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MICROBIOLOGICAL DETERIORATION IN THE WOOD CHIP PILE

by

J. K. Shields

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ABSTRACT

A literature survey has been made to bring together available information on the effect of outside storage on wood chip quality.

Little or no differences in deterioration of the wood have been experienced in comparisons between chip and roundwood methods of storage. Microbiological deterioration is greater in the uncompacted sides of chip piles than in the central compacted areas, while some deterioration has also been found at the bottom of chip piles where the base is either composed of old chips or soil. While some loss in wood substance has been experienced in these areas of greater discolorations due to microbiological activity, losses in the interior compacted areas have been much less.

Methods suggested to control chip deterioration have included: winter piling, water sprinkling, compaction, piling on solid foundations, and preservative-treatments. However, it has been proposed that, to minimize deterioration by fungi, softwood chips should be utilized before eight months and hardwood chips before four months.

RÉSUMÉ

L'auteur passe en revue ce qui a été publié jusqu'à ce jour sur la détérioration microbiologique des copeaux de bois entreposés en plein air.

Il ne semble pas exister de taux différents de détérioration entre le bois sous forme de copeaux ou celui qui est sous forme de billes, mais dans un empilage, les copeaux situés près du sommet ou près de la périphérie tendront à pourrir plus vite. Il en va de même pour ceux qui forment le fond de la pile lorsque l'empilage a été fait sur le sol meuble ou sur une couche de vieux copeaux. Vu que la détérioration est plus lente au centre de la pile, c'est là que le poids spécifique des copeaux diminue le moins.

On a proposé diverses méthodes (empilage d'hiver, arrosage avec de l'eau, tassement, empilage sur un terrain pavé, traitement avec des fongicides) pour retarder l'action des agents de détérioration. Cependant, l'on recommande fortement d'utiliser les copeaux de bois tendre pas plus tard que huit mois après le début de l'entreposage; ou, pour le bois dur, seulement quatre mois.

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J.K. Shields[1]

INTRODUCTION

There has been an increasing trend in recent years toward the storage of pulpwood in outside chip piles for the manufacture of pulp and paper products. Originally, piles were constructed of chips from sawmill and veneer residues obtained from the wood-using industries (20, 31). However, handling and economic advantages of chip storage over log storage (7) have resulted in many mills chipping their logs to provide readily available material for the pulping operations.

The practice of outside chip storage for the manufacture of pulp and paper products spread from the American west coast (where it first originated in the early 1950's) to the southeastern U.S.A., where a considerable amount of research has been conducted on the deterioration of southern pine, oak, and gum chips, and on the comparison of this type of storage with the land storage of roundwood. There has also been great interest shown in the storage of chips in eastern North America and Europe and many chip piles have been set up in these areas.

Qualitative and quantitative studies have been made by American and European investigators on the effect of chip storage on pulp and by-products. Some of these investigators have indicated that quite varied microbiological communities may exist within piles because of the occurrence of different temperature zones. The activities of these communities of micro-organisms and the chemical changes that they produce within the chip pile during storage cause much of the deterioration experienced in the chips which, in turn, influences the quality of the pulp.

Reviews published in America (43, 47[2]) and in Sweden (8) have considered some of the problems associated with chip storage including references to deterioration of the chip piles and its effect on pulp quality. Since these reviews have been published, additional information has been obtained on the deterioration of chips during outside storage. This report is based on the pathological changes that occur in chips stored in outside

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[2]After the completion of this manuscript a review by G.J. Hajny was published.

piles and the influence of physical factors on the deterioration. Alterations in extractives during chip storage and the effect of chip deterioration on the yield, brightness, and strength properties of pulp is dealt with in another publication (49).

COMPARISON OF ROUNDWOOD AND CHIP STORAGE

Most comparisons which have been made on the effect of softwood chip storage as opposed to roundwood storage have indicated that little or no difference in deterioration, yield, or pulp quality was apparent under similar conditions (7, 14, 16, 17, 26, 27, 36, 37). However, in another report (22) there is mention of the risk of larger wood substance losses for chip storage and the need for further research on this problem.

From studies in the southern U.S.A. (26) it has been stated that pine chips, stored outside for 3 summer months failed to show deterioration, while a 3 to 4 per cent reduction in basic specific gravity was obtained for pine roundwood stored during the same period. Only minor chip deterioration was experienced at 4 months. In contrast to this, other studies (37) have indicated that winter-stored pine chips appeared to deteriorate at a slightly faster rate than roundwood during the first 2 months storage although advantages in mechanization were said to have outweighed these losses. Deterioration of the pine chips winter-stored over 3 months was less rapid than roundwood stored under similar conditions. In other reports (29, 36) comparisons with straw-piled pulpwood indicated that deterioration of roundwood proceeded at about the same rate as the chips with wood substance losses of the former reaching about 7 per cent in 12 months.

Less deterioration was experienced with oak chip storage when compared to roundwood storage in the southern U.S.A. (13, 17, 29). The average wood substance loss in the compacted zone of an oak chip pile was calculated to be 3.2 per cent at 3 months storage while the corresponding roundwood lost 5.0 per cent at the same storage period. Gum chips, on the other hand, had more deterioration in the chip form than in roundwood storage. The lower durability of gum wood compared to oak heartwood accounts for the greater deterioration of the former species.

Chip storage is considered to be more advantageous than log storage to pulp mill operations mainly because of lower handling costs (7, 15, 22, 24, 27). Operational advantages (16) have been reported as follows:

1. Reduced fibre loss.
2. Decreased handling costs.
3. Large manpower saving.
4. 20 to 25 per cent increase in production from woodyard-woodroom.
5. Reduced maintenance costs.

6. Elimination of production loss because of woodroom-woodyard breakdowns.
7. Increased bark yield and consequent reduced fuel costs.
8. Improved uniformity in digester furnish.
9. Greater storage per acre.
10. Less housekeeping.
11. Smooth woodyard-woodroom operation.
12. Better, more accurate species handling.

EFFECT OF MICRO-ORGANISMS ON CHIP QUALITY

The microbiological deterioration experienced in stored wood chips can be grouped into two main categories - discolorations, and decay. The discolorations may be further divided into those resulting directly from the presence of coloured fungal filaments (hyphae) in the wood cells, and the staining which results from the chemical changes in wood brought about by the metabolic activities of fungi (Figure 1).

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Figure 1. Comparison of discoloured chips with non-stored chips. Black-stained hardwood chips (right) stored for over 1 year are heavily infected by staining fungi. Brown discoloured softwood chips (middle) were obtained from the bottom of a large pile after 9 months storage.

