

## Effects of Initial Moisture Content on Wood Decay at Different Levels of Gaseous Oxygen Concentrations

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### ABSTRACT

The influence of initial moisture content on wood decay at different levels of atmospheric oxygen concentration was studied. Three fungi, *Coriolus versicolor* (*C. versicolor*) a white rot, *Coniophora puteana* (*C. puteana*) a brown rot, and *Chaetomium globosum* (*C. globosum*) a soft rot, were chosen. The mycelia of the fungi were inoculated in to mini blocks of *Fagus sylvatica* (beech) and *Pinus sylvestris* (Scots pine). Incubation was conducted under four levels of oxygen concentration (1,5,10, and 21% O<sub>2</sub>) at 22° C. At low oxygen concentrations, an increase of moisture content had a negative effect on the wood decay process by both the Basidiomycetes (*C. versicolor* and *C. puteana*) in Scots pine and beech. In air, the effect of initial moisture content on wood decay by these fungi depended on the characteristics of the fungi and the wood species (such as fungal biology and physiology). When *C. globosum* was used as a colonizer, increasing moisture content generally increased weight loss in the wood blocks (especially in beech). When the moisture content in the wood blocks was increased, more sporulations by *C. globosum* were also observed on the wood samples. However, the role of oxygen in inceasing wood decay was more important than the moisture content effect.

**Keywords:** Fungal physiology, Moisture content, Oxygen concentration, Wood decay.

### INTRODUCTION

The physical and mechanical properties, resistance to biological deterioration, and dimensional stability of wood products are affected by the amount of the water present and its fluctuation with time (Haygreen and Bowyer, 1982). In some species there may be little difference between sapwood and heartwood, but in many species the sapwood will have a much higher moisture content than the heartwood.

The moisture content of the trunk of living trees is generally higher than that of harvested logs. In some cases, the moisture content may be as high as 200% (of oven dry weight). However, in *Douglas fir* the moisture content of the sapwood was around 80-90% of oven dry weight (De-kort, 1993). Scots pine absorbs water to around 150%,

while the maximum moisture content for beech, as a heavier denser wood, is about 95% of oven dry weight (Kazemi, 1997). Therefore, many micro-organisms may be unable to be active on living trees as a result of the high moisture content. High moisture content prevents the growth of micro-organisms only by restricting oxygen availability. In the sapwood of a living tree, limited oxygen is only sufficient to keep the parenchyma cell alive, consequently there is not enough oxygen for micro-organism activities. This means that the water in the trees can act as a protector agent against biological deterioration effects. It might well be the reason why heartrot is able to develop in standing trees, since the heartwood is at a much lower moisture content percentage than the sapwood.

However, after harvesting, a log starts to lose some of its water to the atmosphere

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(Haygreen and Bowyer, 1982). If harvested logs are left on the ground, moulds are the first organisms that can attack the cross-section where logs are cut. Timber then becomes a suitable material for other colonisers such as white rot, brown rot and soft rot fungi (Banerjee, 1969). A decrease in the moisture content of harvested logs can cause a special group of organisms to colonise the wood at every stage of seasoning, while when wood is completely saturated with water the risk of deterioration by Basidiomycetes is less than by soft rot fungi (Eaton, 1986). The review of literature has three main sections relating to the effects of water on (a) the moisture content of wood, (b) the growth rate of decay fungi, and (c) the process of wood decay (Griffin, 1977).

Many experiments (Ammer, 1963 and Li-ese and Ammer, 1964) have indicated that there is no practical significance in wood decay by fungi when the moisture content of the wood is less than  $0.3\text{ g g}^{-1}$  (0.3g water in 1 g wood). Other references however suggest, that decay can occur below 30% moisture content (Findlay, 1967). Some investigations have shown that wood in true equilibrium with 100% relative humidity (0 bar matric potential) will be at the fibre saturation point which is typically around 27 to 29% moisture content. On the other hand, complete saturation with water will be around 150% moisture content or  $1.5\text{ g g}^{-1}$  (Griffin, 1977).

