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ORIGINAL ARTICLE

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Resistance of gamma-irradiated sapwood of *Cryptomeria japonica* to biological attacks

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Abstract Any means helpful for the promotion of termite feeding activity has potential for use in a matrix in termite bait application. Therefore, energy transfer by gamma irradiation is worthy of consideration for converting wood into termite-accessible material. Wood specimens gamma-irradiated at 100 kGy and at lower levels were tested for their degrees of polymerization (DP) of cellulose and biological resistance. The DP of cellulose adversely decreased with increased doses of gamma irradiation. Termite wood consumption rates, which were determined by laboratory tests using undifferentiated larvae (workers) of *Coptotermes formosanus* Shiraki, were significantly higher at 100 kGy than at other doses. On the other hand, the decay resistance of gamma-irradiated wood against the fungi *Fomitopsis palustris* (Berkeley et Curtis) Murrill and *Trametes versicolor* (L. ex Fr.) Quel did not vary by irradiation dose.

Key words Gamma irradiation · *Cryptomeria japonica* · *Coptotermes formosanus* Shiraki · Decay fungi · Bait system

Introduction

Early studies demonstrated that high doses of gamma irradiation causes a decrease in the degree of polymerization (DP) of wood cellulose and the resultant chemical and physical changes without any anatomical modifications.[1–5] Originally, it was thought that the polymerization of cell walls by gamma irradiation resulted in enhanced fungal resistance. Although one research work showed no significant difference in the decay resistance of wood after gamma irradiation,[6] the effect of gamma irradiation on the biological resistance of wood is not yet fully understood. In addition, entomic deterioration, which has patterns different from fungal degradation in wood, has never been reported in the case of gamma-irradiated wood.

Materials that can promote termite feeding activity have potential as the bait matrix in bait systems for termite management. Bait systems have been extending their popularity because of the environmental benefits of reducing chemical use. Such systems are effective for suppressing termite populations because termites unconsciously eat bait toxicant(s) until they die.[7] Several wood species were examined for their applicability as bait substrate.[8,9] Previous studies on steamed and heated Japanese larch (*Larix leptolepis* Sieb. et Zucc. Gord) heartwood suggested that termite feeding levels depended on changes in wood components as a result of energy transfer.[10–13]

Gamma rays are another effective measure to transfer energy to wood and have a high transmission factor.[14] The present article is concerned with the results of laboratory termite and decay tests with gamma-irradiated wood according to Japanese standardized test methods, JIS K 1571.[15]

Materials and methods

Test wood specimens

Sound sapwood of *Cryptomeria japonica* D. Don was air-dried and used to prepare 1200 test specimens, each measuring 10 (L) × 20 (R) × 20 (T) mm. These were equally divided into six groups to receive different gamma-irradiation levels [0 (untreated), 0.01, 0.1, 1, 10, and 100 kGy]. Specimens were put into a paper envelope before gamma irradiation. Gamma irradiation was performed with ^{60}Co at the radioactivity intensity of 5.6 PBq at the Koka Laboratory of the Japan Radioisotope Association. The doses were measured by an alanine dosimeter. Following gamma irradiation, 31 specimens were randomly selected from each group for subsequent laboratory biological tests. Three and 18 specimens were assigned to termite tests and decay tests, respectively, and another 10 for the measurement of cellu-

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lose DP. The remaining specimens were saved for subsequent experiments.

Cellulose DP

The degree of polymerization of cellulose was measured by the procedure described in the *Manual for wood science experiments*.[16] Air-dried wood powder was put into a 300-ml Erlenmeyer flask, and 150 ml distilled water, 1.0 g sodium chlorite, and 0.2 ml acetic acid were added to the flask. This mixture was then heated in a water bath at 70°–80°C for 1 h before the further addition of 1.0 g sodium chlorite and 0.2 ml acetic acid. This operation was repeated four times. The content of the flask was then recovered by a glass filter (1 GP 100). Recovered substances were used for the determination of cellulose DP through viscosity measurement. About 0.04 g of the substance after being oven-dried at 103° ± 2°C for 24 h was soaked in 10 ml of distilled water for 2 min; then, 10 ml of 1 M cupriethylenediamine was added. This solution was used for the viscosity measurement.

Termite tests

Termite bioassay with *Coptotermes formosanus* was conducted under a forced feeding condition according to JIS K 1571.[15] Wood specimens were measured by their oven-dried weights after 3 days at 60° ± 2°C; then each of them was exposed to 150 workers and 15 soldiers in a test container. The container was maintained at 28° ± 2°C and greater than 85% relative humidity (RH) in darkness for 21 days. Following the feeding test, the amount of wood consumption was calculated from the difference in oven-dried weights of each sample before and after the test. Wood consumption rates were then determined by dividing the amount of wood consumption by the total days of worker termites during the exposure period, with the assumption that termite mortality increased linearly. Three replicates were tested at each irradiation level. The obtained results of termite tests were statistically analyzed by Tukey's test (inerSTAT-a v1.3[17]).