Blue-gray or black discolorations are common in sapwood, and in some cases the heartwood when colonized by fungi with dark-pigmented hyphae. Some dark discolorations also result from coloured spores or small black fruiting bodies on the surface of the wood chips. In addition to the dark stain there may also be a softening or brashness of the chips because of heavy infection by fungi causing a condition known as soft rot.

Serious chip deterioration occurs as a result of brown discolorations. In some cases, oxidative and photochemical processes may be involved which result in the formation of a yellowish brown discoloration on the chips situated on the surface of the pile where the effect of light and drying are more pronounced. This stain is generally confined to the surface areas of the wood but can also occur in the internal portions of the chips. The activity of wood decay Basidiomycete fungi often results in brown-discoloured chips. This coloration involves those portions of the chips colonized by the fungi and is indicative of early or incipient decay by brown or white rot fungi. The opposite effect, characterized by a bleaching of the wood, sometimes appears in hardwood chips infected with white rot fungi.

Dark brown discolorations have been found to be more widespread at storage periods beyond 7 months near the bottom of a large softwood chip pile (39). In this case it was suspected that the discoloration resulted from the action on the wood by organic acids produced as a result of fungal metabolism, as the pH of such wood was quite low in comparison to that for nonstained chips. The formation of acetyl groups as a result of high temperatures and moisture is also believed to be a factor in the appearance of brown discolorations in stored chips.

Decay fungi, besides being associated with colour changes in wood, cause reductions in wood substance and, together with other microorganisms, are responsible for the losses experienced in the basic specific gravity of infected chips. Most of the Basidiomycete fungi involved in the decay of stored chips are in the group commonly referred to as white rot fungi and are able to utilize both the lignin and cellulose components of wood. Brown rot fungi, which are less commonly isolated from chips, preferentially utilize the cellulose leaving lignin untouched. Certain other fungi belonging to the Ascomycete and Fungi Imperfecti groups are also able to cause decay in wood (soft rot). These latter fungi, while not causing as high weight losses, are able to grow in substrates with higher moisture contents than those required for optimum decay by the Basidiomycete fungi. The greatest amount of damage by the soft rot organisms due primarily to breakdown of cellulose, appears on the surface of the wood while the inner wood is unaffected to a large degree by this deterioration. The possibility always exists that the softening process may extend deeper into wood chips stored for long periods under moisture and temperature conditions favourable for this type of decay. Recently (33, 39) other fungi in the Ascomycete and Fungi Imperfecti groups have been found to cause considerable weight loss in wood at high temperatures. These are heat-tolerant and thermophilic species which have optimum growth at temperatures from 35 to 45°C.

Deterioration of Softwood Chips

The amount of deterioration in outside chip piles has varied considerably in some cases. Little deterioration has been reported in softwood chips stored at mills on the west coast of North America (12, 15, 24, 34) while at some mills (24) it was indicated that softwood species could be stored for as long as 3 years without the occurrence of serious degrade. In other reports (12, 34) it was found that discolorations and rot were present in softwood chips stored for 1 to 3 years at mills in B.C. and Oregon.

Decay was first noticed (23) in pine chips stored for 18 months in South Carolina, while fungal discolorations were observed in only certain areas of pine chip piles. For instance, studies in Georgia, (25) showed that, while the outer one-half inch layer of pine chips were bright and dry after 4 months storage, the underlying chips with a higher moisture content had evidence of mould and stain to a depth of about one foot from the surface of the pile. Chips underneath this zone were still relatively bright. Other reports (26, 27) mention only minor deterioration of pine chips after 4 months storage. Most of the blue-gray fungal discolorations occurred in the pine chips situated in the outer one to two feet of the uncompacted sides of one pile after a month of storage (29, 36, 37). After 5 months storage, the infection had extended several feet into the pile but little visible infection was detected in the chips in the more compacted interior of the pile.

A softwood chip pile became obviously darker in colour after being stored for 9 to 12 months in Nova Scotia (35) and although the stained chips were somewhat lighter in colour upon drying they were still darker than non-stained chips and had an acetic acid odour. In a study of spruce and balsam fir chips stored in New Brunswick (39) discolorations by blue-staining fungi were insignificant in most of the pile after 4 to 8 months storage although more of these organisms were isolated from chips in the lower half of the pile where cooler temperatures prevailed. In Quebec, one study (31) showed deterioration of softwood chips after 4 to 5 months storage.

A non-fungal yellowish-brown or orange discoloration was found to occur in a pine chip pile in the southeastern U.S.A. (29, 36, 37) within 1 month of storage. This stain was associated mainly around resin ducts in the heartwood areas, suggesting that the resins were modified and that moisture and heat may have contributed to its development.

Brownish discolorations, which have been noted in the interior of several softwood chip piles in North America and Europe (11, 37, 39), have been attributed to chemical changes in the piles and can seriously reduce chip quality. The development of the brown stain was progressive with increased storage and appeared to be more widespread near the bottom than the top of one pile (39).

Softness and brashness have been noted in heavily-stained pine chips in the southeastern U.S.A. (29, 36, 37) and were attributed to the activity of soft-rot fungi. These types of deterioration were evident in the chips after 4 months summer storage and after 5 months winter storage. Wood-rotting Basidiomycete fungi have been found in many chip piles and take an important part in the loss of wood substance. Most wood-rotting fungi have been found in the uncompacted parts of piles possibly because of the growth-inhibitory high temperatures experienced in the compacted interior of the piles (33). In another study (39) isolations of decay fungi were greater from softwood chips obtained from the bottom half of a large pile.

Deterioration of Hardwood Chips

Hardwood chips stored in outside piles generally showed greater deterioration from microbiological activity in less time after the commencement of storage than did the softwood chips. In one case (17) oak chips were found to be heavily infected with moulds and staining fungi after 1 week of storage in Florida. In this instance it was felt that the chips had been obtained from infected bolts or were not fresh at the time of arrival at the mill.

Discolorations in oak and gum piles stored outside in Georgia (13, 29) first appeared in the outer few feet of the piles within 1 month. After 2 months storage, gum chips and, to a lesser extent, oak chips had orange and blue-black discolorations in the uncompacted sides. After about 5 months storage the discoloration appeared black and the chips became softened and brash at the surfaces indicating probable soft rot attack. Typical decay by Basidiomycete fungi showed up as bleached and softened areas in the gum chips during the first month of storage in the outer discoloured layer of the piles. Oak chips were not as severely affected but had bleached areas in some of the dark-stained chips after 6 months storage. The chips in the compacted centre of the piles still appeared in good condition after 5 months storage and had no signs of decay. Non-fungal grayish discolorations in gum chips and brownish discolorations in oak chips were thought to be possibly caused by bacterial or chemical action in association with heat.