## MATERIALS AND METHODS

### Impregnation of Wood Samples

Wood blocks (64 each time) of beech and Scots pine measuring  $5 \times 10 \times 30\text{ mm}$  were used (Gray, 1983). All mini wood blocks were oven dried at  $105^\circ\text{C}$  for over 18 hours, cooled in a desiccator and weighed. Special preparation for the impregnation of the wood block was carried out, so that the wood samples were differently impregnated. Five levels of moisture content in wood

blocks of dry, 30, 50, and 80% of saturation point (the maximum percentage of moisture content in wood that may be received by vacuum pressure or waterlogged) were selected. Dry samples were maintained in a normal laboratory atmosphere for two weeks to reach 8-10% moisture content. Other samples were kept dry and prepared for impregnation. Each set of specimens (containing 30, 50, 80% SP) were put into a suitable vessel with weights to prevent them floating when distilled water was admitted. A vacuum made a negative pressure of 0.7 kpa, which was maintained for 15 minutes, after which the distilled water was allowed to be drawn into the wood samples. Wood blocks were kept covered completely with water and left for two hours for liquid uptake (European standard pr EN 113: 1994).

The degree of full impregnation (100% SP) was used as a base for calculating the other levels (80, 50, and 30% SP). For example, in 100% SP the weight of a wood sample of pine was 12g. By controlling the gauge of the vacuum pump, we were able to achieve other percentages of saturation levels such as 80% or 50%. At these percentages, the weight of the wood blocks were 9.6g and 6g, respectively, in this way, all specimens were impregnated with the distilled water, weighed to calculate moisture content, covered with double plastic bags to prevent the evaporation of water from the surface of the wood blocks, and sterilized using the radiation method. The sterilized blocks were then transferred to vessels containing grown cultures, and placed in a constant room temperature for a six week incubation period.

### Media and Organisms

Three fungi, *Coriolus versicolor* (a white rot), *Coniophora puteana* (a brown rot), and *Chaetomium globosum* (a soft rot) were used. *C. versicolor* and *C. puteana* were grown on a medium of 4% malt extract and 2% Agar in one liter of distilled water. For soft rot fungus, a mineral salt medium with

the components 6.00g  $\text{NH}_4\text{NO}_3$ +2.56g  $\text{KH}_2\text{PO}_4$  +1.02g  $\text{MgSO}_4$  + 0.25g KCL + 0.005g NaCL +0.001g  $\text{FeSO}_4$  + 0.001g  $\text{MnSO}_4$  +1.00g Glucose + 1ml trace element solution+20.00 g Agar (Gray, 1983) was used. Autoclaved media were inoculated with the fresh fungal mycelium, and incubated at 22°C. It took two weeks time for the fungal mycelium to cover the bottom of the vessels. The sterilized mini-wood blocks with mesh (wood blocks supported on plastic mesh) were then placed on cultures and inoculated with the organisms. (During the incubation period, a pilot was used to check the moisture content of the wood blocks before they were attacked by fungi.

### Incubation

Three levels of oxygen concentration (1, 5, 10%) balanced with nitrogen were chosen. Air was also used as a control treatment. The effects of different initial moisture contents on wood decay were studied. Petri dishes containing mini wood blocks and cultures were maintained in anaerobic standard jars at constant temperature room (22°C). Three levels of gas mixtures (oxygen balanced with nitrogen) were connected to the pressure and vacuum valves of the anaerobic jars and vacuum pump. Every three days, a new gas mixture was injected into the jars.

At the end of the six-week incubation period, mycelia were gently scraped from the surface of the wood blocks. The blocks were then weighed, oven dried at (105°C), cooled in the desiccator, and weighed again to calculate the percentage of weight loss and their moisture content.

## RESULTS

### Observations on Growth

In the air after six weeks incubation, all the dry samples of Scots pine were covered by *C. versicolor*, but the colour of the wood blocks was unchanged. At 30% SP, a cot-

