EFFECT OF FELLING TIME AND KILN-DRYING ON COLOR AND SUSCEPTIBILITY OF WOOD TO MOLD AND FUNGAL STAIN DURING AN ABOVE-GROUND FIELD TEST

Nasko Terziev
Research Scientist

and

Julius Boutelje
Professor
Swedish University of Agricultural Sciences
Department of Forest Products
Box 7008, S-750 07 Uppsala
Sweden

(Received December 1997)

ABSTRACT

The study shows how the content of low-molecular-weight (LMW) sugars, sugar alcohols, starch, and nitrogenous compounds in Scots pine trees in winter and spring and their subsequent redistribution during drying of timber affect color and susceptibility to fungi during above-ground exposure.

One tree from pairs of Scots pine was felled, sawn, and dried in winter, whereas the other was processed in spring. The content of soluble carbohydrates and nitrogen and also the color of timber surface were measured before and after drying. An above-ground test was carried out to show differences in susceptibility of winter- and spring-felled and dried timber to fungi.

The total content of LMW sugars was 1.59 times higher in winter than in spring. Sucrose was the most common sugar in the living tree at both sampling occasions. The content of oligosaccharides was higher in winter; in spring they were hydrolyzed to monosaccharides. The content of two sugar alcohols was negligible. Starch content rose significantly in spring. Nitrogen content in winter and spring was not significantly different.

Drying enriched the timber surface (0–3-mm zone) with LMW sugars and nitrogen, whereas the deeper zones had an almost constant content of soluble substances. The content of accumulated soluble substances in the 0–3-mm zone after drying was approximately proportional to their content in similarly located wood at the time of felling.

An important practical consequence of the redistribution of LMW sugars and nitrogen is the increased susceptibility to mold. The surfaces of winter-felled and dried timber were more susceptible to mold growth than those of spring-felled and dried timber.

The measured colors on the surfaces of winter- and spring-felled and dried pine timber were not significantly different. At the same time, distinct color differences between regions beside and within sticker marks were observed. It is concluded that the accumulation of water-soluble substances influences the surface color, but a certain difference in concentration has to be exceeded to obtain significant differences in color.

Keywords: above-ground test, color, drying, felling time, fructose, glucose, mold, nitrogen, *Pinus sylvestris* L., starch, sucrose.

INTRODUCTION

The differences in quality between wood felled in winter and that felled in summer have been described by a number of authors. Teischinger (1992), who studied the effect of felling time on some physical and mechanical properties of spruce wood, found that differences observed between winter- and summer-felled and dried wood were small and negligible for practical use. More often, the felling time of trees is discussed with regard to its

Wood and Fiber Science, 30(4), 1998, pp. 360–367

effect on the natural durability of wood. Fellner (1991) stated that the winter-felled wood had higher durability and better capability for drying. Wazny and Krajewski (1984) mentioned less decay caused by the fungus *Coniophora puteana* on winter-felled than on summer-felled pine wood. However, no differences in the natural durability have been found between winter- and summer-felled pine and spruce when the timber after drying was subjected to decay fungi and house-longhorn beetle attack (Boutelje et al. 1986). There is some indication that sapstain fungi grow more slowly in fresh logs from winter- than from summer-felled trees due to the activity of the living host tissue (Uzunovic et al. 1996). It should be mentioned here that in the present study the activity of living tissue is eliminated since the durability test is carried out after drying of the timber.

When discussing the susceptibility to microbiological attack of logs felled in winter and summer, microbiological activity during the respective time of the year should be considered. Drying can have an impact on the composition and distribution of some water-soluble substances. Terziev (1995) showed that different drying schedules redistribute the low-molecular-weight (LMW) sugars and nitrogenous compounds in different ways. This leads to different degrees of enrichment of the timber surface with nutrients and, consequently, different susceptibilities to molds have been observed in laboratory and field tests (Terziev 1997). Since the contents of LMW sugars and nitrogen in the living tree fluctuate during the year, there might be a prerequisite for differences in the contents of these substances accumulated at the timber surface after drying. The aim of the experiment carried out was to relate the content of LMW sugars, some sugar alcohols, starch, and nitrogen in trees at different felling times and their redistribution in the sawn material during drying to subsequent color changes and to susceptibility to fungal attack.

