Food Sci. Biotechnol. Vol. 14, No. 2, pp. 181 ~ 184 (2005)

Food Science and Biotechnology

Effects of Gamma Irradiation and Methyl Bromide Fumigation on the Qualities of Fresh Chestnuts during Storage

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Abstract Effects of irradiation and fumigation on disinfestation and quality attributes of chestnuts during storage were studied. Fresh chestnuts were exposed to gamma irradiation (0-10 kGy) and methyl bromide (MeBr) under commercial conditions and stored at different temperatures for 6 months. Pest of quarantine importance for chestnuts, *Curculio sikkimensis* Heller showed 100% mortality by MeBr on 3rd day after fumigation and by irradiation at 0.5 kGy in about 3 weeks at 23±0.5°C. Respiration rates of samples one day after treatments increased in proportion to irradiation dose. Respiration pattern of MeBr group was equal to that of 10 kGy-group. Both MeBr and irradiation at 0.25 kGy or higher showed 100% inhibition of sprouting during storage at 5°C for 6 months. Flesh firmness was significantly reduced by MeBr or irradiation over 5 kGy ($p<0.05$) 1 day after treatments. MeBr fumigation resulted in appreciable decrease in flesh weight, reducing sugar and ascorbic acid contents ($p<0.05$), as compared to irradiated samples. Irradiation at 0.5 kGy was effective as alternative to MeBr in controlling pests while maintaining overall quality of fresh chestnuts during storage.

Key words: chestnut, methyl bromide, irradiation, disinfestation, physicochemical quality

Introduction

Worldwide, Japanese, European, Chinese, and American chestnuts make up the four different types of chestnuts, with Korea (22%), China (21%), Italy (15%), Turkey (13%), and Japan (5%) producing majority of the chestnuts. Chestnuts produced in Korea belong to the Japanese type, which is bigger and sweeter than those of Chinese and European (1). Fresh raw chestnut is generally utilized by peeling, roasting, and boiling, or processed into syrup pack or marrons glaces. The chestnut produced in Korea is rich in carbohydrate and low in fat, and thus is susceptible to insect infiltration after harvest from September to October (2, 3).

Quality losses of chestnut include damages caused by insect attack, sprouting, and rotting during the post-harvest period. Different treatments have been used to protect the quality of commodities against physiological and biological losses, such as fumigation (CS_2, methyl bromide, aluminum phosphide) (4, 5), low temperature and CA storage (6, 7), irradiation (8), and submerging peeled fruit in icy water (9). However, most fumigants have inherent weakness terms of their safety and environmental concerns even though they are simple to use with a potent efficacy. Methyl bromide (MeBr) is a fumigant most widely used in controlling storage/quarantine pests in food, agricultural, and forestry commodities after harvest, before or during storage, or transportation (4, 10). Due to its serious ozone-depleting properties, however, it is being phased out; thus, alternative treatment is required (11). United States Department of Agriculture has approved the use of irradiation as an alternative on fruits that are host to quarantine pests (12). In addition, the Korean government has approved maximum 0.25 kGy of gamma irradiation on chestnuts for the purpose of sprout control (13).

This work aimed at determining the comparative effects of irradiation and MeBr fumigation on disinfestation of the insect injurious to chestnut fruit, and changes in the physicochemical quality of chestnuts during the post-treatment period.

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Received August 24, 2004; accepted October 12, 2004

Materials and Methods

Materials Chestnuts (Eungi, *Castanea crenata*) in full maturity were purchased at a local market in Kongju, Chungnam, Korea one day after harvest. Sound fruits, approximate 25 g each, were selected for the treatments.

Irradiation and fumigation Gamma irradiation was carried out on the samples packed in a paper box (16 × 10 × 27 cm). A cobalt-60 irradiator equipped with 100 kCi of activity was operated at room temperature (20±1°C) at a dose rate of 1 kGy hr^{-1}. The applied doses were 0, 0.25, 0.5, 1, 2, 3, 5, and 10 kGy. The absorbed doses were assured by a free radical dosimeter and a ceric/cerous dosimeter. The fumigation was carried out under the commercial conditions ($0.9 \times 1.4 \times 0.2$ m^3) using MeBr (4 g/kg) for 4 hr at 21°C. The treated samples together with the untreated controls were placed in a storage container equipped with insect control nets and stored at 5°C and 90-95% RH for 6 months.

