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SALMONELLA CONTROL BY IRRADIATION

The title of this presentation is "*Salmonella* Control by Irradiation." Let's first define the subject. The title refers to ionizing radiation in the form of gamma rays from isotope sources such as ^{60}Co or ^{137}Cs, X-rays of 5 MeV or lower energy, or accelerated electrons of 10 MeV or lower energy (Anonymous, 1990a). The reasons for such precise limitations on the radiation sources will become apparent later in the presentation. The salmonellae referred to are those that may contaminate poultry or poultry products. Is there a salmonellae problem associated with poultry and poultry products that requires control, and, if so, isn't foodborne salmonellosis a rather minor disease resulting in diarrhea for a few days? Assuming that there is a 'Salmonellae' problem with poultry and poultry products, is food irradiation an appropriate method for achieving a solution?

In Carbon County, Pennsylvania, 12 persons attending an office party at which egg-based custard pies were served in 1988 became ill with salmonellosis 7-72 hours after ingestion of the pie (Anonymous, 1990b). Most of the patients had diarrhea and a headache. Abdominal pain and nausea were experienced by 42% and fever and vomiting by a few. Three were hospitalized. One of the three, a 40-year-old previously healthy man, died with acute salmonellosis caused by *Salmonella enteritidis*. This, then, is not necessarily a minor disease even for healthy adults. During the period from 1983-1987 *Salmonella* species were identified as the causative agent in 57% of the bacterial foodborne disease outbreaks in the United States (Bean et al., 1990). Chicken and turkey were confirmed as the etiologic agents in 22 and eggs in 9 out of a total of 342 confirmed outbreaks of salmonellosis from 1983 to 1987. In addition to the public's perception of problems with contaminated poultry is the fact that the number of isolations of *S. enteritidis* from humans has increased dramatically since 1985 in New England and the mid-Atlantic states for a total of 4976 cases and 30 deaths (Anonymous, 1990b). Grade A shell eggs were implicated in 73% of the 89 confirmed foodborne outbreaks of salmonellosis. The Food Safety and Inspection Service of the USDA surveyed poultry plants between 1982 and 1984 and found a 35.2% incidence of *Salmonella* in broilers (Dubbert, 1988). Considering how widespread salmonellae are throughout the environment it is certainly not surprising that such contamination should occur even under the best processing conditions. However, foodborne salmonellosis is not a disease that we can ignore nor can we say that poultry and poultry products do not play a role in the transmission of the disease.

Assuming there is a 'salmonellae' problem with poultry and poultry products, is irradiation an appropriate solution? Let me state that food irradiation can not in any way substitute for proper food sanitation both by the processor and by the housewife and for proper cooking and refrigerated storage of the product. In fact, as we know, proper cooking of poultry and poultry products will kill any salmonellae that may be present on them. Both poultry and other food products may become either contaminated or recontaminated if they are placed on a cutting board on which a contaminated product had been placed. Thorough cooking will also kill salmonellae in egg, but there are a number of foods that contain either raw or partially raw egg.

For food irradiation to be an appropriate technology for protection of the public against contaminated poultry and poultry products the process must be effective while not causing adverse effects. It must effectively control the target pathogen. It must not adversely affect the wholesomeness, nutrient value, and organoleptic properties of the treated products. It must be economical.

One misunderstanding that continues to plague the use of this process is the perception that irradiated food has become radioactive. No radioactive materials are added to irradiated foods. The food is exposed to gamma rays, X-rays, or accelerated electrons. The energy levels of the gamma rays from either ^{60}Co or ^{137}Cs and accelerated electrons of less than 10 MeV lack sufficient energy to induce radioactivity in edible foods. X-Rays of 5 MeV energy might react with the isotopes ^{2}H, ^{17}O, and ^{13}C, which are extremely minor components of food, but the products are the stable non-radioactive isotopes ^{1}H, ^{16}O, and ^{12}C, respectively (Becker, 1983; Koch and Eisenhower, 1967). Thus irradiated foods are slightly less radioactive than untreated foods.