MATERIALS AND METHODS

Material, drying and sampling

Six pairs of Scots pine (*Pinus sylvestris* L.) trees were chosen in a stand, located 70 km south of Stockholm. The average diameters of trees (including bark) and heartwood at breast height were 29 and 17 cm, respectively. Each pair was taken from a small area (2 × 2 m) to provide the best comparability between the trees. One tree from each pair was felled, sawn, and dried in January, whereas the other was processed in April to ensure a maximum difference in LMW sugars and nitrogen between the winter- and spring-felled trees (Terziev et al. 1997). Only the butt log from each tree was debarked and used. Each log was sawn into four 40-mm-thick radial unedged planks, parallel to north/south and west/east directions, i.e., directed 90° to each other. The sawing was carried out the day after the felling of trees and the drying started immediately. Before drying, the end surfaces of planks were sealed with silicone. Winter- and spring-sawn planks were dried under the same conditions in a laboratory kiln to compare the effect of different content of soluble sugars and nitrogen, caused by different felling times, on surface color and fungal susceptibility. The schedule had a constant wet-bulb temperature of 52°C and a maximum dry-bulb temperature of 80°C at the end of the process. Comparative data about planks and drying are given in Table 1.

Increment cores (Ø 12 mm, length ca. 25 mm) were taken from the living trees. The cores were stored in a box, filled with dry ice, transported, and then stored at −25°C until required. After 15 days of storage, parts of the cores (10–20 mm from the cambium) were cut and analyzed for LMW sugars (including also raffinose and stachyose), sugar alcohols, starch, and nitrogen. Samples were taken from a similar location in the planks after drying. The location of the samples in the living trees and planks at the same distance from the cambium (10 mm) made it possible to compare

TABLE 1. *Data about planks and drying. Standard deviation within parentheses.*

	Felled and dried in winter	Felled and dried in spring
Number of planks	24	24
Length, m	1.2	1.2
Width, m	0.113 (0.014)	0.117 (0.018)
Basic density, kg/m^3	474.3 (33.7)	464.7 (39.9)
Initial moisture content, %	82.0 (14.4)	84.3 (13.7)
Final moisture content, %	8.2 (1.3)	9.4 (1.8)
Drying time, h	115	115

the content of substances in winter and spring and their redistribution after drying.

Carbohydrate and nitrogen analyses

The carbohydrate analysis was based on a two-step extraction as described by Steen and Larsson (1986). Soluble sugars were gained in the first step and, after increasing the temperature to 90°C and adding temperature stable α-amylase, starch was extracted. Starch was further hydrolyzed enzymatically and analyzed using a spectrophotometer (Hitachi U 1100) attached to a programmable autosampler (Hitachi AS3000). The extracted soluble sugars and sugar alcohols were analyzed by ion exchange chromatography (Dionex DX300 HPAE), with a pulsed electrochemical detector, and a column designed for carbohydrate analyses (CarboPac PA1).

For nitrogen determination, Dumas analysis was carried out according to a method described by Kirsten and Hesselius (1983). The total content of nitrogen, including both soluble and insoluble nitrogenous compounds, was determined.

Color evaluation

The evaluation of surface color of timber was done with a tristimulus colorimeter (Topcon RD-1, measuring head RD-10D). The three-dimensional L*a*b* color space (Commission International de l'Eclairage-CIE publ. No. 15, 1976) was used for color evaluation, in which L* specifies the lightness in a range from black (0) to white (100), and a* and b* are positive/negative co-ordinates defining the hue and intensity of the color. The lowest saturation of the colors within the color space is represented by the crossing point of the latter two axes. The color of the timber surface was measured at 10 points in the sapwood, located at a 10-mm distance from the cambium, before and after kiln-drying. The measured 10 points for each plank were in the same zone as that in which the samples for carbohydrate and nitrogen analyses were later taken. The total difference ΔE^*_{ab} between the two colors was calculated according to standard ISO 7724/3-1984(E). The measurements were carried out after both dryings, and the color constituents (L*, a* and b*) of surfaces of winter- and spring-processed timber were statistically compared by *t*-test.