Pest identification and survey on mortality Identification of pests found in chestnut fruit was performed based on the checklist of pests from Korea (14). Pest control efficacy was expressed as total mortality (%) depending on treatments for the corresponding pests found in chestnuts when cut off each plot of 150 fruits during the post-treatment period at 23±0.5°C.

Measurement of respiration rate Respiration rate of the chestnut was determined at 24-hr intervals one day after treatments until 11th day at 23±0.5°C by placing the sample in a desiccator. Subsequently, the evolved CO_2 (mg/kg/hr) was absorbed in KOH solution prepared. The remaining KOH was titrated with HCl (15).

Sprouting rate The sprouting (including rooting) rate (%) of chestnut was measured during storage at 5°C, and expressed as the number of samples having more than 1 mm of sprout length over total tested samples (n=100).

Measurement of firmness The chestnut was peeled off mechanically, and its firmness (kg) was periodically measured using a fruit firmness tester (FHM-1 Hardness Tester, City, Japan) (n=20).

Measurement of weight loss The weight loss (%) of fresh chestnut was periodically measured individually during storage at 5°C (n=50).

Determination of reducing sugar and ascorbic acid The content of reducing sugar in edible portion of the chestnut was periodically determined during storage by the modified Somogyi method (16) and expressed as glucose content (g/100 g, d.b.). The ascorbic acid content (mg/100 g, d.b.) was determined for the stored samples by 2,4-dinitrophenylhydrazine colorimetry (17).

Results and Discussion

Insect mortality *Curculio sikkimensis* Heller (CSH) was identified as one of the major target pests, which has quarantine importance for various fruits as well as nuts in the international trade of agricultural commodities (14). Total mortality of CSH (100%) was attained 3 days after MeBr fumigation, whereas irradiation at 0.5 kGy showed the same mortality on day 23 (Fig. 1). Mortality of CSH increased with increasing irradiation dose; 2 and 4 kGy irradiations resulted in 100% mortality by days 17 and 3, respectively. These results reveal that MeBr-fumigation is very potent for the control of chestnut pests. On the other hand, irradiation at 4 kGy or higher was needed for attaining 100% mortality of CSH immediately after irradiation; however, high dose irradiation would cause quality deterioration (18). On the basis of these results, the level of 0.5 kGy is recommended in terms of sprout inhibition as well as pest control in chestnuts (19), which is a higher dose than the presently approved limit (0.25 kGy) in Korea (13).

Respiration rate of irradiated and fumigated chestnuts The respiration pattern was measured to evaluate the metabolic response induced by gamma irradiation and MeBr fumigation. Respiration rate of the samples 1 day after treatment increased in proportion to the irradiation doses, and 10 kGy-irradiated sample was equal to fumigated one in their respiration rate (Fig. 2). Irradiated samples at 0.25-0.5 kGy showed a similar tendency to the untreated control sample with the lapse of time at 23±0.5 °C. In the case of 10 kGy and fumigation groups, however, the respiration rates continuously increased to reach values 2 or 3 times higher than that of the control, indicating that serious damages occurred in the tissue. The initial stimulation effect and subsequent normalization have been reported for different fruits and vegetables exposed to ionizing energy (15, 20, 21).

Sprouting, firmness and weight loss of irradiated and fumigated chestnuts The sprouting rates of chestnuts during 6 months of storage at 5°C following irradiation or fumigation are given in Table 1. The sprouting/rooting of the stored samples was completely inhibited during storage by both treatments, while approximately 9% sprouting rate was observed in the untreated control at the 2nd month of storage (data not shown). Several reports have been made on the sprout inhibition of chestnuts by irradiation at around 0.25 kGy (21-23). However, conflicting results are found for fumigated chestnuts, as compared to fumigated acorn; no inhibition effects on sprouting have been observed during storage (24). Negligible changes were observed in the flesh firmness of chestnuts immediately after both treatments (Table 1). However, the stored samples showed a gradually decreasing tendency in their flesh firmness; during 6 months of storage, the firmness of samples irradiated up to 0.5 kGy was little changed, similar to that of the untreated control, while those irradiated from 1.0 to 5.0 kGy showed firmness decreases of about 10% and 23 to 26% in both 10 kGy-irradiated and fumigated samples,