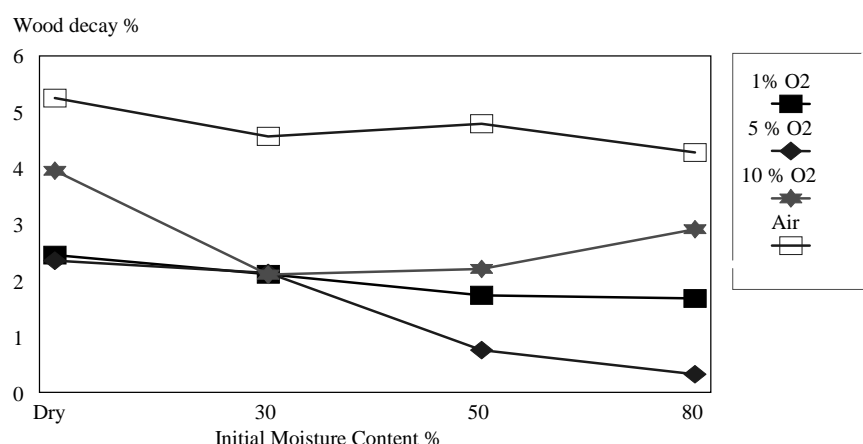
tony mycelium covered the wood blocks and the culture seemed vigorous. At 50% SP, although mycelium occurred on all samples this covering was not thick. At 80% SP, the growth rates of the mycelium was a little thicker and all samples were under fungus covering. With increasing moisture content in the wood samples the amount of mycelium on wood blocks decreased. In 80% SP, the mycelium of *C. puteana* covered all the pine blocks, the mycelium seemed aged, and some samples were destroyed. In 30% SP, the mycelium of *C. puteana* seemed to be more than at higher levels of moisture, and it was fresher. In dry wood samples, the colour of the mycelium was lighter, and its amount was greater than the others. In the case of *C. globosum* on beech blocks (containing initial 30, 50, and 80% SP), more sporulation was seen and the samples were completely wet. It appeared that increasing the moisture content in the wood blocks caused the fungus to grow very well on the beech blocks and, as a result, more spore germination was observed. However, with a decrease in oxygen concentration from air to 10%, 5%, and 1%, the growth rates of mycelium were decreased.

### Numerical Results

Studies on initial moisture content and wood decay by different organisms under various oxygen concentrations in beech and Scots pine were continued. Mini blocks (5×10×30 mm) of both species of the culture media were exposed to *C. versicolor*, *C. puteana* and *C. globosum*, under 1%, 5%, 10% and 21% oxygen concentrations. However, specimens had different initial moisture content (dry, 30%, 50%, and 80% SP).

### Decay in Scots Pine

Increasing the moisture content in timbers and trees normally causes the oxygen level to be reduced. Organisms are generally not able to degrade wood as a result and, for this



**Figure 1.** Relationship between moisture content and wood decay at several levels of oxygen by *C. versicolor* in Scots pine.

reason, logs are stored in pools. However some organisms such soft rot fungi are able to degrade wood even at a high moisture content. Therefore, even though the role of reduced oxygen is considerable, the role of moisture content in wood degradation, especially when its rate is below of fibre saturation point (FSP), must also not be ignored. The data show that a high moisture content at the beginning of the wood decay process generally had an inverse relationship with weight loss, so that weight loss was mostly decreased with increasing moisture content (Figure 1). The results of some pilots on mini pine blocks (30×10×5 mm), at six weeks, incubation and large blocks (50×25×15) at 16 week's incubation showed that pine blocks were less effected by *C. versicolor* than by *C. puteana*, and so weight losses on both blocks (mini and large) were too low.

Increasing the oxygen concentration from 1% to 21% (air) generally caused weight losses to be increased. At 5% oxygen concentration, there was an inverse relationship between various initial moisture contents and wood decay which indicated that *C. versicolor* at this level of oxygen concentration is not able to degrade wood when its moisture content is increased. However, moisture contents in wood blocks were generally

maintained during the incubation period. With increasing the moisture content at 10% oxygen concentration, wood decay was not increased although at this level of oxygen, there was no inverse relationship between moisture content and wood decay.

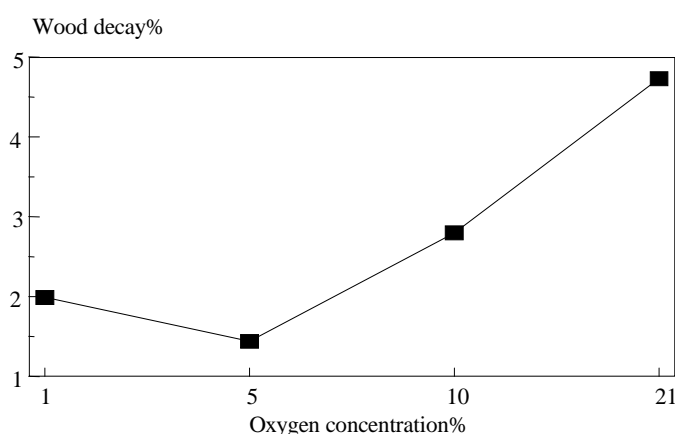
In air, when the moisture content was increased, wood decay was also increased, but various moisture contents (dry, 30, 50, and 80% SP) in wood samples did not create a big difference between weight losses. However, the role of oxygen was more important than moisture content in increasing wood decay (Figure 2).