Decay tests

Decay tests were conducted using a monoculture of two decay fungi.[15] Test fungi were a brown-rot fungus, *Fomitopsis palustris* (Berkeley et Curtis) Murrill (FFPRI 0507) and a white-rot fungus, *Trametes versicolor* (L. ex Fr.) Quel (FFPRI 1030). Wood specimens were weighed after oven drying at 60° ± 2°C for 3 days and sterilized with gaseous ethylene oxide prior to the decay test. A glass jar containing 250 g quartz sand and 80 ml nutrient solution was autoclaved and then inoculated with a fungal suspension. When the mycelial mat fully covered the medium, three replicate wood specimens of the same treatment were placed on the mycelial mat surface of *F. palustris* and *T. versicolor* with or without a plastic net, respectively. The jars were incubated at 26° ± 2°C for 12 weeks. Nine replicates were assigned to each decay fungus. The extent of the fungal attack was expressed as percent mass loss, as determined by the difference in oven-dried weights of each wood specimen before and after the fungal exposure. The obtained results of the decay tests were statistically analyzed by Tukey's test (inerSTAT-a v1.3[17]).

Results and discussion

Measurement of gamma-irradiation doses

Doses of gamma irradiation measured by alanine dosimeter are shown in Table 1. The measured figures ranged from 94% to 143% of target doses. The variations in doses were caused both by the radiation period and by the distance between the radiation source and the irradiated specimen.

Changes in cellulose DP

Gamma irradiation decreased the DP of cellulose as shown in Fig. 1. The DP of the specimens with target irradiation of 0 and 100 kGy were respectively 2394 and 1753, and the resultant proportional decrease in DP after 100-kGy irradiation was 26.8%. This decreasing trend was similar to the results of a previous work.[4]

Table 1. Actual doses of gamma irradiation

Target (kGy)	Actual measurement (kGy)
0.010	0.010–0.011
0.100	0.094–0.100
1.00	1.39–1.43
10.0	11.1–11.7
100	102–106

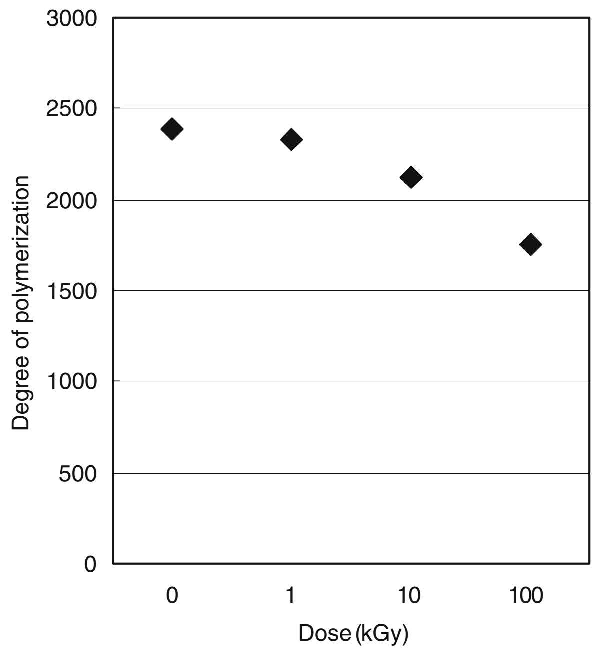

Fig. 1. Degree of polymerization of gamma-irradiated wood

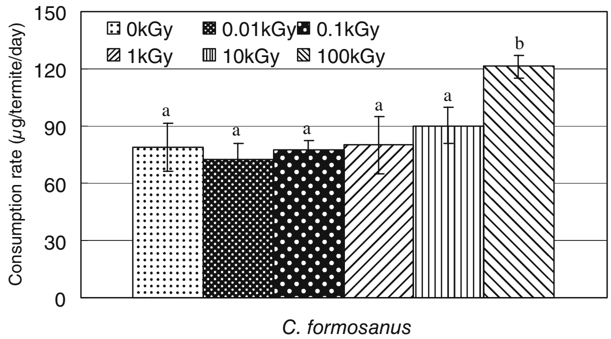

Fig. 2. Termite consumption rates of gamma-irradiated woods by *Coptotermes formosanus*. *Different letters* indicate a significant difference (Tukey's test; $P < 0.01$). *Error bars* indicate standard deviations