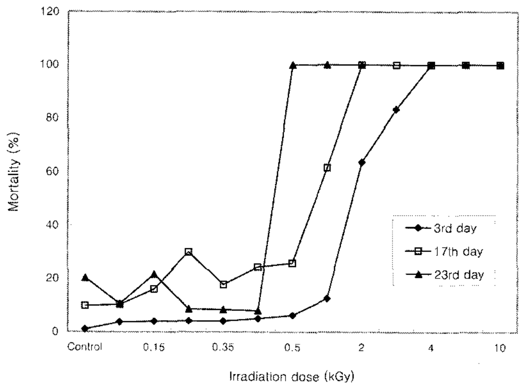

Fig. 1. Effects of gamma irradiation and methyl bromide (MeBr) fumigation on disinfestation of *Curculio sikkimensis* Heller of fresh chestnuts.

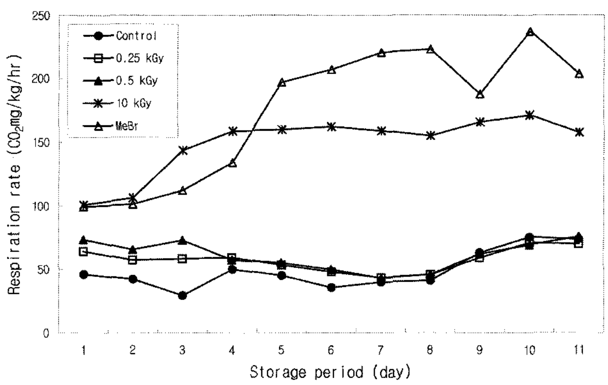

Fig. 2. Changes in respiration patterns of gamma-irradiated and methyl bromide (MeBr) fumigated fresh chestnuts during the post-treatment period at 23±0.5°C.

Table 1. Comparative effects of gamma irradiation and methyl bromide (MeBr) fumigation on flesh firmness and weight loss of fresh chestnuts during storage at 5°C

Quality	Storage period (month)	Treatment[1)]								
		Cont.	Irradiation dose (kGy)							MeBr
			0.25	0.5	1	2	3	5	10	
Flesh firmness (kg)	0	0.96[2)a]	0.94[a]	0.95[a]	0.94[a]	0.95[a]	0.93[a]	0.92[b]	0.92[b]	0.91[b]
	2	0.92[a]	0.92[a]	0.91[a]	0.90[a]	0.89[a]	0.89[a]	0.87[b]	0.86[b]	0.85[b]
	4	0.92[a]	0.91[a]	0.92[a]	0.89[a]	0.89[a]	0.89[a]	0.88[a]	0.83[b]	0.84[b]
	6	0.94[a]	0.90[a]	0.92[a]	0.85[b]	0.85[b]	0.86[b]	0.83[b]	0.71[c]	0.67[c]
Weight loss (%)	0	0.00[3)]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	5.22[b]	4.71[c]	4.81[c]	4.83[c]	4.92[c]	4.84[c]	4.61[c]	4.90[c]	7.14[a]
	4	10.14[b]	6.81[c]	6.92[c]	7.95[c]	9.50[b]	9.74[b]	9.81[b]	13.62[a]	15.10[a]
	6	17.00[b]	12.80[c]	13.21[c]	14.82[c]	22.05[a]	22.51[a]	22.42[a]	22.82[a]	24.09[a]

[1)]Chestnuts were irradiated with ^{60}Co gamma rays at room temperature, or fumigated with methyl bromide(4 g/kg) for 4 hr at 21°C.
[2)]Mean of 20 measurements.
[3)]Mean of 50 measurements.
[a-c] Different letters within a row are significantly different (p<0.05).