Regression data indicated there was a negative relationship between moisture content and the wood decay process by *C. versicolor* in Scots pine at different levels of oxygen so that, with increasing moisture content, wood decay was decreased (Figure 3).

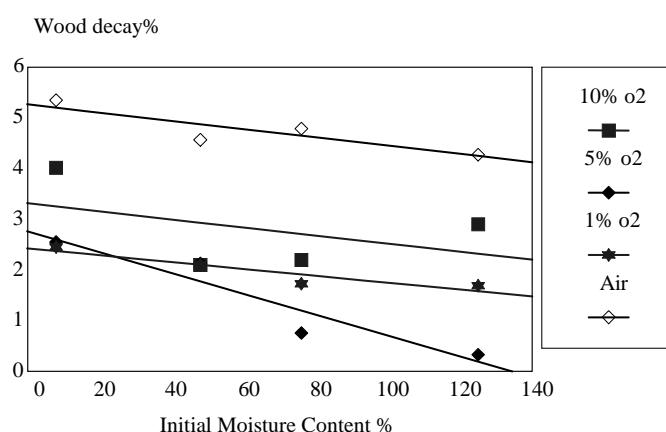
This result indicates that, as wood is placed in environments with high moisture content and in contact with liquid water, wood decay by Basidiomycetes is decreased. *C. puteana* was very sensitive to low oxygen levels and a high moisture content, especially when the fungus was exposed to both. This could indicate that below ground with limited air and accessibility to liquid water, there is no serious risk of *C. puteana* growth

on wood. When the growing mycelium was exposed to the above factors, the fungal growth on the wood blocks was limited. In order to confirm this result, the experiment was repeated and similar results were obtained. By increasing the oxygen concentration from 5 to 10%, wood decay was seen to occur. However, at lower levels of oxygen (1 and 5%) and with different moisture contents, no decay was observed. The reason may be due to the sensitizing of *C. puteana* to very low oxygen concentrations. In air, there was extensive decay with each moisture content. A relationship between initial

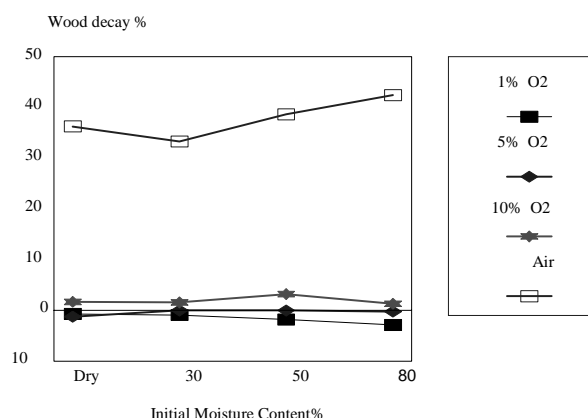
moisture content and weight loss was seen in pine blocks. In air, weight loss was generally also increased with increasing moisture content. Finally, high moisture content in wood samples appeared to have a negative effect on the wood decay process by *C. puteana* and *C. versicolor*, especially when low oxygen levels were used. In Figure 4, the lack of a strong correspondence between moisture content and wood decay, as well as large differences in weight loss caused by *C. puteana*, between air and different lower oxygen levels are well illustrated.



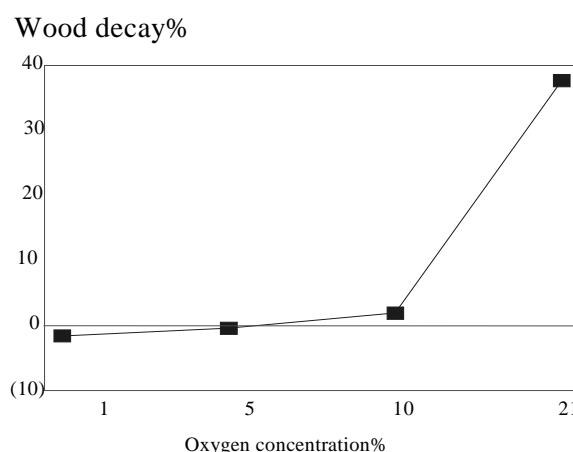
**Figure 2.** Relationship between oxygen concentrations and wood decay by *C. versicolor* in Scots pine



**Figure 3.** Regression between moisture content and wood decay by *C. versicolor* at 1, 5, 10, and 21 % oxygen in Scots pine.