Above-ground test

After drying, test samples (40 × 50 × 250 mm along the grain), containing sapwood, were cut from the unedged planks. Since the logs were radially sawn, the growth ring orientation of the samples was the same. One test sample represented each plank. In total, the experiment included 48 samples, which were conditioned at room temperature before the field test. The above-ground test, performed in Uppsala, Sweden, started in mid-June and lasted 120 days. The samples were arranged with the grain vertical (40 × 50 mm face upward) in a wooden rack (1.5 × 1.5 m), ca. 100 mm above the ground. The ground's top layer (300 mm) was made of unsterilized forest soil and was irrigated daily with 30 liters of water. The rack was double-wrapped with black plastic, and the temperature and relative humidity of the air inside and outside the wrapped cham-

TABLE 2. *Range of temperature and relative humidity of the air during the field test.*

	Temperature, °C		Relative humidity, %	
	Min.	Max.	Min.	Max.
In the chamber	7	28	75	90
Surrounding air	−3	24	36	91

ber were measured constantly with a thermohygrograph (Table 2).

The samples were observed weekly (at the end—daily), and the test was stopped when abundant fungal growth was registered on some of the samples. Fungal discoloration of the timber surface was classified by visual examination according to a seven-grade scale (0—no growth; 6—very abundant growth, coverage >75%), described in an earlier paper (Terziev et al. 1996). The non-parametric Kruskal-Wallis test (Milton 1992) was used for comparison with regard to fungal growth on winter and spring material. After the test, samples for identification of mold, stain, and decay fungi were isolated from six pairs of samples. Three isolates were taken from each sample and cultured on three media as follows: malt extract agar (2.5% malt, 1.5% agar), malt extract agar with 0.1% sterile filtrated streptomycin, and malt extract agar with 0.05% copper sulphate ($CuSO_4 \cdot 5H_2O$). The first medium is appropriate for any fungus, whereas the second and third medium were intended to inhibit bacteria and basidiomycetes, respectively.

RESULTS AND DISCUSSION

The contents of studied carbohydrates and nitrogen in the living trees and after drying of the timber are presented in Table 3. Sucrose was found as the most common sugar in the living tree in winter and spring. This contradicts the results of Terziev et al. (1997). The lower content of sucrose, compared to those of glucose and fructose in their study, might be a sign of enzymatic hydrolysis during the long storage of the samples. The content of fructose in the living trees was higher than that of glucose. Raffinose and stachyose showed a higher level than glucose in the winter. In the

TABLE 3. *Content of LMW sugars, sugar alcohols, starch, and nitrogen in living trees and after drying of planks, % of dry weight. Samples are taken 10–20 mm from the cambium and at the original surface of the planks (0–1 mm) after drying. Standard deviation within parentheses.*

Item	Living tree		After drying	
	January, 1996 (n = 12)[1]	April, 1996 (n = 12)	January, 1996 (n = 8)	April, 1996 (n = 8)
Arabinose	n. m.[2]	n. m.	0.01 (0.01)	0.02 (0.01)
Galactose	n. m.	n. m.	0.07 (0.01)	0.06 (0.01)
Mannose	n. m.	n. m.	0.04 (0.01)	0.03 (0.01)
Fructose	0.07 (0.02)	0.04 (0.01)	1.23 (0.20)	1.02 (0.34)
Glucose	0.04 (0.01)	0.03 (0.01)	0.89 (0.12)	0.81 (0.16)
Sucrose	0.28 (0.07)	0.19 (0.04)	0.79 (0.30)	0.40 (0.23)
Maltose	tr.[3]	tr.	tr.	0.01 (0.01)
Raffinose	0.07 (0.02)	0.02 (0.01)	0.26 (0.07)	0.08 (0.04)
Stachyose	0.06 (0.02)	0.04 (0.01)	0.39 (0.18)	0.30 (0.13)
Pinitol	0.02 (0.01)	0.02 (0.01)	0.33 (0.13)	0.43 (0.15)
Sorbitol	tr.	tr.	0.03 (0.01)	0.01 (0.01)
TOTAL	0.54 (0.12)	0.34 (0.01)	4.04 (0.42)	3.17 (0.35)
Ratio Jan./April	1.59		1.27	
Starch	0.06 (0.01)	0.25 (0.09)	0.04 (0.02)	0.26 (0.12)
Ratio Jan./April	0.24		0.15	
Nitrogen	0.023 (0.008)	0.021 (0.005)	0.089 (0.015)	0.061 (0.010)
Ratio Jan./April	1.10		1.46	

