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Assessment of the Wholesomeness of Irradiated Food

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INTRODUCTION

Four criteria must be met to assure wholesomeness of foods treated with ionizing radiation (Josephson 1983): a) absence of induced radioactivity, b) absence of viable pathogens or their toxins, c) absence of excessive loss in nutrients, and d) absence of toxic, mutagenic, or carcinogenic radiolytic products. Because other speakers in this symposium are considering the effects of ionizing radiation on pathogens, the discussion of that factor will not be presented in this review.

INDUCED RADIOACTIVITY

The maximum energies of the gamma radiations from either ^{60}Co or ^{137}Cs and electrons with an energy of 10 MeV or less are below the threshold needed to activate elements in foods (Becker 1983). Thus foods subjected to ionizing radiation from ^{60}Co, ^{137}Cs, or accelerated electrons of 10 MeV or less will not become radioactive.

RADIOLYTIC PRODUCTS

Radiolytic products are those which are formed when a substance is exposed to ionizing radiation. Thus, for a product to be considered as radiolytic, there must be a dose-response relationship between the product and the absorbed radiation. From the standpoint of the wholesomeness of an irradiated food product, we have to consider whether or not a radiolytic product will be present in the food following treatment at a potentially toxic level. As an example, the major radiolytic products identified in chicken following irradiation at 45 kGy (^{60}Co source) and -30°C are pentadecane (0.033 mg/g), heptadecane (0.035 mg/g, hexadecanal (0.038 mg/g), octadecenal (0.015 mg/g), ethyl palmitate (0.01 mg/g), ethyl oleate (0.006 mg/g), 16/16 propanediol diesters (0.006 mg/g), and 16/18:1 propanediol diesters (0.015 mg/g) (Merritt 1984). These do not represent toxic concentrations.

Objections have been made to the use of food irradiation because ionizing radiation produces free radicals and their subsequent ingestion "may result directly in toxic free radical and peroxide formation within the body" (Federal Register 1986). The FDA panel concluded that the high water content of all fresh food provides a medium for the rapid degradation of such free radicals. This conclusion is supported by data reported by Merritt & Taub (1983) in which the commonality and predictability of radiolytic products in several irradiated meats were considered. Lifetimes of free radicals generated in beef muscle proteins by irradiation to 50 kGy at -40°C were only 8 hours when the protein was warmed to -10°C and the electron spin resonance signal completely disappeared when the sample was thawed (Taub et al., 1978).

The consumption of peroxides and hydroperoxides produced in foods by irradiation is a concern but these also formed in foods which have not been irradiated. The chemistry of the formation of these products and their subsequent reactions with other food components has been studied by many investigators and was recently reviewed by Nawar (1983). Gower & Wills (1986) reported that large concentrations of lipid peroxide were formed when mackerel oil and cod-liver oil were exposed to radiation doses of 1-4 kGy. The rate of benzo [α] pyrene (BP) oxidation, which is required for BP to be mutagenic or carcinogenic, was closely related to the extent of peroxidation and was dependent on the dose and the presence of air. Oxidation products of BP were formed during storage of both irradiated and unirradiated mixtures of starch and mackerel oil but greater amounts were formed in the irradiated sample. Irradiation *in vacuo* or in the presence of antioxidants greatly reduced the oxidation of BP. When herring flesh + BP was exposed to a radiation dose of 3 kGy, the peroxide content increased to 516% of the preirradiation value; only a small increase occurred in the unirradiated sample. But Adam et al. (1982) reported that eicosapentaenoic and docosahexaenoic acids were not destroyed by gamma irradiation (50 kGy) of herring fillets, if air was excluded.

NUTRITIONAL QUALITY

At doses of ionizing radiation relevant to food irradiation, proteins and carbohydrates are not significantly affected (Josephson 1983, Murray 1983, Wierbicki et al. 1986).

There will be some hydrolysis of carbohydrates, such as starch, but the effects will be mainly on the functional properties, not their nutritional value. The products of irradiation of lipids and fatty acids are similar to those of heating (Nawar 1983), but irradiated lipids have produced adverse feeding results. Kraybill (1982) stated that the ingestion of highly oxidized fats produces many toxic effects, and some diets containing irradiated lipids have had reduced acceptability or toxicity. Wierbicki (1985) found that the peroxide and thiobarbituric acid values of both gamma and electron beam sterilized enzyme inactivated chicken at 3 months were significantly reduced after 81 months of storage.