Doubts about the wholesomeness of poultry that has been treated with ionizing radiation to control foodborne pathogens perhaps can be best offset by referencing the Food and Drug Administration's approval of the process in May 1990 (Food and Drug Administration, 1990). The U.S. Food and Drug Administration authorized treating fresh or frozen, uncooked poultry with ionizing radiation at doses up to 3 kGy (1 kGy = 100 krad) to control foodborne pathogens. Three studies were considered in which test animals were fed irradiated chicken: an 80-week chronic feeding study in mice, a multigeneration study in rats, and a 1-year chronic feeding study in beagle dogs. In each of these studies the chicken fed to the test animals had received a radiation dose of 7 kGy. It was fed at a level of 50% by weight in the mouse study in Canada and 35% by weight in the rat and dog feeding studies in The Netherlands. The FDA also considered the results of toxicological, teratogenic, and nutritional studies of radiation-sterilized (45 to 59 kGy) chicken meat (Thayer et al. 1987). The radiation doses used for these latter studies were many times those under consideration for the control of foodborne pathogens in fresh and frozen poultry and were administered *in vacuo* at a temperature of -30 ± 15°C. No evidence of treatment-related adverse toxicological, teratogenic, or nutritional effects was observed in any of the test animals fed irradiated chicken meat. Neither the studies in The Netherlands nor a study by Fox et al. (1989) indicated adverse effects on the vitamin content of the treated chicken at doses up to 3 kGy. Fox et al. (1989) reported a thiamin loss of 8.6% from chicken breast meat irradiated to an absorbed dose of 3 kGy at 0°C, a minute effect on the total intake of thiamin.

The current regulations will allow a maximum radiation dose of 3.0 kGy for chicken. Will such treatments significantly alter the organoleptic properties of the chicken? This will depend on at least four factors: the irradiation temperature, radiation dose, the storage time before consumption, and preparation method. Klinger et al. (1986) irradiated both broiler breast and leg meat at doses up to 4.5 kGy and found the irradiated meat to be free of *Salmonellae, Coliforms, and Staphylococci* and to have reduced bacterial counts. Trained panelists were unable to detect changes in the sensory quality of irradiated (3.7 kGy) chicken meat cooked for 60 min in water immediately following irradiation compared to fresh or frozen chicken meat prepared in the same manner. The sensory results indicated that the quality of chilled irradiated chicken leg meat was acceptable for about two weeks and breast meat for three weeks. When the irradiated chicken was refrigerated and stored sensory differences became increasingly detectable among the fresh, frozen, and irradiated chicken after cooking. After 21 days the frozen breast meat was preferred to the irradiated but the irradiated was preferred to the untreated. It should be noted that fresh batches of similar untreated meat were required for each taste panel as chilled storage (1-2°C) permitted quality retention for about four days only.

When raw chicken was irradiated in polyethylene bags by Klinger et al. (1986) and by Hanis et al. (1989), both groups detected an off odor in the presence of the polyethylene. There are at least two possible sources for this odor: from sulfhydryl compounds produced from the proteins in the chicken and from the slight decomposition of the polyethylene which takes place. Acetic, propionic, n-butyric, and n-valeric acids are produced when polyethylene is subjected to ionizing radiation (Azuma et al., 1984). All of these are extremely volatile and are produced in minute amounts and dissipate rapidly during storage. However, we are reminded that some research may be necessary to select approved packaging materials for prepackaged irradiated foods which will give the irradiated food the desired organoleptic properties. The processor should not assume that the packaging material currently in use will be approved or satisfactory for use during irradiation. The chemical and physical changes in food packaging materials subjected to ionizing radiation were reviewed by Elias (1979) and Thayer (1988).

