solani*, but it did result in a noticeable increase in growth delay across all treated samples compared to the untreated controls (Figure 7).

Due to its low power, the NTP2 exhibited a significantly lower inhibitory effect on the growth of *F. solani*. Although the NTP2 was able to completely inhibit the growth of *F. solani* on the MEA surface for cultures up to 24 h old[19], its effectiveness on building materials was limited to freshly inoculated samples. Nevertheless, even this less powerful NTP source was able to alter fungal growth parameters, supporting the assumption that longer or repeated exposure may be necessary for the NTP2 to achieve complete inhibition of *F. solani* on surfaces of both MEA and building materials[17,43].

Notably, NTP was less effective at inhibiting the growth of *F. solani* on plasterboard compared to wood fiberboard. This difference can be attributed to several factors. One key factor is that *F. solani* grew better on plasterboard, forming a denser mycelial layer that may have shielded the underlying fungal structures from NTP exposure. In contrast, *F. solani* exhibited poorer growth on fiberboard, resulting in lower fungal biomass and allowing the plasma to impact mycelium more easily and exert a stronger inhibitory effect. Additionally, differences in the surface properties of the materials may have played a role: the porous structure of fiberboard could have facilitated deeper plasma penetration, whereas the smoother and denser surface of plasterboard could have limited the plasma's ability to reach subsurface fungal structures.

The Myco-surface model used describes very well both the growth of fungi itself and the dependence of this growth on temperature, and its parameters can be used as a useful interpretation of inactivation. However, the model was verified in a previous study for one fungus, *F. solani*, on agar medium, and in this work on two selected materials. Although it may seem very useful, it is necessary to keep in mind that for its practical application, it will be necessary to verify its applicability on other strains and other species of fungi. We assume this as our inspiration for further work.

To the best of our knowledge, this study is one of the first to explore the potential of NTP for eradicating mold growth on building materials. The observed inhibitory effect of NTP on the growth of *F. solani* is therefore particularly indicative, offering a foundation for further exploration. Importantly, the timing of NTP application was found to be crucial: *F. solani* was most effectively inhibited when exposed during the lag phase of its growth cycle. The inhibitory effect of NTP was demonstrated using two different types of NTP sources. The first, a DCSBD-based NTP source, is a powerful commercial unit (up to 400 W) designed for the rapid treatment of large, flat surfaces. The second, based on a 1 W corona discharge, is less powerful but advantageous for treating heat-sensitive, delicate materials[44], and even living tissue such as human skin[43,45]. Our experiments also revealed that the effectiveness of NTP in inhibiting mold growth strongly depends on the substrate: the growth of *F. solani* was more resistant to plasma inhibition on plasterboard than on fiberboard. The difference in plasma effectiveness across materials is likely due to a combination of biological factors (such as the favorability of conditions for fungal growth and the phase of fungal development) as well as the surface characteristics of the materials.

These results show that NTP could be a suitable method for controlling fungal growth in building interiors. However, as in the case of the proposed model, it is important to remember

that the study was conducted on only one fungal strain, and for possible practical application, it will be necessary to expand the study to include more strains and species.

It should be noted that no specific chemical analyses of the plasterboard and fiberboard were conducted. Additives such as aluminum sulfate, paraffin, or starch, which are commonly present in commercial boards, may affect both fungal susceptibility and plasma penetration. Future studies should quantify these components to better understand their influence on the observed inhibition effects.

4. Conclusion

This study successfully demonstrated the growth dynamics of *Fusarium solani* on plasterboard and wood fiberboard, highlighting the significant impact of temperature on mold growth. The Myco-Surface model effectively described the growth patterns, providing valuable insights into the optimal conditions for *F. solani* growth. The findings revealed that plasterboard supports faster mold growth compared to fiberboard, likely due to its cellulose-rich composition and favorable pH levels.

In addition, the study explored the potential of NTP as an innovative method for inhibiting mold growth on building materials. The high-power diffuse coplanar surface barrier discharge system proved highly effective in completely inhibiting *F. solani* growth on fiberboard and freshly inoculated plasterboard samples. In contrast, the low-power negative corona discharge showed limited effectiveness, suggesting the need for longer or repeated exposure to achieve similar results. NTP can be an effective alternative to standard methods of treatment, such as chemical or mechanical removal.

Overall, the research underscores the importance of temperature control in managing mold growth on building materials and highlights the promising application of NTP as a non-chemical, environmentally friendly solution for mold inhibition. These findings contribute to the development of effective strategies for maintaining indoor air quality and structural integrity in buildings.

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Declarations

Conflict of interest

The authors declare no competing interests.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

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