Table 2. Comparative effects of gamma irradiation and methyl bromide fumigation (MeBr) on the change in reducing sugar and ascorbic acid content in fresh chestnuts during storage at 5°C

Quality	Storage Period (mon)	Treatment[1)]								
		Cont.	Irradiation dose (kGy)							MeBr
			0.25	0.5	1	2	3	5	10	
Reducing sugar (%, d.b.)	0	1.54[2)b]	1.66[b]	2.42[a]	2.40[a]	2.50[a]	2.52[a]	2.38[a]	2.26[a]	1.14[c]
	2	2.44[b]	2.35[b]	2.51[b]	2.57[b]	2.57[b]	2.53[b]	2.55[b]	2.52[b]	1.65[a]
	4	2.56[b]	2.90[a]	3.18[a]	3.22[a]	3.31[a]	3.34[a]	3.14[a]	2.90[a]	1.67[c]
	6	1.22[c]	1.19[c]	1.13[c]	1.75[a]	1.10[c]	1.71[a]	1.95[a]	1.47[b]	1.12[c]
Ascorbic acid (mg/100 g, d.b.)	0	59.74[a]	56.13[a]	53.23[b]	53.23[b]	51.90[b]	51.52[b]	49.71[b]	46.03[c]	54.61[c]
	2	48.38[a]	47.25[a]	49.92[a]	49.92[a]	49.90[a]	47.00[a]	49.15[a]	47.90[a]	47.39[a]
	4	24.55[b]	28.45[b]	24.22[b]	24.22[b]	26.64[b]	31.97[a]	29.04[a]	23.77[b]	2.97[c]
	6	15.37[b]	21.63[a]	19.32[a]	19.32[a]	21.35[a]	22.47[a]	19.18[a]	20.56[a]	2.64[c]

[1)]Chestnuts were irradiated with ^{60}Co gamma rays at room temperature, or fumigated with methyl bromide(4 g/kg) for 4 hr at 21°C.
[2)]Mean of triplicates.
[a-c] Different letters within a row are significantly different (p<0.05).

respectively. The flesh firmness of stored samples appeared closely related to the development of spoilage induced by irradiation and chemical treatments (18, 20). The flesh weight of all treated samples showed a decreasing tendency with the lapse of storage time. The cumultative percentage of weight loss was significantly high in the order of MeBr, control, and irradiated groups (p<0.05). Several reports have been made on the effectiveness of irradiation, which is closely related to sprouting, rotting, and respiration, for reducing storage loss in some fruits and vegetables (20-23).

Reducing sugar and ascorbic acid content of irradiated and fumigated chestnuts One day after treatments, the reducing sugar contents of irradiated samples at doses above 0.5 kGy increased (p<0.05), whereas decreased in fumigated chestnut (p<0.05). The sugar contents of stored samples fluctuated to some degree, showing a decrease at the 2nd month and an increase at the 4th month of storage at 5°C (Table 2), which might be due to the physiological changes induced by irradiation and subsequent storage (15, 20), as illustrated in the respiration pattern (Fig. 2). On the other hand, except for the initial reduction, the fumigated sample showed a relatively constant sugar level up to 6th month of storage. Fumigants are reported not only to reduce volatile and nonvolatile oils of spices, but to cause their discoloration (25, 26). After 6 months of storage, the overall contents of reducing sugar showed similar levels in all groups. Higher doses are known to bring about physicochemical changes in pure carbohydrates (27); however, negligible changes in sugar content resulting from irradiation at doses lower than 10 kGy have been reported for various foods (28, 29). Table 2 shows the changes in ascorbic acid content of gamma-irradiated or fumigated chestnuts during storage. One day after treatments, ascorbic acid contents of irradiated and fumigated chestnuts were lower than that of the untreated sample. The decrease in ascorbic acid content was in proportion to irradiation dose (p<0.05), and the level in fumigated samples equaled those of 0.5 and 1 kGy-irradiated samples. Ascorbic acid content showed a gradual decreasing trend with the lapse of storage time. At the 2nd month of storage, ascorbic acid levels of all samples were not significantly different among each other; however, negligible amount of ascorbic acid was detected after 3 months of storage in fumigated samples, mainly due to the spoilage of the stored samples (20, 22). Although approximately 35% of the initial level, at 4th month of storage, irradiated samples showed higher levels of ascorbic acid than the untreated sample. Ascorbic acid is sensitive to ionizing radiation, and is largely influenced by factors such as type, state, and packaging condition of the food containing the acid (30, 31). Irradiation at 1 to 10 kGy decreased ascorbic acid level from 27.4 to 44.9% in standard solutions (10 mg%, phosphate buffer, pH 4.6), while from 6.9 to 21.9% in citrus fruits (31).