In one report (5) it was found that hardwood chips obtained from logging residues could not be stored outside for more than 8 months in small piles in Michigan without risk of loss due to decay. After 8 months storage, discoloration had extended to a depth of about 18 inches into the piles. Deterioration was found in hardwood chip piles stored at a Quebec mill (31) after 4 to 5 months storage. A recent study (48) indicated discolorations and reductions in pulp yields occurred after one month storage of birch, beech, and maple chips.

Oak chips stored outside in France (3) were reported to be in excellent condition after 6 months storage and were not visibly attacked by moulds or insects. It was also stated that some of the chips had been stored up to 18 months without obvious alterations being noted in their quality. For storage periods in excess of 2 years, evident humification of hardwood chips had occurred (28). Brown and black discolorations on the surface of beech chips was not considered serious even after 6 to 12 months storage in Austria (45) since non-bleached hardwood pulp is seldom manufactured by the sulphite process.

Insects in Outside Chip Storage

Little attention has been given to the role of insects in chip deterioration. In one case (17) mites and nematodes have been noted in an oak chip pile in Florida, while in Sweden (22) small springtail insects (*Collembola* species) have been found in chip piles where they apparently burrow into the warm moist areas of the piles to overwinter. The significance of the presence of insects in chip piles is not clearly defined, however it is expected that serious insect degradation of wood material is negligible.

EFFECT OF MICRO-ORGANISMS ON THE QUANTITY OF WOOD SUBSTANCE IN PILES

Many reports on the losses in wood substance which have occurred during chip storage have come from studies made in the southern U.S.A. and Sweden, and indicate some variability in basic specific gravity losses not only between different piles but also within the pile itself. The type of micro-organisms inhabiting chips and the degree of microbiological activity are important factors involved in the amount of wood substance lost during storage.

Only minor reductions in specific gravity have been noticed in pine chips stored for up to 2 months (4) when compared to non-stored chips. In another study (37) losses in specific gravity during the first few weeks of pine chip storage were greater in those chips situated near the centre of the pile. While these losses were unexplained at the time it is possible that very high temperatures resulting from the initial rapid growth of heat tolerant and thermophilic micro-organisms may have been involved. With longer storage it was found that losses were not as great in the centre of the pine chip pile (37). This reduction in specific gravity losses corresponded to a lowering of the temperatures, an increase in moisture and perhaps depletion of oxygen.

After 5 months storage (36, 37) there was an approximate average loss of 7 per cent of the wood substance which amounted to about 1.5 per cent per month. It was noted that while wood substance losses in the compacted centre of the pile were low (about 4 per cent) even after 12 months storage, greater reductions (about 9 per cent) occurred in the outer three feet of the sloping sides of the pile where compaction was the least and where visible chip deterioration resulting from the growth of stain and decay fungi was evident (29, 36).

Other studies (26, 40) indicated similar average losses in the specific gravity (5 to 8 per cent) of pine chips after from 5 to 6 months storage in the southern U.S.A., while losses in Swedish spruce chip piles (1, 38) were reported to vary from 2 to 5 per cent for storage periods of 4 to 5 months. At temperatures of 20 to 30°C losses of 5 to 10 per cent occurred in pine chips (9) stored for 7 months in Sweden while little or no loss occurred in frozen chips during this time. A loss of approximately 11 per cent in the basic specific gravity of brown-deteriorated balsam fir and spruce chips was determined from a sample stored for just over 9 months near the bottom of a pile in New Brunswick (39). Indications are that further decreases in the specific gravity of pine (15, 38, 40) spruce (1, 38) and birch (38) chips are slight beyond 5 months storage.

Greater losses also occurred in the outer layers of gum and oak chip piles in Florida (17) than in those chips obtained from the interior regions of the piles. Oak chips had an average loss of 1.4 per cent per month which amounted to almost 8 per cent loss after approximately 6 months storage while an average loss 2.5 per cent per month and cumulative losses of almost 14 per cent were experienced in the gum chips after 5 1/2 months storage.

Other results (14,29) indicated a loss of about 4 per cent in compacted oak chips while losses of 6 and 7 per cent were experienced in the compacted areas of unwetted and wetted gum chips. Gum chips with bleached decayed areas had as much as a 30 per cent reduction in specific gravity after 6 months storage (29). After 6 months storage, losses of about 6 per cent were experienced in birch, beech, and maple chips (48).

The initial higher losses experienced in the hot areas of some piles within a few weeks after piling has commenced can, perhaps, be attributed to a combination of biological and chemical activity operating at the same time. The metabolic activity of the thermophilic and heat-tolerant fungi on the wood probably accounts for some of this loss with other losses occurring from the deacetylation process as a result of high temperatures and moisture, as well as from the oxidation of other substances, such as resins, in the wood. With increased storage time however, the losses in the upper interior regions do not surpass the losses experienced in the cooler uncompacted sides of some piles where wood-rotting Basidiomycete fungi and staining fungi are more active.

The occurrence of greater numbers of white rot fungi in the lower levels of some softwood chip piles is one major cause of wood substance loss in these areas (39). The observations that chips in the lower part of a pile are frequently dark brown discoloured and have an acetic acid odour, suggests that there is also a possible hydrolysis of the hemicelluloses by organic acids formed in the pile during biological or chemical processes, and that this results in further reductions in wood substance with increased storage.

MICRO-ORGANISMS CAUSING WOOD CHIP DETERIORATION

The type of micro-organisms involved in the colonization of chip piles are represented by several classes of fungi. Those fungi reported in the literature on chip deterioration are listed in the appendix, and in addition, information is also included to indicate the capabilities of the species to cause stain or decay of wood. Bacteria were reported to be common in most chip piles but were not identified to species in the literature references. The numbers of different micro-organisms are generally much higher in chip storage than in roundwood storage per wood unit and probably influence the rate and type of deterioration.

Common moulds isolated from chip piles include *Aspergillus* species, *Trichoderma viride*, *Paecilomyces* and *Penicillium* species, while *Graphium*, *Phialophora* and *Ceratocystis* species are the main blue- or gray-staining fungi isolated from wood chips during storage. Many of the staining fungi are also able to cause soft rot in wood and would therefore contribute to the deterioration of stored chips. A recent article (21) deals with the micro-organisms colonizing hardwood chips in northeastern U.S.A.

