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A NOTE ON ANATOMICAL CHANGES OF WHITE OAK WOOD UPON EXPOSURE TO GAMMA RADIATION

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ABSTRACT

White oak heartwood samples were exposed to 650, 950 and 1900 MRad of cobalt-60 gamma radiation. The holocellulose portion of the heartwood cell walls was degraded while the lignin percentage remained relatively unchanged. Tangential vessel diameter, ray cell length, and length and width of intervessel pits increased upon exposure while tangential vessel-wall thickness, ray cell double-wall thickness, and latewood fiber double-wall thickness decreased.

Keywords: *Quercus alba*, irradiated wood, gamma radiation, anatomy, ultrastructure, chemical analysis.

INTRODUCTION

Available information shows that ionizing radiation affects wood resulting in either deteriorated wood or a product that can be used by man. Seifert (1964) found that when wood was subjected to high energy radiation, by-products such as alcohols and sugars were formed. It was mentioned that gamma radiation increases or decreases the mechanical properties of wood depending upon the dosage applied, but no detailed aspects regarding the microstructure of gamma-irradiated wood were presented. Schuller et al. (1975) also reported that radiation affected the elasticity of wood. Lawton et al. (1951) found that finely ground irradiated basswood yields carbohydrate compounds which were available to ruminant bacteria. Remmert and Butts (1955) at Oregon State University had done similar work using Douglas-fir sawdust. Their objective was to devise a method for the economic conversion of such sawdust to ruminant feed. Of particular interest was the idea of treating sawdust and thereby rendering the cellulose available for digestion by ruminant livestock.

Results of studies by Antoine et al. (1971) involving the exposure of softwood *Pinus* spp. to gamma radiation indicated that the wood was rendered friable enough to be broken easily in any direction. It was also found that the gross morphological characteristics of wood do not change, and thus the anatomical features of the wood may be clearly seen by scanning electron microscopy (SEM) or other techniques.

The objective of this study was to determine microstructural changes of white oak when it was exposed to gamma radiation. Scanning electron microscopy and standard chemical tests for selected wood components were used.

METHODS

A 15-cm-long wedge consisting of 43–58 annual rings was cut along the grain from the heartwood section of a white oak (*Quercus alba* L.). Twenty pieces of wood, each measuring 1 cm on the radial and tangential sides and 4 cm along the grain were cut from this wedge. From these 20 pieces of wood, four matched (longitudinally) sets of 20 samples each were prepared by cutting 1-cm cubes from the 4-cm pieces. Set #1 was used for the control SEM analyses. Wood samples were smoothed on all surfaces (radial, tangential, and cross-sectional) using a sliding microtome. The samples were then oven-dried to constant weight at 105 C and subsequently cooled over P_2O_5 in a desiccator. The smooth surfaces were mounted on SEM discs and coated with approximately 0.3–0.4 μm of gold using a vacuum evaporator. Samples were scanned in a JEOL-JSM-S1 facility at a tilt angle of 45° and accelerating voltage of 10 kV.

Set #2 was used for the control analyses to determine the percentage composition of extractives, holocellulose, and lignin, to be later compared with those of the gamma-irradiated wood. The extractives content was determined using the standard TAPPI (T12m) procedure. Holocellulose determinations were done in accordance with the method outlined by Browning (1967). Lignin determinations were done according to the standard TAPPI (T13m) procedure.

Sample set #3, consisting of 18 cubes, was irradiated in the University of Missouri's Research Reactor High Intensity Cobalt-60 Facility. The 1 kCi cobalt-60 source consists of 6 pins 25 cm long arranged at 60° intervals around a 15-cm-diameter circle under 4.5 m of water. The samples were sealed in a weighted watertight aluminum irradiation vessel and placed in the center of the source at a dose rate of 1 MRad per hour (measured by gamma activation and cobalt-glass dosimetry relative to a National Bureau of Standards calibrated cobalt-60 source). Set #3 was divided into 3 groups of 6 cubes (oven-dry) each exposed to 650, 950, and 1900 MRad doses of cobalt-60 gamma radiation, respectively. Set #4 was kept in reserve.

Irradiated samples were scanned on the SEM as described above and the representative photomicrographic elements of the microstructures were measured using the methods devised by Harlow et al. (1975) as subsequently applied by McGinnes et al. (1976).

RESULTS AND DISCUSSION

Tables 1 and 2, respectively, summarize microstructural and chemical changes in the irradiated oak samples. The missing values in Table 1 indicate parameters that could not be measured.