Treatment of chicken carcasses or meat with ionizing radiation for the purpose of controlling foodborne pathogens such as *Salmonella* was studied by several workers including Ley et al. (1970), Licciardello et al. (1970), Previte et al. (1970), Mulder (1976, 1982), Mulder et al. (1977), and Hanis et al. (1989). In my laboratory we are studying the effects of gamma radiation on salmonella and other foodborne pathogens in mechanically deboned chicken and chicken parts to develop predictive models for those effects under various irradiation doses and temperatures and in the presence or absence of air. Conceptually such models will allow either the processor or the regulator to predict the efficacy of an actual process. Radiation-sterilized mechanically deboned chicken meat was used as the substrate for the studies in order not to complicate the interpretation of the results with the effects of the indigenous microbial population on the recovery of the added salmonella. Previous studies by Thayer et al. (1987) demonstrated that chicken meat could be sterilized *in vacuo* at -30±15°C without significant changes in its chemical or toxicological properties.

Thayer et al. (1990) determined the resistance of six different *Salmonella* serotypes in radiation-sterilized mechanically deboned chicken meat. Recently Thayer and Boyd (1991) reported the development of predictive equations for the response of *S. typhimurium* when irradiated at temperatures of -20 to +20°C, in the presence or absence of air in radiation-sterilized mechanically deboned chicken meat. Predictive models for the survival of *Salmonella* were developed from the studies with non-sterile mechanically deboned chicken and chicken parts and were in excellent agreement with the original predictions developed using sterile meat. These studies are currently *in press* in Poultry Science (Thayer and Boyd, 1991a,b).

In these studies the chicken was inoculated prior to treatment with approximately 10^9 colony forming-units per gram or cm^2 of surface of a streptomycin-resistant mutant of *S. typhimurium*. The use of an antibiotic-resistant mutant allowed the use of noninhibitory media to determine the number of surviving colony-forming units. The substrates were chicken legs purchased from a local poultry supplier or mechanically deboned chicken meat obtained from a local manufacturer of poultry frankfurters. Response surface methodology was used to develop predictive equations for the response of the *S. typhimurium* to gamma radiation. Samples were packaged either with air present or *in vacuo*. Samples were irradiated at temperatures of -20, -10, 0, +10, and +20°C and at radiation doses of 0, 0.90, 1.80, 2.70, and 3.60 kGy at a dose rate of 0.12 kGy/min.

The *Salmonella* cells on chicken legs were very sensitive to gamma radiation. In contrast with our previous results using sterile mechanically deboned chicken meat, the presence or absence of air during irradiation was not significant. However, there were highly significant effects of radiation dose, irradiation temperature, and for the interaction of radiation dose with irradiation temperature. So predictably, a radiation dose of 1.5 kGy will kill 1.8, 2.4, 2.9, 3.3, or 3.6 logs of *S. typhimurium* per cm^2 of chicken leg irradiated at temperatures of -20, -10, 0, +10, or +20°C, respectively. At 3.0 kGy, the maximum radiation dose permitted under current regulations, 3.4, 4.3, 5.1, 5.8, or 6.4 logs of *S. typhimurium* per cm^2 of chicken leg should be killed when irradiated at temperatures of -20, -10, 0, +10, or +20°C, respectively.

The results with mechanically deboned chicken meat were very similar to those described for chicken legs, and the presence or absence of air did not alter the results. Highly significant effects were identified for radiation dose, irradiation temperature, and for the interaction of radiation dose with irradiation temperature. Predictably, a dose of 1.5 kGy will kill 1.6, 2.3, 2.8, 3.1, or 3.2 logs of *S. typhimurium* per gram of mechanically deboned chicken meat when irradiated at temperatures of -20, -10, 0, +10, or +20°C, respectively; and a dose of 3.0 kGy, will kill 3.5, 4.4, 5.2, 5.8, or 6.2 logs of *S. typhimurium* at irradiation temperatures of -20, -10, 0, +10, or +20°C, respectively.