Temperatures above 60°C are considered lethal to fungi while warm temperatures up to this level result in greater activity by thermophilic and heat tolerant micro-organisms which would contribute to the heating of the pile by their metabolic processes. In a study (9) of the types of organisms involved in the deterioration of stored chips, thermophilic and heat-tolerant fungi were isolated in the areas of the piles where high temperatures were recorded, while many wood decay, stain, and mould fungi were found in the cooler portions of the pile. *Polyporus amorphus* and an unidentified decay fungus were heat-tolerant species which grew well at 40°C. The mould *Chrysosporium lignorum*, another heat-tolerant species, was reported to have caused as much as 33 per cent weight loss in laboratory tests on pine sapwood after 4 months incubation at a temperature of 25°C. The thermophilic mould *Sporotrichum thermophile* caused significant weight losses of wood when incubated at high temperatures in laboratory experiments in Sweden (33) and eastern Canada (39). A heat-tolerant wood-decaying fungus, *Ptychogaster* species, which was isolated from the Canadian pile, caused considerably more decay of pine sapwood when incubated at 37°C than at 27°C.

The majority of the wood-decaying Basidiomycetes isolated from stored chips cause so-called white rots. *Peniophora gigantea* and *Polyporus* species were the most commonly identified fungi in this group although other species such as the *Ptychogaster* isolates may be more widespread in stored chips than indicated in the literature.

FACTORS INFLUENCING MICROBIAL DETERIORATION

Temperature and moisture are two of the most important variables in determining the type of microflora in a chip pile and the nature and rate of deterioration. While high temperatures over 35°C are important in inhibiting certain wood-staining and decay fungi they also result in the development of totally different communities of micro-organisms which are also able to cause a certain amount of deterioration. The depletion of oxygen and the evolution of carbon dioxide are dependent on the high degree of compaction and moisture in a pile as well as being an indication of microbial metabolism. While a total lack of free oxygen in a water-saturated substrate does inhibit fungal growth, it is expected that oxygen levels are sufficient for growth of fungi in areas of piles where chips are not completely saturated. There is also some indication that the durability of the wood species influences the type of fungi and the rate of deterioration in chip piles.

Moisture Content and Temperature

Both the moisture content and the temperature existing within many outside chip piles have been found to vary considerably during the storage period. European and American investigators (1, 9, 11, 13, 17, 29, 30, 36, 37) have observed that the drier interior conditions are usually associated with the high temperatures found in the centre of the piles. The presence of excessive moisture together with high temperatures has been suspected both of increasing chip deterioration by chemical means and of decreasing discolorations by the blue-staining fungi.

Within a few weeks of the construction of large chip piles, the phenomenon of "heating" occurs in the upper interior regions of the piles. Initially, temperatures of the order of 63 to 65°C have been recorded in these hot areas (26, 29, 37, 40), with one record of 82°C being reported from a softwood chip pile in eastern Canada (31). With longer storage, the temperatures in the interior of the piles were not quite as great as the high temperatures recorded soon after the start of chip storage and generally ranged from 32 to 38°C in piles situated in the southern U.S.A. (4, 13, 14, 36, 37) and from 30 to 43°C in an eastern Canadian pile (39). The drop in the temperature sometimes occurs rather abruptly (29, 36, 37) but this decline has also been reported to occur more gradually in a larger more compacted chip pile in Sweden (1). This difference was attributed to the larger volume of chips in the Swedish pile which gave greater insulatory protection against atmospheric changes. Low winter ambient temperatures did not reduce the interior pile temperatures although in some cases (9, 10) the temperatures of chip piles were reported to have decreased to freezing levels during winter storage. Indications (9) are that specific gravity reductions are much less when chips remain in a frozen condition during storage. Temperatures of small hardwood and softwood piles are found to approximate the changes in weather conditions and to follow the ambient air temperatures after the initial rise.

Temperatures have fluctuated (1, 13) according to the degree of compaction in the piles with greater compaction resulting in higher average temperatures. Temperatures were therefore not as high in the uncompacted sides of the piles as they were in the interior compacted area while the surface layers of chips down to a depth of approximately 24 inches generally followed ambient temperatures very closely during the storage periods (29, 36, 37).

The cause of the heating which occurs in outside stored chip piles has been attributed in part to the presence of bark, the condensing of water vapour on the chips and the microbiological activity within the pile. It is not expected that solar radiation would influence the conditions deeper within a large pile although heat from the sun will increase the temperature of the surface chips. What is believed essentially to occur in a large chip pile is the transfer of warm moist air from the lower regions of the pile to the upper cooler chips. This creates a chimney effect whereby the evaporation of moisture from the lower chips results in cooler temperatures in these regions while the condensing of water vapour on the chips in the upper portion of the piles causes not only an increase in the moisture content but also higher temperatures (1, 13, 30, 36). As a consequence, the wood chips situated in the lower central regions of a pile become cooler and drier. While chemical activity occurring in the lower part of the pile during early storage is thought to be the cause of the higher temperatures which increase the evaporation of some of the moisture (1) it is also known that heat arising from the increased metabolic activity of micro-organisms growing in a favourable environment can occur in a relatively short period of time. It is therefore believed (36) that the excessive heat is generated within the pile as a result of oxidative reactions including the participation of micro-organisms (1, 39). Thermophilic or "heat-loving" fungi have been found to be active in the hot areas of chip piles and would be expected to contribute considerably to the maintenance of elevated temperatures over long storage periods. The association of thermophilic fungi with hot areas is also found in the storage of grain and other organic materials. Thermophilic fungi grow within the range of 20 to 60°C, while some bacteria will continue their growth at temperatures beyond 60°C. In contrast, most wood-stain and decay fungi are inhibited at temperatures above 35°C except for some heat-tolerant wood-decay species which apparently can grow up to 50°C (33, 39). There is, therefore, some probability that chip quality will be adversely affected because of the activity of these heat-tolerant fungi.

An additional outcome of increased fungal metabolism in the chip pile is the production of carbon dioxide and water (29) as end products of the degradation of carbohydrates in wood. While little has been said about this source of additional moisture in the chip pile, fungal activity does probably increase the moisture content of chips to some extent. Precipitation is another important source of moisture within the pile and has been thought to have contributed to chip deterioration at the bottom of one pile in western Canada (34), while at other mills (24) it was felt that higher moisture content at the lower levels of a pile was not detrimental. The amount of moisture in small piles at another west coast situation was not found to be directly related to precipitation because the moisture contents remain uniformly high during storage (44).

The initial moisture content of stored chips is generally within the range of 45 to 55 per cent, green weight basis, although contents as high as 66 per cent have been recorded in the upper layer of a gum chip pile in the southeastern U.S.A. (17). With longer storage periods the moisture content generally becomes more or less uniform throughout the piles (4, 17, 37, 44) with rainfall or snow contributing to additional moisture in the surface layers of the piles (13, 17, 25, 35, 36, 45). Moisture content, probably, will not be a limiting factor in retarding all deterioration in outside chip piles because of the difficulty in maintaining either dry (below 17 per cent M.C. green weight basis) or the fully water-saturated conditions required to inhibit the growth of fungi.