[1] n indicates the number of samples.
[2] n. m. not measurable.
[3] tr. trace amount, less than 0.01% of dry weight.

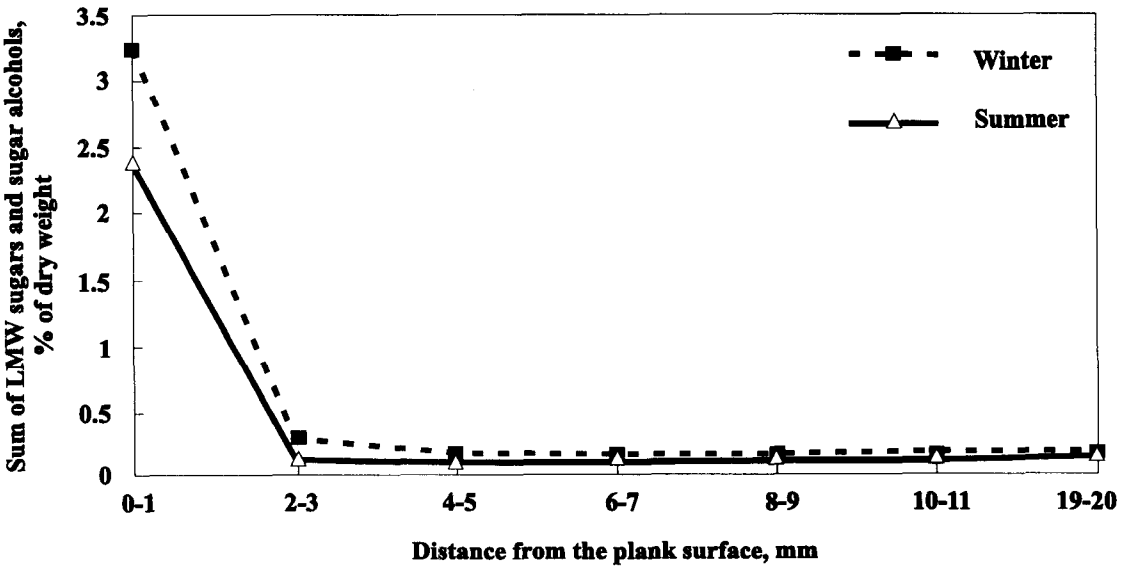

FIG. 1. Gradients of sum of LMW sugars and sugar alcohols in pine planks after drying.

spring, however, the content of raffinose decreased to one-fourth of the winter level. The content of stachyose decreased from winter to spring as well, but to a lesser extent and remained higher than glucose. Starch content rose significantly in April. The total content of LMW sugars and sugar alcohols was 1.59 times as high in the winter as in the spring. The total nitrogen content in the living trees during winter and spring was not significantly different.

The ratio between the winter and spring content of LMW sugars described above was similar to that at the surface of the sawn material after drying. Some monosaccharides, not found in the living tree (arabinose, galactose, and mannose), were formed, probably by enzymatic hydrolysis of the oligosaccharides. Their contents, however, were negligible compared to these of fructose, glucose, and sucrose. Fructose was found to be the most common sugar after drying, followed by glucose and sucrose. The sucrose content was significantly less than that of fructose and glucose, due to its hydrolysis. No evidence of degradation of starch caused by drying was found. The surface of winter-sawn timber (0–1 mm zone) had a content of LMW sugars and alcohols that was 1.27 times as high as that of the surface of spring-sawn timber. Nitrogen content after drying was significantly different between winter- and spring-felled timber as indicated in Table 3.