In conclusion, MeBr fumigation was very effective in accomplishing 100% mortality of *Curculio sikkimensis* Heller even 3 days after treatment. Similar effect was obtained with 4 kGy irradiation, but with quality deterioration (18, 20). However, in fresh chestnuts, taking total mortality of pest during storage into consideration, irradiation at 0.5 kGy was effective as one of the alternatives to MeBr fumigation for pest control during the post-harvest period.

Acknowledgments

This work was supported by Ministry of Science & Technology (MOST), Korea, through the National Nuclear Technology Program.

References

1. Considine GD. Foods and Food Production Encyclopedia. Van Nostrand Reinhold Company, New York, NY, USA. pp. 393-395 (1982)
2. Tanaka K, Kotobuki K, Kakiuchi N. Numerization of peeling easiness and role of phenolic compounds of the pellicle in the adhesion between the pellicle and embryo in comparison of Japanese (*Castanea crenata* Sief. et Zucc.) and Chinese embryo (*Castanea mollissima* Blume) chestnuts. J. Jpn. Soc. Hort. Sci. 50: 363-371 (1981)
3. AFMC. Korea Agricultural Trade Information. Agricultural and Fishery Marketing Corporation, Seoul, Korea (1998-2002)
4. UNEP. Montreal Protocol on Substances That Deplete the Ozone Layer. Report of the methyl bromide technical options committee. City, Country. pp. 1-294 (1995)
5. Hatton TT, Cubbedge TH, Windeguth DL, Spalding DH. Phosphine as a fumigant for grapefruit infested by Caribbean fruit fly larvae. Proc. Fla. State. Hort. Soc. 95: 221-224 (1982)
6. Gould WP, Sharp JL. Cold-storage quarantine treatment for carambolas infested with the Caribbean fruit fly (*Dipera: Tephritidae*). J. Econ. Entomol. 83: 458-460 (1990)
7. Delate KM, Brecht JK, Coffelt JA. Controlled atmosphere treatment for control of sweet potato weevil (*Coleoptera: Curculionidae*) in stored tropical sweet potatoes. J. Econ. Entomol. 83: 461-465 (1990)
8. Sommer NF, Mitchell FG. Gamma irradiation - a quarantine treatment for fresh fruits and vegetables. HortScience 21: 356-360 (1986)
9. Kwon JH, Lee J, Lee SB, Chung HS, Choi JU. Effects of water soaking and gamma irradiation on storage quality of chestnuts. Korean J. Postharvest Sci. Technol. 89: 9-15 (2001)
10. NPQS. Summary of Plant Quarantine Systems in Different Countries. National Plant Quarantine Service Report 92-2-41. Anyang, Korea. pp. 1-157 (1992)
11. Landolt PJ, Chambers DL, Chew V. Alternative to the use of probit mortality as a criterion for quarantine treatment of fruit fly (*Dipera: Tephritidae*) infested fruit. J. Econ. Entomol. 77: 285-287 (1984)
12. United States Department of Agriculture, Animal and Plant Health Inspection Service. Use of irradiation as a quarantine treatment for fresh fruits of papaya from Hawaii. Fed. Regist. 54: 387-393 (1989)
13. IAEA(ICGFI). Clearance Database. http://www.iaea.org/icgfi/ (2003)
14. ESKKSAE. Check List of Insects from Korea. The Entomological Society of Korea and Korean Society of Applied Entomology, Kon-Kuk Univ. Press, Seoul, Korea. pp. 1-744 (1994)
15. Hong SI, Park HW, Kim DM. Respiratory characteristics and storage quality of Korean fresh ginseng influenced by harvest time and plastic film packaging. Food Sci. Biotechnol. 11: 494-499 (2002)