The high temperatures and moisture contents experienced in the upper interior regions of chip piles is thought to be responsible for the reduction in the bluish-gray discolorations caused by staining fungi (26, 27, 30). In one study (4) heavy fungal discolorations occurred only when the temperature of the pile fell below 32°C. As most blue-staining fungi require temperatures between approximately 20 to 30°C for optimum growth, the higher temperatures experienced in certain areas of piles would have an inhibitory effect on the growth of these fungi.

There is some indication that excessive moisture content and high temperatures could contribute to other types of chip discoloration. This is due in part to the dark water-soaked appearance of the chips. However, it has been noticed that such chips do appear lighter upon drying. The presence of bark has been thought to be responsible for excessive heat within piles and the subsequent rapid development of brown stain due to fungal attack (42, 44). High temperatures and moisture content are also factors in contributing to brown chemical staining and are reported (1) to result in the deacetylation of hemicelluloses in the wood although no change in acetyl content was detected in one hardwood chip pile after 6 months storage (48).

Since the high temperatures existing within some chip piles do not inhibit thermophilic fungi, or the heat-tolerant wood-rotting species, and are also suspected of contributing to brown chemical deterioration, then it would seem desirable to reduce temperatures in the pile to retard some of this biological and chemical deterioration associated with chip storage. Where water sprinkling has been attempted, the deterioration by wood-rotting fungi has been reduced (13), although other fungi of the soft-rot type which decay the surface layers of wood chips have been found to increase in numbers where moisture content is high. The storage of chips in a frozen condition has reduced deterioration considerably (9, 39) indicating the desirability of winter piling.

Oxygen and Carbon Dioxide Levels

In an early report (10) on storage conditions in a chip pile, it was suggested that the oxygen needed for the life processes of aerobic organisms might be quickly used up and that the resulting deficiency of oxygen would have an unfavourable effect on the growth of decay fungi in the pile. However, later studies in Louisiana, U.S.A. (26) and in Sweden (11) indicated that there were no great variations in carbon dioxide and oxygen levels in loosely-compacted chip piles during storage. In laboratory experiments (11) it was observed that certain wood-decay fungi and the mould, *Trichoderma lignorum*, grew well in an atmosphere containing as much as 40 to 50 per cent carbon dioxide, and that in other tests these same fungi were not inhibited until the concentration of oxygen was practically zero. It was concluded that there must be very large changes in oxygen or carbon dioxide concentration to inhibit the growth of the fungi which could cause deterioration of chips during storage.

In another investigation (40) there was a measurable increase in the concentration of carbon dioxide in a pine chip pile stored in Louisiana which was more evident during the first six weeks of storage. After this initial period, the carbon dioxide content of the pile dropped to levels slightly above the atmospheric content. It was thought that this increase in carbon dioxide was possibly due to a chemical or a biological oxidation of wood constituents. Swedish investigators (1) found no increase in the carbon dioxide level of a softwood chip pile although a slight decrease in the oxygen concentration down to approximately 18 per cent was detected in the centre of the pile by the second week of storage. The oxygen level did not begin to rise again until the end of the second month. Some relationship may exist between low oxygen values and outside temperature as the lower oxygen levels were obtained when outside temperatures were coldest (9). Compaction of chips (13) was believed to be a factor in inhibiting fungal development in a pile as this was thought to act as a barrier to oxygen replenishment by restricting the free movement of air in the piles. Other studies (46) indicated that deterioration was negligible after 12 months storage when pine chips were sealed in drums to exclude oxygen while chips not sealed in containers had a 7 per cent reduction in specific gravity.

Wood Species

The main species used in chip piles on the west of North America are Douglas-fir, western hemlock, white fir, cedar, pine, red alder and cottonwood (12, 24, 44). In the southeastern U.S.A., many chip piles are composed of pine species (4, 25, 36, 37) but studies have also been made on the effect of storage on oak and gum chips (13, 17).

In eastern Canada, balsam fir, spruce, pine and hemlock have been stored in chip form (31, 35, 39) while hardwood trimmings from veneer cutting operations have been converted to pulpwood chips at one mill (31) since 1955. Deterioration of hard maple, birch, and beech chips have been studied in the northern U.S.A. (5, 48).

Pulp companies in Scandinavian countries have experimented with birch, spruce, and pine species (1, 2, 9, 10, 19, 30), while piles in other parts of Europe have comprised fir, spruce, aspen, beech, birch, linden, and oak chips (3, 28, 41, 45).

Chip pile studies have shown that different opinions are held on the amount of deterioration experienced during outside storage. The use of moderately durable species such as Douglas-fir may account for some of the variability found in large piles where deterioration is not considered to be too serious. Discolorations by blue-staining fungi are more prominent in the surface layers of pine chip piles where the lack of durability of this species results in poorer quality chips which would influence the brightness of pulps. Less durable hardwood chips can deteriorate quite rapidly and sometimes appear black after 4 to 5 months storage. Gum chips showed more deterioration than oak chips while the latter were also more deteriorated than pine chips stored for similar periods.

METHODS OF CONTROLLING CHIP DETERIORATION

Compaction

The compaction of chips in piles increases the amount of wood stored in a given area and has been accomplished by blow-packing the chips (1, 15, 25, 27), and by compacting with tractors (4, 25, 36). Blow-packing has been reported (1, 34) to give superior compaction to other methods. Depending upon the degree of compaction, the temperatures have been found to increase in the pile and to remain high throughout the winter (1). These high temperatures are not only believed to influence the resin content of stored chips (29) but also cause a profound change on the types of micro-organisms which are able to grow under these conditions (1, 33). The usual wood-rotting fungi cannot grow at the elevated temperatures experienced in some parts of the chip piles.

There was less chip compaction on the sides of piles where the tractor did not operate. In these areas where compaction was the least it was found that more fungal deterioration and greater wood substance losses occurred during storage (13, 36). At first, little or no differences were noted (13) in chip deterioration between the compacted and uncompacted areas during the first month of storage. However, after 6 months storage the uncompacted chips had lost three to four times more wood substance than the compacted chips. Larger piles have greater compaction of chips together with less exposed surface area, and are reported to be subject to less deterioration (36).

Watering

Storage under water or water sprinkling have been successful methods in preventing fungal deterioration of roundwood until utilization for the manufacture of pulp.

Water sprinkling of some chip piles has been made in an attempt to decrease deterioration during long storage in the belief that complete water saturation would result. In one experiment (13) a green gum chip pile was wetted during its construction and water-sprinkled during the storage period. These chips had fewer bleached decay areas which did not develop as fast as the bleached areas in the non-wetted gum chips. However, these tests were considered to be inconclusive (29) due to incomplete wetting of the pile since only slightly lower over-all specific gravity losses occurred when comparisons were made to a non-wetted gum chip pile. It was believed (13) that soft rot organisms were able to cause some degradation under the environmental conditions of the wetted gum chip pile. In another study (40) pine chip consistency was found to be lowered if the pile was wetted and strength losses were not as great when compared to the unwetted pile. In other studies (41) it was concluded that softwood and hardwood chips could be stored for about 1 month without water sprinkling.