**Figure 4.** Relationship between moisture content and wood decay at different levels of oxygen concentrations by *C. puteana* in Scots pine.

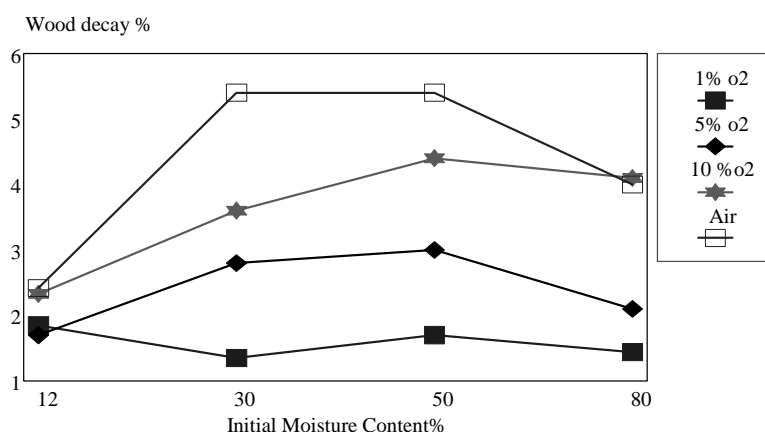


**Figure 5.** Relationship between different oxygen levels and wood decay by *C. puteana* in Scots pine.

The total average weight loss at each level of oxygen concentration containing different moisture contents (dry, 30%, 50%, and 80% SP) were -1.55, in 1% O<sub>2</sub>, -0.36, in 5% O<sub>2</sub>, 1.96, in 10% O<sub>2</sub>, and 37.66, in 21% O<sub>2</sub>. This relationship is clearly shown in Figure 5.

In the case of *C. globosum*, there was no direct relationship between the initial moisture content and weight loss at 1% and 5% oxygen levels. However at 10% and 21% oxygen concentrations, there was a direct relationship between moisture content and wood decay (Figure 6).

The total average of weight loss at each oxygen level, containing different moisture contents, showed that the role of oxygen in the wood decay process is very important. The following numerical results due to weight losses were obtained: 1.51%, in 1% O<sub>2</sub>, 2.47, in 5% O<sub>2</sub>, 3.23, in 10% O<sub>2</sub> and 3.80, in 21% O<sub>2</sub> or air. The results of *C. globosum* effect on both species, indicate several important points in this study: first, when *C. globosum* was inoculated into dry wood samples (low moisture content) with different oxygen level, very low weight



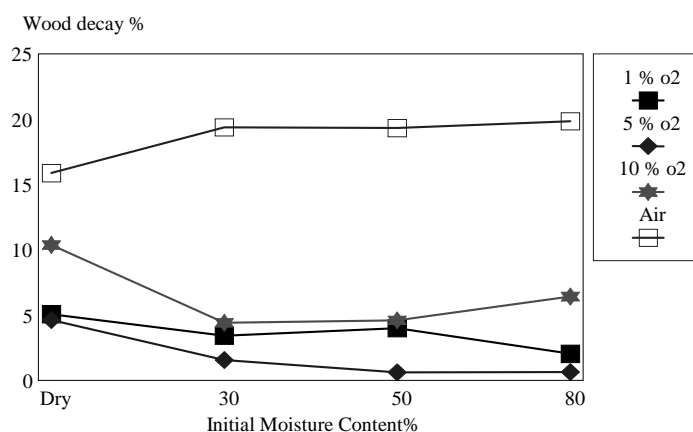
**Figure 6.** Relationship between moisture content and wood decay at several levels of oxygen by *C. globosum* in Scots pine.

losses obtained; second, more sporulation by this fungus was observed on wood blocks when a high moisture content was used; and third, with increasing moisture content in the wood samples, decay occurred and increased.