The gradients of LMW sugars and nitrogen from the middle of the plank to its surface after drying are shown in Figs. 1 and 2. All measurements represent a sapwood region located 10–20 mm from the cambium. The drying caused a distinct gradient only in the 0–3-mm zone at the surface of the winter- and spring-sawn timber, whereas the deeper zones had a constant and approximately equal content of LMW sugars and nitrogen. If only the 0–3-mm zones are compared, the ratio of sugars between winter- and spring-sawn and dried timber is 1.43, a value similar to that in the living trees (Table 3). The profiles, shown in Figs. 1 and 2, are an argument in favor of planing (Terziev et al. 1996) as a simple means to decrease the susceptibility of wood surfaces to molds and blue stain.

It was inferred that the content of LMW sugars and nitrogen could affect the degree of color change caused during drying. The final

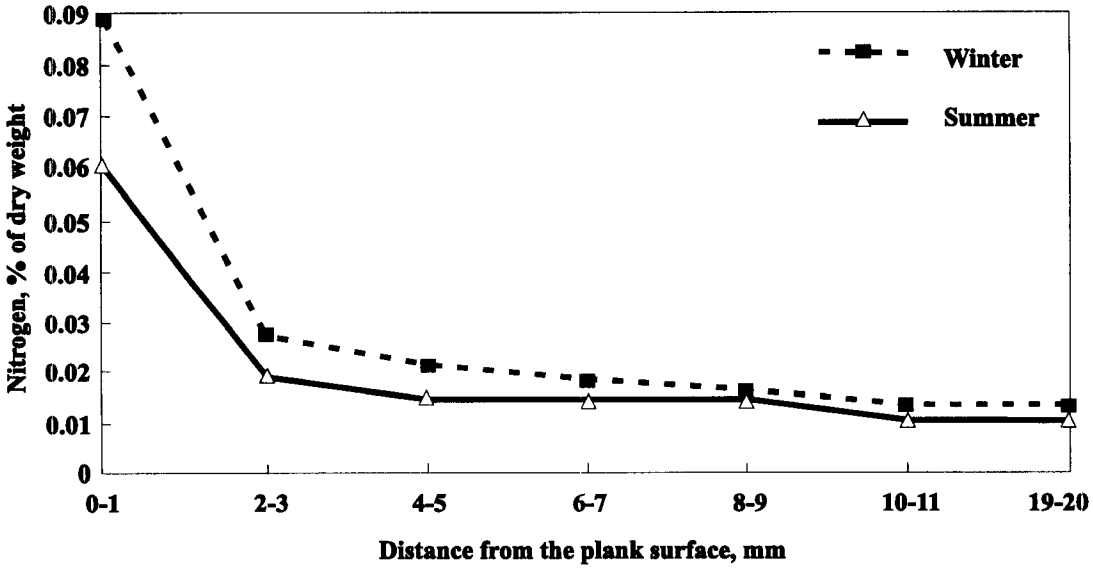

FIG. 2. Gradients of nitrogen in pine planks after drying.

wood moisture content in the winter- and spring-sawn timber was similar (Table 1). No significant differences were found between the color constituents (L*, a* and b*) of surfaces of winter- and spring-felled and dried timber. The total difference ΔE^*_{ab} between the colors of the winter- and spring-sawn timber was 0.95, which is far below the distinguishing ability of the human eye, of 2–3 units.