Ray cell length of the samples irradiated to 650 MRad had degraded to such an extent that it could not be measured. However, as radiation dosage increased to 950 MRad and above, the same parameter became clear enough to be measured. A similar case was experienced with measurement of the length of the intervessel pits. Since fibers in the oak samples examined in this study were restricted to the latewood section or zone, the results reported here reflect the effect of gamma radiation on latewood fibers only. The tangential vessel diameter and the ray cell length increased in dimension, while their corresponding wall thickness decreased with an increase in the radiation dose. In this study double wall thickness of fibers and ray cells were measured instead of their respective single cell-wall thicknesses because it was found that the radiation doses had caused the walls of the adjacent cells to appear to fuse together as for charcoal (McGinnes et al. 1976), so it was not possible to measure the thickness of a cell wall of one particular cell. However, as the dosage increased, individual cell walls became clear enough to be measured. In some cases, at a dosage of 650 MRad, the tangential vessel walls of some latewood vessels showed a similar phenomenon.

These observations indicate that gamma radiation has an appreciable influence on cell-wall thicknesses; it tends to decrease cell-wall thickness; and such decreases in cell-wall thickness might attribute to the appreciable increase in dimension of the various cell lumens measured in this study. It is interesting to note that at a dosage of 1900 MRad, the earlywood section began to crush, and measurement was difficult. Chemical analyses of the irradiated hard-

TABLE 1. *Microstructural changes in white oak wood after exposure to gamma radiation dosages of 650, 950, and 1900 MRad. EW and LW refer to earlywood and latewood zones respectively. Values in micrometers*[a]

Anatomical Dimension	Control Wood		650 MRad		950 MRad		1900 MRad	
	EW	LW	EW	LW	EW	LW	EW	LW
Tangential Vessel Diameter	210.64	30.60	212.72	31.07	250.98	31.83	251.48	37.31
Tangential Vessel Wall Thickness	3.02	2.67	2.21	1.71	1.85	1.25	1.83	1.07
Ray Cell Length	65.06	24.29	--	--	66.22	34.02	67.33	42.85
Ray Cell Double Wall Thickness	4.40	6.01	3.71	5.83	3.65	5.52	3.45	4.09
Fiber Double Wall Thickness	--	8.50	--	7.55	--	7.35	--	6.94
Intervessel Pits Length	5.42	3.23	--	--	3.34	2.51	4.08	3.26
Intervessel Pits Width	1.30	0.83	2.00	0.55	2.25	0.70	2.26	0.86

[a]Each entry based on minimum of 200 measurements.

wood samples indicated that the decrease in cell-wall thickness was related to cellulose degradation. This was detected by an increase in extractives content while the holocellulose content decreased. Lignin content (percentage) remained relatively unchanged. Further studies on lignin properties, however, such as average molecular weight or identification and quantification of functional groups, were not undertaken; hence it is not known what alterations in the lignin molecular structure have occurred.

A comparison of effects of charcoaling (McGinnes et al. 1976) and gamma radiation of white oak heartwood samples upon wood anatomy at the cellular level reveals that:

1. Charcoaling results in considerable shrinkage of cell walls with a loss of the middle lamella zone as a cellular feature. Adjacent cells appear to "fuse" together.
2. Gamma radiation, even to the levels used in this study, does not result in appreciable gross shrinkage. Cell-wall material is degraded (Table 2) with an appreciable increase (see Table 1) in cell void (lumen) areas;

TABLE 2. *Effect of gamma radiation dosages of 650, 950 and 1900 MRad on extractives, holocellulose and lignin contents of irradiated white oak wood. Values in percent*[a]

Chemical Constituent	Wood	Wood Irradiated to 650 MRad	Wood Irradiated to 950 MRad	Wood Irradiated to 1900 MRad
Extractives	8.98	52.8	58.0	69.1
Holocellulose	58.1	14.5	11.0	3.70
Lignin	32.6	30.2	29.6	27.0

[a]Approximate deviation based on handling is 1%.