In contrast to the above, ionizing radiation may produce significant changes in the vitamin content of some foods (Kraybill 1982). The extent of those effects depends on dose, dose rate, temperature of irradiation, type of food, and subsequent storage and treatment. Fat soluble vitamins are sensitive to ionizing radiation in the order Vitamin E > Carotene > Vitamin A > Vitamin D > Vitamin K. The water-soluble vitamins ascorbic acid and thiamin may be the most sensitive to ionizing radiation (Kraybill 1982). Vitamin C is actually converted to dehydro-ascorbic acid which is also biologically active. Interactive effects occur with other vitamins and there are protective effects from other components of the food. Irradiation at low temperatures protects vitamins (Kraybill 1982). Thomas et al. (1981)and Diehl (1975) reported synergistic destructive effects on thiamin between heating, storage, and irradiation of pork, bacon, and grains. A 56% loss of vitamin E occurred in rolled oats given a radiation dose of 1 kGy and stored for 8 months in air but only 5% in nitrogen (Diehl 1979). Irradiated rolled oats (0.25 kGy) that were stored for four months lost 52% of their thiamin; when the oats were heated for 10 minutes at 100°C there was an additional 20% loss of thiamin. Thayer et al. (1987) reported that gamma- (46-68 kGy at -25 ± 15°C) sterilized chicken lost 26.5% and electron-sterilized chicken 8.7% of its thiamin content whereas the thermally-sterilized chicken lost 33.5%. The only other significant vitamin loss occurred in the contents of Vitamin K of 21.7% in thermally-sterilized, 37.2% in gamma-sterilized, and 34.1% in electron-sterilized chicken. It is apparent from the widely divergent results reported in the literature that the interactive and possibly synergistic effects of irradiation temperature, storage time, atmosphere both during irradiation and storage, cooking time, and cooking temperature on vitamins for each type of product need to be carefully investigated.

FEEDING STUDIES

It is well recognized that the traditional feeding study which incorporates exaggerated amounts of the test substance to obtain a 100-fold safety factor is difficult, if not impossible, to accomplish with irradiated foods because such amounts of foods would severely disturb the nutritional balance of the animals diet. Similarly, the use of ionizing radiation doses which are much greater than that desired are not practical because of the overall effects on the acceptability of the food. But there have been many feeding studies conducted with irradiated foods and generally with excellent results. Many of the reported adverse effects due to consumption of irradiated foods were discussed by the FDA in its final rule permitting the use of irradiation for inhibition of growth and maturation of fresh foods and disinfestation of arthropod pests and for the sterilization of dehydrated aromatic vegetable substances (Federal Register 1986).

The FDA received comments objecting to the irradiation of any fruit or vegetable because irradiated sucrose solutions produced abnormal anaphase formation in bean root tips, decreased growth of carrot tissue cultures, and increased revertants in *S. typhimurium* (Federal Register 1986). The FDA countered that the biologically active compounds in the irradiated sugar solutions were predominantly dicarbonyl sugars which would be converted to alpha, beta-unsaturated carbonyl sugars that are also present in nonirradiated foods. Further, fewer biologically active compounds would be produced in foods because of reactions with other components. Several feeding studies with irradiated fruit which produced no evidence of toxic effects were cited by the FDA (Federal Register 1986).

A study concluding that polyploidy (chromosomal changes) resulted from the consumption of irradiated wheat by both animals and humans was rejected on the basis of poor design and interpretation (Federal Register 1986).

Thayer et al. (1987) noted an unexplained reduction in the hatchability of eggs of *Drosophila melanogaster* which was most pronounced in those reared on gamma-irradiated (46-68 kGy at $-25 \pm 15°C$) chicken meat and was dose-related. "The cause of the reduction in number of offspring and the biological significance of these results with *Drosophila*, as they relate to man, is unknown" (Thayer et al. 1987). The results most likely represent inadequate knowledge of *Drosophila* nutritional requirements rather than reproductive effects. However, it would be desirable to study this effect further before the human consumption of large amounts of radiation-sterilized chicken is approved. None of the four processed chicken meats (frozen control; thermally-, gamma-, and electron-sterilized) produced sex-linked recessive lethal mutations.

Mated female CD-1 mice fed frozen, thermally-, gamma-, or electron-sterilized chicken had similar patterns of mortality, but virgin females fed gamma-irradiated chicken meat had significantly ($p < 0.05$) poorer survival than virgin females fed the frozen control chicken meat (Thayer et al. 1987). However, because the results were only marginally significant and only occurred in one sex group, the authors concluded that the effect was not treatment related. Thayer et al. (1987) concluded that there was no evidence of genetic toxicity or teratogenic effects in mice, hamsters, rats, or rabbits due to the ingestion of the radiation-sterilized chicken meat. Nor was there definitive evidence of toxicological effects in mammals in multigeneration studies with mice and beagle dogs.

Because of known interactions of radiation dose, processing temperature and atmosphere, storage conditions and time for some foods it is suggested that greater attention should be given to the interactive effects of processing variables on nutritional and toxicological properties of irradiated foods.

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