During drying of Scots pine timber, sticker marks become apparent due to the contrast between the light-colored zones under the stickers and the comparatively darker areas adjacent to the sticker zones. The water-soluble substances that would have been deposited at the sticker position if free evaporation had been possible have migrated to the adjacent zones, thus adding to the concentration of soluble substances in that area and causing darker color. Reduced oxidation is often given as another reason to explain the lighter color underneath stickers. After drying of the winter-sawn timber, a comparison between the content of LMW sugars within and beside a sticker mark, as well as between the color of both areas, was carried out. The content of LMW sugars beside the sticker mark was 3.55 times as high as the content within the mark (see also Theander et al. 1993). The corresponding value for nitrogen was 2.62. The total difference ΔE^*_{ab} in the colors of the two areas was 4.2, i.e., easily visible to the naked eye. The result supports the conclusion that the content of LMW sugars and nitrogen influences surface color. The transport of water during drying affects the distribution of LMW sugars and nitrogenous compounds and consequent formation of products by the so-called Maillard reactions. The Maillard products are substances formed by various combinations of sugars and amino acids. Some of them contribute to the discoloration of timber surfaces during drying (Theander 1987; Theander et al. 1993). It is probable that the difference in the content of sugars and nitrogen in the winter- and spring-sawn and dried timber obtained in the present study (Table 3) was not large enough to lead to a sufficient difference in the content of Maillard products and consequently, to a statistically significant or visible difference in the color of planks.

The intent of the isolation test was to register the variety of fungi inhabiting the surface of the exposed wood samples. The fluctuations

TABLE 4. *Comparison between mean mold growth on plank samples from winter and spring felled trees. Standard deviation within parentheses.*

Felled and dried in winter (n = 24)[1]	Felled and dried in spring (n = 24)
4.3 (0.9)	3.3 (0.6)

[1] n indicates the number of samples.

of the temperature and particularly, of the relative humidity in the chamber were lower than those of the surrounding air (Table 2) and in a favorable range for fungal growth (Viitanen and Ritschkoff 1991). Only *Penicillium* spp. (31 isolates) and *Trichoderma* spp. (5 isolates) were isolated from the sample surfaces. Mold fungi are much more tolerant to the air temperature and relative humidity, and have lower minimum temperature and humidity requirements than decay fungi (Viitanen 1996). Independently of felling time and isolation medium, *Penicillium* spp. dominated over the *Trichoderma* spp. on the lumber surfaces. The same mold fungi were identified previously (Terziev 1997). The mean values of visual estimates of mold growth on original surfaces for the winter- and spring-felled and dried timber after the above-ground test are presented in Table 4. These mean values of mold growth are significantly different at the 0.05 level, according to the Kruskal-Wallis test. The surface of winter-felled and dried timber, which was more enriched with LMW sugars and nitrogen after drying, had higher susceptibility to mold than the spring-processed timber.

CONCLUSIONS

Winter-felled and dried timber was richer in soluble nutrients than spring-felled timber. Felling time determines the initial content of LMW sugars, sugar alcohols, starch, and nitrogen in Scots pine timber. The higher the initial content of LMW sugars, the higher its content at the timber surface after drying. The distribution of the starch seems not to be changed by drying, because starch has low solubility and is not able to move with water during drying. Although the differences in nitrogen content of living trees in winter and spring were insignificant, the surface of winter-processed timber was significantly more enriched than that of summer-processed timber.

No significant differences were found between CIE color constituents (L*, a* and b*) of winter- and spring-processed timber. The total difference ΔE^*_{ab} between the colors of winter- and spring-sawn timber was far below the level distinguishable to the naked eye. However, the color measurements beside and within the sticker mark support the conclusion that the content of LMW sugars and nitrogen influence surface color. It is probable that the difference in the content of sugars and nitrogen in winter- and spring-sawn and dried timber obtained in the present study (Table 3) was not large enough to lead to a statistically significant or visible difference in the color of planks.

Mold growth was higher at surfaces of winter-processed timber than at surfaces of spring-processed material. This is because the surface of winter-processed timber was more enriched with LMW sugars and nitrogen, i.e., had higher nutrient content. Additional tests should be carried out to study the effect of felling time on susceptibility of timber to decay fungi.