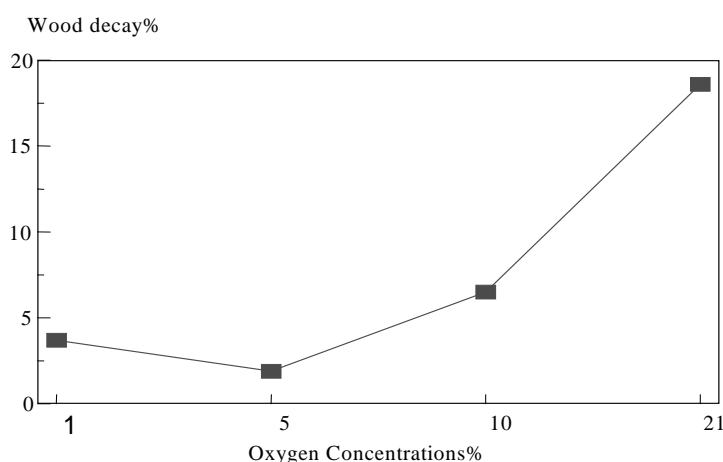
### Decay in Beech

Beech sapwood was exposed to the same organisms under the various levels of oxygen concentration and moisture content. All the treatments and incubation times were as for pine. However, the data obtained from the experiments with beech differed from

those obtained with Scots pine. Increasing moisture content at the beginning of the wood decay process by *C. versicolor* at 1% and 5% O<sub>2</sub> caused weight losses to be generally decreased, while at 10% and 21% oxygen concentrations with an increase in moisture content, weight losses were increased. This may indicate that, if beech is exposed to very low oxygen levels (1-5%), an increase in moisture content will not strongly effect the wood decay process. While, if both the oxygen and moisture content together are increased, weight loss will also be increased. More details are illustrated in the graph given in Figure 7.



**Figure 7.** Relationship between moisture content and wood decay at several levels of oxygen by *C. versicolor* in beech.



**Figure 8.** Relationship between oxygen concentrations and wood decay by *C. versicolor* in beech.

On the other hand, there was an inverse relationship between initial moisture content and wood decay at low oxygen concentrations (1% and 5%) when the wood samples were exposed to *C. versicolor*. With increased levels of oxygen concentration (10%-21%) weight losses were greatly increased, but increasing the moisture content still reduced weight loss in the beech blocks. For further investigations, the average weight losses at all moisture levels with different oxygen concentrations were obtained as follows: 3.7%, in 1% O<sub>2</sub>, 1.9%, in 5% O<sub>2</sub>, 6.5%, in 10% O<sub>2</sub>, and 18.6%, in 21% oxygen. This indicated that, by increasing the oxygen concentration from 1% to 21%, the wood decay process was also increased. However the role of oxygen concentration in increasing or decreasing of wood degradation was more important than that of moisture content. The weight losses shown in Figure 8 represent the average of the weight losses for each oxygen level.

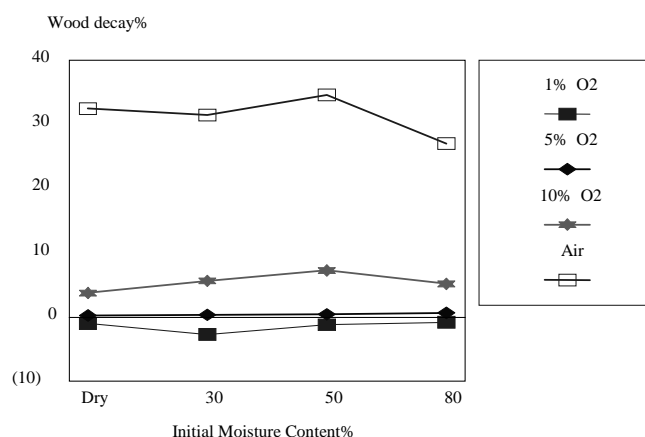
The effect of initial moisture content on beech decay by *C. puteana* at different levels of oxygen was also studied. It is known that, in air, *C. puteana* has a strong effect on both species (Scots pine and beech). However, if the environmental conditions change, this fungus may show changes in its physiology. For example, this fungus is sen-

sitive to low oxygen concentration and high moisture content. Therefore, when the blocks were exposed to a low oxygen and high moisture content, the growth of mycelium was reduced in the culture and on the blocks. Weight loss at 1% oxygen concentration, with different moisture contents was negative or no weight loss was seen. At 5% oxygen also, there was slight weight loss in the wood blocks.