It is apparent that there are some difficulties in adequately wetting chip piles to maintain the fully water-saturated condition necessary to prevent fungal discolorations and other types of deterioration caused by micro-organisms. However, if satisfactory wetting could be maintained during storage, chip deterioration would probably be considerably reduced.

Winter Storage

Some mills prefer to store their chips from October to May because of reduced fungal activities. Experiments in Georgia (37) indicated that deterioration of pine chips stored in the winter was one-third to one-half less than that of summer-stored chips.

Heat generated within chip piles prevents freezing in all but the outer layer of chips. The frozen crust presents little trouble although some handling difficulty has been reported (34). Many of the pine chips stored in Sweden (9) from the end of October to the following May were found to be frozen during most of this period at the bottom level of the pile. Where the average storage temperature was close to freezing, it was found that specific gravity losses were very low in comparison to losses in samples stored in the warmer areas of the pile.

The construction of chip piles during freezing temperatures would appear to be promising in providing protection against subsequent fungal deterioration because the majority of micro-organisms are dormant at or near 0°C.

Foundation

Many chips are stockpiled on the ground from trucks or pneumatic conveyors (15) without too much preparation for the base. In some cases, old chips from previous piles or hogged fuel serve as a base for fresh chips, while others stored their chips directly on the ground (6, 12, 17, 24, 34). From one to three feet of chips (6) have been reported as lost during reclamation where the piles have been constructed on old chips.

Certain mills on the west coast of North America and in the southeastern U.S.A. (12, 13, 24, 25, 34) store their chips on asphalt pavement because of less risk from dirt contamination. Proper drainage is emphasized where asphalt or other types of solid pavement are used (15, 34).

Considerable amounts of dirt and rot are sometimes introduced when unsurfaced bases are used. The use of surfaced areas is said to be effective in decreasing this deterioration of chips at the bottom of the piles. In eastern Canada (32), one company which stored chips on unsurfaced areas from October to May found signs of fungal infection after 12 to 18 months storage. The larger numbers of wood-decay fungi isolated from the bottom of a softwood chip pile in New Brunswick (39) would indicate that the risk of introducing rot into the lower regions of piles is great when piles are constructed on old chips or directly on the ground.

Storage Time

Although some chip piles had been kept for 2 to 3 years on the west coast of North America with little or no noticeable deterioration (6, 12, 15), some mills try to utilize their chip piles by 6 to 18 months while other mills average about 9 months storage (12).

One mill which manufactures fibreboard in eastern Canada reported that freshly-cut chips gave best results at up to 4 to 5 months storage. Pulp and paper mills in eastern Canada plan on utilizing their softwood chip piles by 1 year or less (32, 34) and expect little deterioration to occur within this storage period. Storage of softwood chips for 15 or more months involves risk of deterioration to spruce chips (11) and it has been suggested (22) that chip piles should be turned over every few months to minimize this risk.

Hardwood chips cannot be stored as long as softwood chips because of greater deterioration. While an earlier study in Michigan (5) indicated that hardwood chips could not be stored over 8 months without danger of loss due to decay, the storage time would depend upon the season when the chips were piled. In Austria (45), it has been reported that beech chips could be stored for 6 to 12 months without serious deterioration occurring.

The conflicting reports on how long chips can be stored without serious deterioration would appear to be related to a number of variables including the wood species piled, the size of the pile and the degree of compaction, and the season when storage commenced. Deterioration was found to be severe in the lower third of a spruce and balsam fir chip pile at approximately 9 months storage (39), indicating that complete utilization of a pile should occur before 8 months at least in order to minimize reductions in chip quality that could affect the pulp adversely.

Use of Fungicides

Control of deterioration in chip piles by chemical means has been suggested (29) as one means of improving pulp yields and quality provided the cost of treatment is not too high. It has been proposed that only certain areas of the piles, such as the outer layers, need to be treated since greatest biological deterioration seems to occur here. The use of fungicides such as pentachlorophenates has been proposed to offset losses in wood raw material (18).

In eastern Canada (35), some success was obtained in reducing discolorations by treating softwood chips with fungicides. Indications were that a sodium pentachlorophenate-borax treatment was more effective than borax alone. The more soluble boric acid-sodium borate preparation gave better protection than conventional borax. Nevertheless, some staining still occurred even with these chemical treatments.

Investigations in Sweden (38) indicated that pulps made from spruce chips stored for 4 months had no reduction in brightness when the chips had been treated with either a pentachlorophenate or a mercury preparation before being placed in a pine chip pile.

There would probably be little need to treat softwood chips with fungicides for short term storage, with the possible exception of the outer layer of chips where blue-staining may occur. However, for storage exceeding 6 months, it may be advantageous to also treat the chips at the lower levels of piles where serious deterioration sometimes occurs. As most hardwood species used for the manufacture of pulp are non-durable, the treatment of these chips with fungicides may prevent severe degradation when storage exceeds 3 or 4 months. The season of piling would be an additional factor to consider if some thought has been given to the use of fungal-inhibiting chemicals.

SUMMARY

Recent developments in the storage of pulpwood in the chip form in outside piles have resulted in much interest in the advantages of this method of stockpiling over conventional roundwood storage.

Although fungal and chemical deterioration of pulpwood chips does occur in outside piles during storage, the amount and type of deterioration apparently varies according to the durability of the wood species used, the size of the pile and degree of chip compaction, the season when piling commenced, and the length of storage. General conclusions are that the deterioration of chips is not greater, and is sometimes less than would be expected in the case of roundwood stored for similar periods. One reported exception occurred in which stored gum chips in the southern U.S.A. had greater deterioration than the roundwood.

The size of the piles appears to be a determining factor which influences the rate of deterioration and the length of time that chips can be stored outside to obtain good yields of high quality pulp. Greater chip compaction and higher temperatures have been noted in the larger piles than in the smaller piles. This has resulted in the establishment of heat-tolerant micro-organisms in the interior upper regions of piles. Although this storage period may vary from 2 to 4 years on the west coast of North America, a turnover of at least once a year for softwood chips is planned in most mill operations.