16. Kobayashi T, Tabuchi T. A method employing a tribasic sodium phosphate buffered reagent for estimating semimicro quantities of reducing sugars. J. Agric. Chem. Soc. Jpn. 28: 171-174 (1954)
17. The Korean Society of Food Science and Nutrition. Handbook of Experiments in Food Science and Nutrition. Hyoil press, Seoul, Korea. pp. 256-261 (2000)
18. Kertesz Z, Glegg RE, Boyle FP, Parsons GF, Massey LM. Effect of ionizing radiations on plant tissues. 1. Softening and changes in pectins and cellulose of apples, carrots, and beets. J. Food Sci. 29: 40-48 (1964)
19. Kwon JH, Chung HW, Kwon YJ. Infrastructure of quarantine procedures for promoting the trade of irradiated foods. pp. 209-254. In: Symposium of The Korean Society of Postharvest Science and Technology of Agricultural Products on Irradiation Technology for the Safety of Food and Public Health Industries and Quality Assurance. October 13, Place of conference. Publisher, Daejon, Korea (2000)
20. Kwon JH, Yoon HS, Sohn TH, Byun MW, Cho HO. Effect of gamma irradiation on the physiological characteristics of garlic bulbs during storage. Korean J. Food Sci. Technol. 16: 408-412 (1984)
21. Uchiyama Y. Effect of gamma irradiation on sprout inhibition and its physiological mechanism of chestnuts. J. Jpn. Soc. Hort. Sci. 35: 86-94 (1966)
22. Cho HO, Yang HS, Byun MW, Kwon JH, Kim JG. Batch scale storage of sprouting foods by irradiation combined with natural low temperature (°C). Storage of chestnuts. Korean J. Food Sci. Technol. 15: 231-237 (1983)
23. Park NP, Kim YJ, Kim SK, Rhee CO. Studies on the preservation of Korean chestnut by gamma irradiation. Korean J. Food Sci. Technol. 9: 36-40 (1977)
24. Kwon JH, Kim SJ, Chung HW, Kwon YJ, Chung HS, Byun MW. Comparative effects of gamma irradiation and methyl bromide fumigation on disinfestation and physiochemical quality of acorn. Korean J. Postharvest Sci. Technol. 5: 199-206 (1998)
25. Kwon JH, Byun MW, Cho HO. Quality evaluation of ground garlic and onions treated with chemical fumigants and ionizing radiation. Korean J. Food Sci. Technol. 19: 107-112 (1987)
26. Vajdi M, Pereira RR. Comparative effects of ethylene oxide, gamma irradiation and microwave treatments on selective spices. J. Food Sci. 38: 893-895 (1973)
27. Elias PS, Cohen AJ. Radiation Chemistry of Major Food Components. Elsevier Scientific, New York, NY, USA. pp. 131-167 (1977)
28. Auda H, Khalaf Z, Mirjan J. Effect of gamma irradiation on the sugar and protein composition of Iraqui dates. Vol. 1. pp. 459-468. In: Food Preservation by Irradiation. Proceedings of the International Symposium on Food Irradiation. Dates, place of conference. IAEA/FAO/WHO (Wageningen, 21-25 November, 1977). IAEA, Vienna, Austria(1978)
29. Kwon JH, Belanger JMR, Sigouin M, Lanthier J, Willemot C, Pare JRJ. Chemical constituents of *Panax* ginseng exposed to γ-irradiation. J. Agric. Food Chem. 38: 830-834 (1990)
30. Karel M. Prediction of nutrient losses and optimization of processing conditions. pp. 233-263. In:Nutritional and safety aspects of food processing. Tannebaum SR (ed). Maecel Dekker, New York, NY, USA (1979)
31. Byun MW, Lee IS, Lee KH, Yook HS, Kang KO. Changes of ascorbic acid contents induced from gamma irradiation, heating and microwave treatments. J. Korean Soc. Food Sci. Nutr. 28: 954-957 (1999)