Weight losses caused by *C. puteana* in beech at 10% and 21% O<sub>2</sub>, in contrast to the lower oxygen levels (1% and 5%), were increased. At these levels of oxygen concentration, the highest weight losses were found in wood blocks with 50% SP. Therefore, it can be concluded that the best moisture content in beech blocks for degradation by this fungus may be around 50% SP. The role of oxygen was also important at all levels of moisture content so that, by increasing the level of oxygen, wood degradation was increased. Equally, with decreased levels of O<sub>2</sub> wood decay was reduced. The average of total weight loss at each level of oxygen concentration, containing different levels of moisture content, were as follows: -1.4%, in 1% O<sub>2</sub>, 0.5%, in 5% O<sub>2</sub>, 5.5%, in 10% O<sub>2</sub> and 31.4%, in 21% oxygen.

As is illustrated in Figure 9, there is a big gap between wood decay in air and other





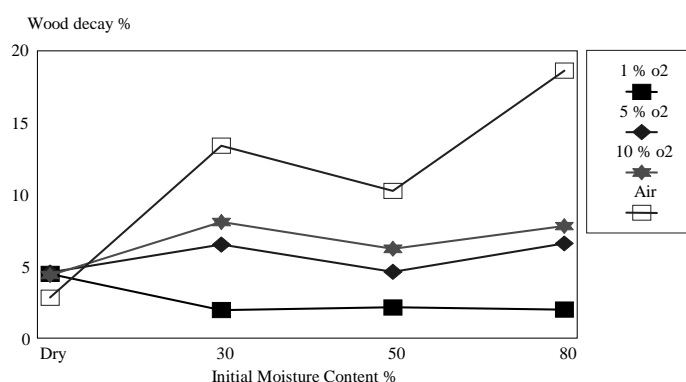
**Figure 9.** Relationship between moisture content and wood decay at different levels of oxygen by *C. puteana* in beech.

plentiful levels of oxygen concentration. This shows that, if oxygen is not available for fungal activity, wood degradation can be greatly reduced, and that a high moisture content has no strong effect on wood decay. The consequence of the oxygen level on wood decay was clearly observed. It showed there was a gradual increase in weight loss between 1% to 10% oxygen, but in air it was greatly increased such that the amount of weight loss rose from 5% to 32%.

Mycelia growth of *C. globosum* on beech blocks was completely different from that on Scots pine mini-blocks. All beech specimens were covered in spores at different initial moisture contents (30, 50, and 80% SP). More sporulation was a result of good cul-

ture growth on specimens by this fungus. Large weight losses were also observed on the wood blocks. However, no sporulation was seen on wood samples at 1% oxygen concentration. Therefore, the results suggest that for sporulation, in addition to the necessity for high relative humidity (RH) and suitable moisture content, the oxygen requirement was also another important factor. Thus, *C. globosum* had a good growth rate on beech blocks when all factors were used.

The highest weight loss (18.6%) at this stage of the experiment was related to 80% SP at a 21% level of oxygen concentration (air). This would indicate that the fungus should be dangerous for hardwood species if all conditions optimum temperature, high



**Figure 10.** Relationship between moisture content and wood decay at several levels of oxygen by *C. globosum* in beech.



moisture content, and air are present. The relationship between moisture content and wood decay at several oxygen concentrations is illustrated in Figure 10.

## DISCUSSION

The main objective of this research was to investigate the dual role of oxygen concentration in the wood decay process at different moisture contents. Essentially, where the oxygen concentration was reduced, weight loss in the wood decay process by Basidiomycetes (specially by *C. puteana*) was very low. At low levels of oxygen concentration, increasing the moisture content not only was unable to increase weight losses but, indeed, reduced them. In the case of the influence of moisture content on wood decay caused by *C. versicolor*, the highest negative relationship between wood decay and moisture content was related to a 5% oxygen concentration ( $r^2 = 0.90$ ). Average weight losses in wood blocks caused by *C. versicolor* at all levels of moisture content (30%, 50%, and 80% SP) indicated that, with increasing oxygen levels, wood decay in Scots pine is also increased ( $r^2 = 0.88$ ). In view of the low oxygen effect on wood decay caused by *C. puteana*, very low wood decay in Scots pine at levels of 1%, 5% and 10% oxygen concentration was mostly observed, and regression data indicated that no significant relationship existed between moisture content and wood decay. In air, a positive relationship between decay and moisture content was observed ( $r^2 = 0.58$ ).