Microbiological activity in chip piles includes loss of wood substance because of decay which reduces the quantity and strength of pulps, and discolorations which influence pulp brightness. Most of the microbiological activity which results in these deterioration problems is reported to occur in the surface layers of piles to a depth of approximately two to three feet. This outer zone is largely composed of relatively loose-packed chips on the sloping sides of the piles where temperatures approach the surrounding ambient air conditions. The higher temperatures which occur in the central compacted areas of chip piles are apparently a factor in reducing the amount of dark fungal discolorations here. However, the increase in heat-tolerant decay fungi and moulds that commonly takes place in the "hot" regions of piles can cause some deterioration in stored chips and is, therefore, potentially detrimental to chip quality.

A second probable area of deterioration is in the lower regions of piles, particularly if the foundation for the piles is either soil or old chips. It is possible that brown discolorations can occur in these areas due to the action of organic acids which are formed as a result of microbiological activity, and the deacetylation of hemicelluloses brought about by high temperatures and moisture. Smaller, more loosely packed, chip piles may also be affected by this type of deterioration and may have a higher incidence of wood-rotting fungi than in the larger, more compacted, piles.

Various attempts have been made to reduce microbiological deterioration during chip storage. To minimize deterioration in the pile, softwood chips should be utilized by 8 months, and hardwood chips by 3 or 4 months. Longer periods may be possible if the season of piling and fungicidal treatment of the chips are considered.

Less deterioration has been experienced when chips have been piled during the winter months than during the summer, and little or no loss in wood substance occurs in chips which remain frozen during storage. In other experiments, continual water sprinkling of chip piles has been attempted and, although results were mostly inconclusive owing possibly to incomplete wetting, chip quality generally appeared better. Building piles on an asphaltic or other type of solid surface and compacting the chips are other ways which have been reported to have been effective in reducing the degradation of chips at the bottoms of piles stored outside. Promising results in reducing fungal discolorations in chips which affect pulp quality adversely have been obtained by preservative-treating the chips, particularly in the regions of the piles where microbiological deterioration is high.

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APPENDIX

Fungi reported as occurring in stored wood chip piles

	Host	Locality and Reference
PHYCOMYCETES		
Chytrid	spruce, balsam fir	New Brunswick, Can. (39)
Mucor sp.	spruce? pine? birch, pine	Sweden (33) Sweden (11)
Rhizopus sp.	oak, gum	Florida, U.S.A. (17)
FUNGI IMPERFECTI		
Moulds		
Arthobotrys sp.	oak	Georgia, U.S.A. (29)
Aspergillus fumigatus Fres.	spruce, balsam fir pine	New Brunswick, Can. (39) Sweden (9, 33)
Aspergillus sp.	pine	Georgia, U.S.A. (36, 37) Sweden (11)
	oak	Florida, U.S.A. (17) Georgia, U.S.A. (29)
	gum	Florida, U.S.A. (17) Georgia, U.S.A. (29)
	birch	Sweden (11)
Calcarisporium sp.	spruce, balsam fir	New Brunswick, Can. (39)
Cephalosporium sp.	spruce, balsam fir oak, gum pine	New Brunswick, Can. (39) Florida, U.S.A. (17) Sweden (9)
Chrysosporium lignorum (Bergman & Nilsson 1966 nomen nudum)[1]	pine	Sweden (9)

[1]These fungi are reported to cause substantial weight losses in wood at temperatures from 25 to 45°C.

Chrysosporium pruinosum (Gilman & Abbot) Carmichael[1]	pine, spruce	Sweden (33)
Chrysosporium sp.	spruce, balsam fir	New Brunswick, Can. (39)
Cylindrocarpon didymum (Hartung) Wollenweber	pine	Sweden (9)
Fusarium sp.	oak, gum	Georgia, U.S.A. (29)
Geotrichum candidum Link	pine	Sweden (9)
Gliocladium fimbriatum Gilman & Abbot	spruce, balsam fir	Nova Scotia, Can. (35)
Gliocladium viride Matruchot	spruce, balsam fir	New Brunswick (39)
Gliocladium sp.	pine	Sweden (9, 33) Georgia, U.S.A. (29, 36)
	oak	Georgia, U.S.A. (29)
Paecilomyces variota Bainier	spruce, balsam fir	New Brunswick, Can. (39) Nova Scotia, Can. (35)
Paecilomyces sp.	spruce, balsam fir	New Brunswick, Can. (39)
Penicillium cylindrosporum	pine	Sweden (9)
Penicillium funiculosum Thom	pine	Sweden (33)
Penicillium rubrum, Stoll	pine	Sweden (33)
Penicillium sp.	spruce, birch, pine	Sweden (11, 33)
	oak, gum	Florida, U.S.A. (17) Georgia, U.S.A. (29)
	pine	Texas, U.S.A. (26, 27)
Spicaria sp.	oak	Georgia, U.S.A. (29) Nova Scotia, Can. (35)
Scopulariopsis sp.	spruce, balsam fir	New Brunswick, Can. (39)
	Birch? spruce? pine?	Sweden (33)
Sporotrichum thermophile Apinis [1,2]	spruce, balsam fir	New Brunswick, Can. (39)
	pine	Sweden (9, 33)

[2]Thermophilic species growing within the range of temperatures from 20 to 60°C.

Sporotrichum sp?	pine	Georgia, U.S.A. (29, 37)
Sporothrix sp.	pine	Sweden (9)
Trichoderma koningi Oud. (= *T. viride*)	spruce, balsam fir	Nova Scotia, Can. (35)
Trichoderma lignorum (Tode.) Harz (= *T. viride*)	pine, birch, spruce pine	Sweden (11) Sweden (9, 33)
Trichoderma viride Pers. ex Fries	spruce, balsam fir	New Brunswick, Can. (39)
Trichoderma sp.	spruce, balsam fir red alder pine gum, oak gum, oak	New Brunswick, Can. (39) Oregon, U.S.A. (44) Texas, U.S.A. (26, 27) Florida, U.S.A. (17) Georgia, U.S.A. (29)
Verticillium albo-atrum Reinke & Berthold	pine	Sweden (9)
Staining Fungi		
Acrotheca sp.	pine	Georgia, U.S.A. (29, 37)
Alternaria sp.[3]	pine	Georgia, U.S.A. (36)
Bactrodesmium sp.	pine oak	Georgia, U.S.A. (29, 37) Georgia, U.S.A. (29)
Bispora betulina (Cda.) Hughes [3]	spruce, balsam fir	New Brunswick, Can. (39)
Bispora sp.[3]	pine	Georgia, U.S.A. (36, 37)
Bisporomyces sp.[3] (= *Chloridium*)	pine	Georgia, U.S.A. (36, 37)
Brachysporiella sp.	spruce, balsam fir	New Brunswick, Can. (39)
Cordana sp.	spruce, balsam fir	Nova Scotia, Can. (35)
Cladosporium herbarum (Pers.) Link	spruce, pine	Sweden (11)
Cladosporium sp.	spruce, balsam fir	New Brunswick, Can. (39)

[3]These fungi can cause soft rot or are believed to be capable of causing soft rot under certain environmental conditions.