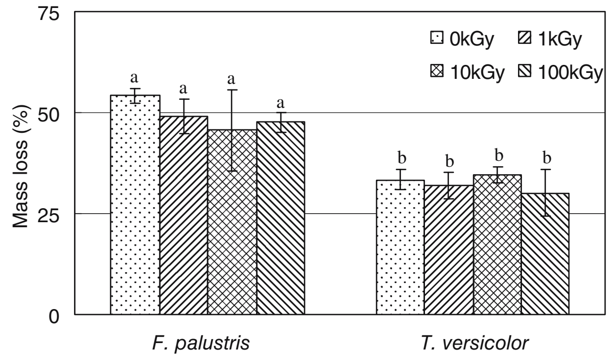

Fig. 4. Mass losses of gamma-irradiated woods after decay tests. *Different letters* indicate significant difference (Tukey's test; $P < 0.01$). *Error bars* indicate standard deviations

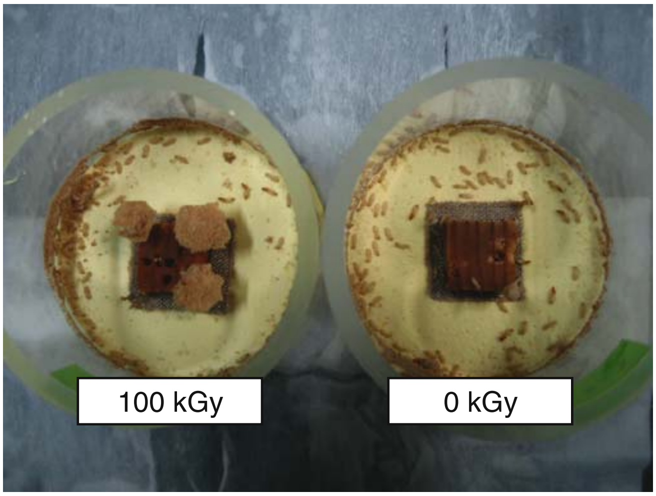

Fig. 3. Conditions of termite test after 7 days for specimen irradiated at 100 kGy and control specimen

Wood consumption rates by termites

Wood consumption rates by termites are shown in Fig. 2. The highest consumption rate was recorded for specimens that were irradiated at 100 kGy, and this was significantly different from other treatment levels (Tukey's test; $P < 0.01$). The consumption rate of treated specimens relative to that of untreated specimens at 10 kGy was 1.5 fold of that at 0 kGy, indicating that the termite species is more sensitive to the change of cellulose DP in gamma-irradiated wood. There were many small wood pellets produced by termites in a test vessel that contained a test specimen irradiated at 100 kGy (Fig. 3), while there was no substantial change between any other irradiated specimens and untreated ones. Although this suggests the termites' ease in tearing small pellets off the 100-kGy-irradiated wood, such phenomena could not be explained by the limited evidence in the present study. Teszler et al.[18] demonstrated that the strength of cellulose material was related to the DP of the cellulose, and gamma-irradiated wood had lower compressive, bending, and tensile strength than untreated wood.[19]

Percent mass loss by decay fungi

Mean mass losses of wood specimens after fungal exposure are shown in Fig. 4. No treatments produced a significant effect on the mean mass loss by *Fomitopsis palustris* (Tukey's test; $P < 0.01$). There was no significant difference in mean mass losses by *Trametes versicolor* regardless of gamma irradiation (Tukey's test; $P < 0.01$). This seemed to indicate that dose range in this study did not have any effect on the mass loss by fungi. The results of decay tests showed that the decrease in cellulose DP caused by gamma irradiation up to 100 kGy did not significantly affect fungal damage. Although the changes of lignin by gamma irradiation were not investigated in the current study, it is known that the lignin would remain intact after gamma irradiation.[3] Scheffer[6] reported that there was no significant effect on the decay resistance of white oak, red oak, sweetgum, and Douglas fir against *Poria monticola* at or less than 3.2 kGy gamma irradiation. This phenomenon was common to our results even at the higher levels of gamma irradiation.

Conclusions

The current laboratory biological tests demonstrated that the amount of wood eaten by *Coptotermes formosanus* increased with doses of gamma irradiation. In contrast, gamma irradiation did not exhibit any remarkable effect on the decay susceptibility of wood. These results seem to suggest that the decreased cellulose DP by gamma irradiation contributed to the increase in feeding activity of the termites and that the matrix of the cell wall did not change, resulting in the consistency of decay resistance. Bait matrix (substrate) for termite management is required to have two factors. One is the ability to accelerate termite feeding activity, and the other is a lack of promotion of microbial deterioration. This study showed that gamma-irradiated wood could contribute to enhanced termite feeding activity while keeping mass losses from decay fungi stable. It is thus thought that gamma-irradiated wood has potential as a bait matrix (substrate) in bait systems.

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