ACKNOWLEDGMENTS

The study was funded by the Swedish Council for Forestry and Agricultural Research and the Swedish Sawmill Research Foundation. The authors thank Anders Rosenkilde for help and valuable discussions and Anita Flower-Ellis for the chemical analyses. The technical assistance of Allan Jonsson and Kjell Sjöberg is gratefully acknowledged.

REFERENCES

BOUTELJE, J., T. NILSSON, AND S. RASMUSSEN. 1986. An analysis of the effects of some factors on the natural durability of pine (*Pinus sylvestris* L.) and spruce (*Picea abies* Karst.). Int. Res. Group on Wood Preservation, Document IRG/WP/1279.

CIE PUBLICATION NO. 15, SUPPLEMENT NO. 2. 1976. Rec-

ommendations on uniform color spaces—Color difference equations—Psychometric color terms.

FELLNER, J. 1991. Schlägerungszeit und Holzqualität—eine Literaturübersicht. Holzforschung und Holzverwertung 43(1):25–28.

INTERNATIONAL STANDARD ISO 7724/3–1984(E). Paints and varnishes—Colorimetry. Part 3: Calculation of colour differences.

KIRSTEN, W. J., AND G. U. HESSELIUS. 1983. Rapid, automatic, high capacity Dumas determination of nitrogen. Microchem. J. (28):529–547.

MILTON, J. S. 1992. Statistical methods in the biological and health sciences. McGraw-Hill, Inc., New York, NY. Pp. 437–439.

STEEN, B., AND K. LARSSON. 1986. Carbohydrates in roots and rhizomes of perennial grasses. New Phytol. 104: 339–346.

TEISCHINGER, A. 1992. Effect of different drying temperatures on selected physical wood properties. 3rd IUFRO Conference on Wood Drying, August 18–21, Vienna, Austria.

TERZIEV, N. 1995. Migration of low-molecular sugars and nitrogen in *Pinus sylvestris* L. during kiln and air drying. Holzforschung 49(6):565–574.

———. 1997. Fungal discolouration of kiln- and air-dried Scots pine lumber in above ground testing and its assessment by digital image processing. Forest Prod. J. 47 (9):43–46.

———, J. BJURMAN, AND J. B. BOUTELJE. 1996. Effect of planing on mould susceptibility of kiln- and air-dried Scots pine (*Pinus sylvestris* L.) lumber. Mat. u. Org. 30 (2):95–103.

———, J. BOUTELJE, AND K. LARSSON. 1997. Seasonal fluctuations of low-molecular weight sugars, starch and nitrogen in sapwood of *Pinus sylvestris* L. Scand. J. For. Res. 12(2):216–224.

THEANDER, O. 1987. Conversion to phenols and enones. With special reference to humification and to colour formation in pulping and food processes. Pages 481–492 *in* Industrial polysaccharides. Proceedings of the conference on recent developments in industrial polysaccharides, Gordon and Breach Sci. Publ., New York, NY.

———, J. BJURMAN, AND J. BOUTELJE. 1993. Increase in the content of low-molecular carbohydrates at lumber surfaces during drying and correlations with nitrogen content, yellowing and mould growth. Wood Sci. Technol. 27(5):381–389.

UZUNOVIC, A., J. F. WEBBER, AND D. J. DICKINSON. 1996. Comparison of blue stain fungi growing *in vitro* and *in vivo*. Int. Res. Group on Wood Preservation, Document IRG/WP 96-10149.

VIITANEN, H. 1996. Factors affecting the development of mould and brown rot decay in wooden material and wooden structures. Dissertation, Swedish Univ. of Agr. Sci., ISBN 91-576-5115-9. Pp. 8–20.

———, AND A-C. RITSCHKOFF. 1991. Mould growth in pine and spruce sapwood in relation to air humidity and temperature. Swedish Univ. of Agr. Sci., Dep. of Forest Prod., Report No. 221.

WAZNY, J., AND K. J. KRAJEWSKI. 1984. Jahreszeitliche Änderungen der Dauerhaftigkeit von Kieferholz gegenüber holzzerstörenden Pilzen. Holz Roh- Werkst. (42): 55–58.