Cladotrichum sp. (= *Oedemium* sp.)	pine	Georgia, U.S.A. (29, 37)
Graphiopsis sp. (= *Phaeoisaria* sp.)	pine, oak	Georgia, U.S.A. (29)
Graphium sp. (imperfect of *Ceratocystis* sp.)	Douglas fir red alder oak spruce, balsam fir pine	Oregon, U.S.A. (44) Oregon, U.S.A. (44) Florida, U.S.A. (17) New Brunswick, Can. (39) Sweden (9)
Helicosporium sp.[3]	pine	Georgia, U.S.A. (36, 37)
Hormiscium sp. (= *Torula* sp.)	spruce, balsam fir	Nova Scotia, Can. (35)
Humicola lanuginosa (Griffon & Maublanc) Bunce (ii)	pine? spruce? birch?	Sweden (33)
Leptographium sp.	pine	Georgia, U.S.A. (29, 37)
Melanographium sp.	pine	Georgia, U.S.A. (29, 37)
Paradiplodia sp.	pine	Georgia, U.S.A. (29, 37)
Pestalotia sp.[3]	pine, oak	Georgia, U.S.A. (29)
Phialocephala dimorphospora Kendrick	pine	Sweden (9)
Phialophora americana (Nannf.) Hughes	spruce, balsam fir	New Brunswick, Can. (39)
Phialophora fastigiata (Laberb. & Mel.) Conant	spruce, balsam fir birch	New Brunswick, Can. (39) Sweden (12)
Phialophora melinii (Nannf.) Conant	spruce, balsam fir	New Brunswick, Can. (39)
Phialophora sp.[3]	spruce, balsam fir gum, oak pine	New Brunswick, Can. (39) Georgia, U.S.A. (29) Sweden (9, 33)
Pullularia pullulans (De Bary) Berkhout (= *Aureobasidium pullulans* (De Bary) Arnaud)	pine	Sweden (9)

Pullularia sp. (= *Aureobasidium* sp.)	gum, oak	Florida, U.S.A. (17) Sweden (33)
Rhinocladiella atrovirens Nannf.	spruce, balsam fir	New Brunswick, Can. (39)
Rhinocladiella sp.	spruce, balsam fir	New Brunswick, Can. (39)
Scytalidium lignicola Pesante	spruce, balsam fir	New Brunswick, Can. (39)
Spondylocladium sp. (= *Stachylidium*)	oak	Georgia, U.S.A. (29)
Trichocladium canadense Hughes	spruce, balsam fir	New Brunswick, Can. (39)
Verticicladiella sp.	pine	Sweden (9)
ASCOMYCETES		
Allescheria terrestris Apinis[2]	pine	Sweden (9, 33)
Byssochlamys sp.[2]	pine	Sweden (9)
Ceratocystis floccosa (Mathiesen) Hunt[4]	pine	Sweden (9)
Ceratocystis minor (Hedgc.) Hunt[4]	pine	Sweden (9)
Ceratocystis moniliformis (Hedgc.) C. Moreau[4]	oak	Florida, U.S.A. (17)
Ceratocystis pilifera (Fr.) C. Moreau[4]	pine	Texas, U.S.A. (26, 27)
Ceratocystis sp.[4]	pine	Georgia, U.S.A. (29, 37)
	oak, gum	Georgia, U.S.A. (29)
	spruce and balsam fir	Nova Scotia, Can. (35) New Brunswick, Can. (39)
	spruce, pine	Sweden (11)
	pine	Sweden (9, 33)
Chaetomium thermophile La Touche[2,3]	pine? spruce? birch?	Sweden (33)

[4]These fungi cause dark gray or bluish discolorations in sapwood.

Chaetomium sp.[3]	gum	Georgia, U.S.A. (29)
Dactylomyces thermophilus Sopp (= *Thermoascus aurantiacus* Miche)[2]	pine	Sweden (9)
Thermoascus aurantiacus Miche[2]	pine	Sweden (9, 33)
BASIDIOMYCETES		
Coniophora sp.	spruce, pine	Sweden (11)
Corticium evolvens (Fries ex Fries) Fries (= *C. laeve* Pers.)	pine birch aspen spruce, balsam fir	Sweden (10) Sweden (11) Sweden (33) New Brunswick, Can. (39)
Corticium pruinosum Pat. (= *Xenasma pruinosum* (Pat.) Donk)	pine	Sweden (9)
Gloecocystidium tenue (Pat.) v. Höhn & Litsch. (= *Hyphoderma tenue* (Pat.) Donk)	pine	Sweden (9, 33)
Hyphodontia sp.	spruce, balsam fir	New Brunswick, Can. (39)
Lenzites saepiaria (Wulf. ex Fries) Fries	spruce, balsam fir	New Brunswick, Can. (39)
Merulius tremellosus Schrad. ex Fries	birch	Sweden (33)
Peniophora cinerea (Fries) Cooke	birch	Sweden (33)
Peniophora gigantea (Fries) Massee	pine, pine, spruce pine spruce, balsam fir	Sweden (10) Sweden (11) Sweden (9, 33) New Brunswick, Can. (39)
Peniophora incarnata (Pers. ex Fries.) Karst.	birch	Sweden (33)
Polyporus adustus Willd. ex Fries	birch, pine pine	Sweden (33) Sweden (9)
Polyporus amorphus Fries	pine	Sweden (9, 33)

Polyporus betulinus Bull. ex Fries	birch	Sweden (33)
Polyporus hirsutus Wulf. ex Fries	birch	Sweden (33)
Polyporus versicolor L. ex Fries	aspen	Sweden (33)
Polyporus zonatus Fries	aspen	Sweden (33)
Poria ambigua Bres.	birch	Sweden (33)
Ptychogaster radiatus (Björkman and Haeger 1963, nomen nudum)	pine, spruce	Sweden (11)
Ptychogaster sp.	spruce, balsam fir	New Brunswick, Can. (39)
Sistotrema coroniferum (v. Höhn. & Litsch.) Donk	pine	Sweden (9, 33)
Sistotremastrum suecicum Litsch. ex J. Erikss.	aspen	Sweden (33)
Stereum hirsutum (Willd. ex Fries) Fries	birch aspen	Sweden (33) Sweden (33)
Stereum rugosum (Pers.) Fries	birch	Sweden (33)
Stereum sanguinolentum (A. & S. ex Fries) Fries	pine pine, spruce	Sweden (10) Sweden (11)
Trechispora raduloides (Karst.) Rogers, (= Sistotrema raduloides Karst.) Donk)	pine	Sweden (9, 33)

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