In the case of *C. puteana*, there was no clear correlation between moisture content and wood decay caused by this organism. Although it can generally be suggested that its sensitivity to low oxygen and moisture meant that this fungus was not able to decay wood, but increasing the oxygen content mostly caused average weight loss to be increased, and oxygen clearly had an important role to play in the brown rot decay process.

The same effects were observed on wood decay caused by *C. versicolor* in beech. These results indicated that, at low levels of oxygen concentration, there was a negative relationship between moisture content and wood decay. The regression data ( $r^2 = 0.84$ ) showed that  $r^2$  values corresponded to 1%, and then 5% and 10% oxygen concentrations indicating that, where the oxygen level was very low, increasing the moisture content could have a negative effect on wood decay. Therefore, this fungus may be less aggressive in applications where wood is placed in ground with a high moisture content.

Weight losses obtained by *C. versicolor* in beech were generally higher than in Scots pine. Therefore, it could be concluded that the moisture content had a negative effect on wood decay in both species at a very low oxygen level (1%), and its effect at 5%, 10% and 21% oxygen levels was variable.

The important influence of moisture content was shown by *C. globosum*. A high moisture content (80% SP) in wood blocks led to great weight losses in both wood species, especially beech blocks, caused by *C. globosum*. High sporulation by this fungus was observed when both wood species were exposed to a high moisture content, and it was higher seen in beech. In beech specimens, increasing the moisture content had a positive effect on the wood decay process in all situations. Around 20% weight loss was a result of increasing moisture content in wood blocks exposed to air.

Finally from the results, it can be summarized that, mostly at low levels of oxygen concentration, increasing the moisture content had a negative effect on the wood decay process in both wood species both the Basidiomycetes. In air, the effect of moisture content on wood decay by these fungi corresponded to the fungal characteristics and wood species. In the case of the soft rot fungus (*C. globosum*), increasing the moisture content in wood blocks generally caused weight loss to be increased, and greater effects were seen at 10% and 21%

oxygen than at very low oxygen concentrations (1% and 5%).

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## تأثیر رطوبت اولیه و سطوح مختلف اکسیژن روی پوسیدگی چوب

م. کاظمی، د. دیکینسون و ر. مرفی

### چکیده

تأثیر رطوبت اولیه چوب و سطوح مختلف اکسیژن روی پوسیدگی چوبها مورد مطالعه قرار گرفت. برای این بررسی قارچهای سفید رنگین کمان (*Coriolus versicolor*)، پوسیدگی قهوه‌ای (*Coniophora puteana*) و پوسیدگی نرم (*Chaetomium globosum*) انتخاب شدند. ریشه‌های قارچهای فوق‌الذکر بلوکهای کوچک چوبهای راش و کاج اسکاتلند (*Pinus sylvestris*) را در یک بررسی آزمایشگاهی مورد حمله قرار دادند. این چوبها به ترتیب دارای رطوبتهای ۸، ۳۰، ۵۰ و ۸۰ درصد بودند. در طول تأثیر قارچها روی نمونه‌های چوبها، اثرات سطوح مختلف اکسیژن (۱، ۵، ۱۰ و ۲۱ درصد) نیز بر روی فعالیت قارچها مطالعه شد. نتایج بدست آمده حاکی از آن بود که در غلظت‌های پایین اکسیژن (کمتر از هوا) افزایش رطوبت یک تأثیر منفی روی روند پوسیدگی بوسیله قارچهای سفید و قهوه‌ای داشت. بدین ترتیب که با زیاد شدن رطوبت میزان پوسیدگی کاهش یافت. بهر حال روند پوسیدگی در هوا



بسته به خواص بیولوژیکی و فیزیولوژیکی قارچ فرق می‌کرد. هنگامی که قارچ پوسیدگی نرم استفاده گردید. افزایش رطوبت موجب افزوده شدن پوسیدگی به خصوص در راش گردید و این افزایش در پوسیدگی با زیاد شدن اکسیژن رابطه مستقیم داشت. افزایش رطوبت همچنین موجب اسپرزایی بر روی چوب راش شد. بهر حال اهمیت اثرات افزایش اکسیژن، از اثرات افزایش رطوبت بر روی پوسیدگی بیشتر بود.