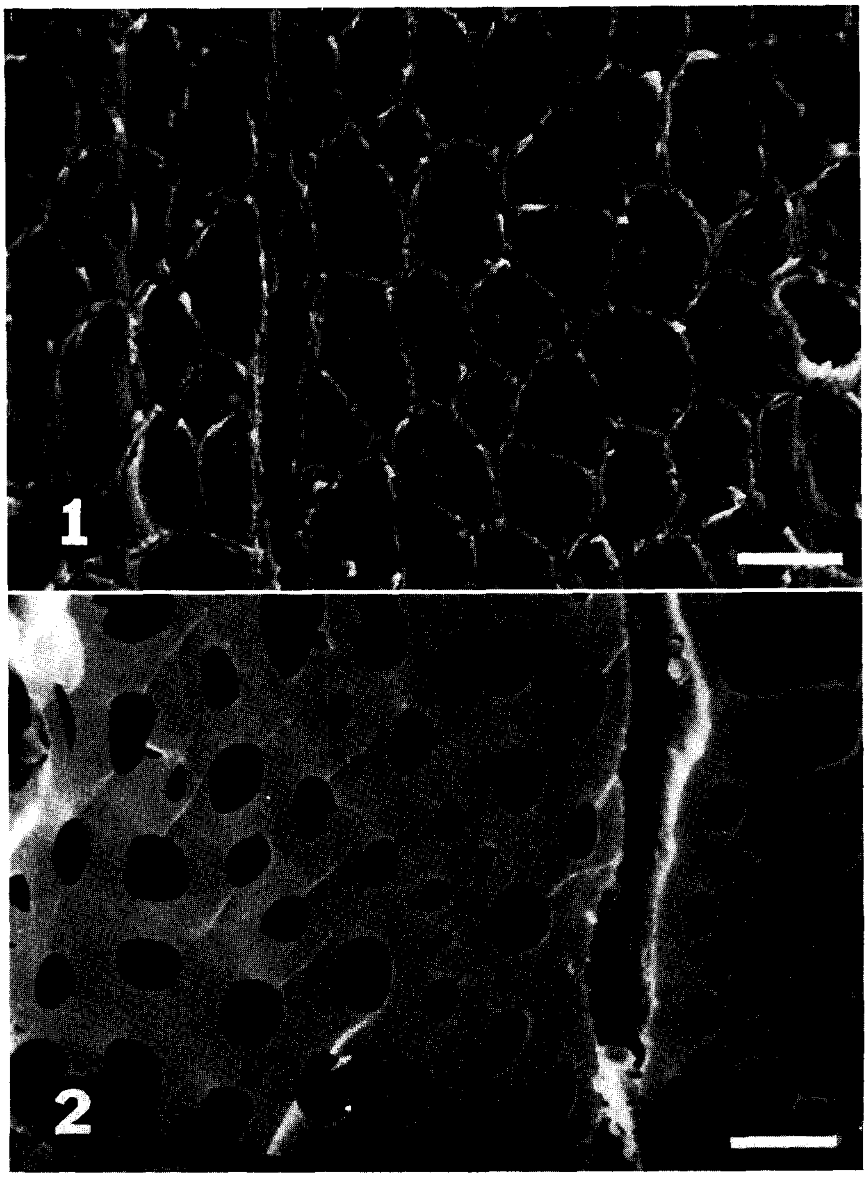

FIG. 1. Cross-sectional view of latewood fibers of white oak wood. Magnification bar, 10 μm; tilt angle, 30°.

FIG. 2. Latewood fiber zone of white oak charcoal as seen in cross section. Note absence of middle lamella zone. Magnification bar, 10 μm; tilt angle, 30°.

however, the degraded walls appear similar (SEM studies) to the "fused" ones of corresponding oak charcoals. Anatomical features are shown in Figs. 1–3 for fibers in the latewood zone of annual increments of normal wood, charcoal, and irradiated wood.

Even though the increasing application of gamma radiation to wood for one purpose or another has generated many studies in this area, only minimal attention has been paid to the microstructural aspect per se of gamma irradiated hardwoods. An attempt has therefore been made in this study

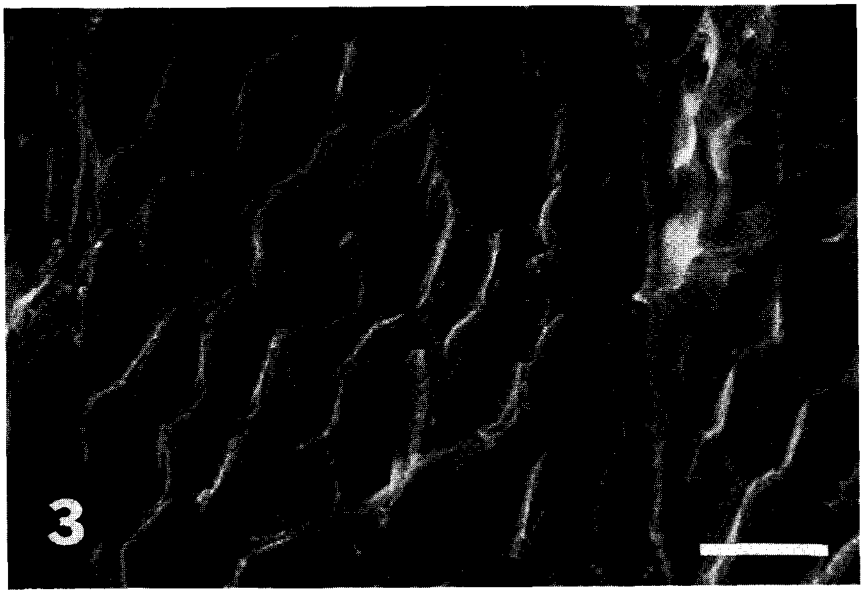

FIG. 3. Latewood fiber zone of white oak wood exposed to gamma radiation. Compare with Figs. 1 and 2. Magnification bar, 10 μm; tilt angle, 45°.

to offer information on the behavior of some microstructures and main polymeric constituents (cellulose, lignin, and extractives) of oak upon exposure to gamma radiation. It is hoped this paper will stimulate further investigations in view of possible future applications of gamma irradiation of woods in wood industries and research.

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