Irradiation of shell eggs has not been considered desirable since most such studies have indicated thinning of the albumin and weakening of the yolk membrane (Urbain, 1986). Several studies have, however, demonstrated that the number of viable salmonellae can be reduced dramatically in liquid whole egg (Schaffner et al., 1989) and in egg powder (Matic et al., 1990). Proctor et al. (1953) found that a noticeable off-flavor was detectable in scrambled egg dishes prepared directly from whole egg irradiated to 3.0 kGy, but that this off-flavor disappeared when the egg was spray dried before cooking.

Poultry meat can be treated with ionizing radiation very effectively to control foodborne bacterial pathogens such as salmonellae. The results presented here indicate that very significant reductions of the numbers of *S. typhimurium* present in or on chicken meat can be obtained by radiation doses as low as 1.5 kGy. The results will be significantly affected by the irradiation temperature. The results obtained with widely diverse products such as chicken legs and mechanically deboned chicken were remarkably similar. Poultry irradiated under proper conditions will be wholesome, may have an extended shelf life when properly refrigerated, and will have a significantly improved microbiological safety.

REFERENCES

Anonymous. 1990a. Irradiation in the production processing and handling of food. Federal Register. 55:18538-18544.

Anonymous. 1990b. Update: *Salmonella enteritidis* infections and grade A shell eggs - United States, 1989. Morbidity and Mortality Report. 38:878-880.

Azuma, K., Y. Tanaka, H. Tsunoda, T. Hirata, and T. Ishitani. 1984. Effects of film variety on the amounts of carboxylic acids from electron beam irradiated polyethylene film. Agric. Biol. Chem. 48:2003-2008.

Bean, N. H., P. M Griffin, J. S. Goulding, and C. B. Ivey. 1990. Foodborne disease outbreaks, 5-year summary, 1983-1987. Morbidity and Mortality Weekly Report. 39:15-57.

Dubbert, W. H. 1988. Assessment of *Salmonella* contamination in poultry - past, present, and future. Poultry Science. 67:944-949.

Becker, R. L. 1983. Absence of induced radioactivity in irradiated foods. In Recent Advances in Food Irradiation. (P. S. Elias and A. J. Cohen, eds.) pp. 285-313, Elsevier Biomedical Press, Amsterdam, The Netherlands.

Elias, P. S. 1979. Food irradiation and food packaging. Chem. Indust. 10:336-341.

Food and Drug Administration. 1990. 21 CFR Part 179 Irradiation in the production, processing, and handling of food; Final rule. Federal Register. 55:18538-18544.

Fox Jr., J. B., D. W. Thayer, R. K. Jenkins, S. A. Ackerman, J. G. Phillips, G. R. Beecher, J. Holden, F. D. Morrow, and D. M. Quirbach. 1989. Effect of gamma irradiation on B vitamins of pork chops and chicken breasts. Int. J. Radiat. Biol. 55:689-703.

Hanis, T., P. Jelen, P. Klir, J. Mnukova, B. Perez, and M. Pesek. 1989. Poultry meat irradiation--effect of temperature on chemical changes and inactivation of microorganisms. J. Food Prot. 52:26-29.

Klinger, I., V. Fuchs, D. Basker, B. J. Juven, M. Lapidot, and E. Eisenberg. 1986. Irradiation of broiler meat. Isr. J. Vet. Med. 42:181-192.

Koch, H. W. and E. H. Eisenhower. 1967. Radioactivity criteria for radiation processing of foods. In Radiation Processing of Foods, Advances in Chemistry Series No. 65, pp. 87-108, American Chemical Society, Washington, D.C.

Ley, F. J., T. S. Kennedy, K. Kayashima, D. Roberts, and B. C. Hobbs. 1970. The use of gamma radiation for the elimination of *Salmonella* from frozen meat. J. Hyg. Camb. 68:293-311.

Licciardello, J. J., J. T. R. Nickerson, and S. A. Goldblith. 1970. Inactivation of *Salmonella* in poultry with gamma radiation. Poultry Sci. 49:663-675.

Matic, S., V. Mihokovic, B. Katusin-Razem, and D. Razem. 1990. The eradication of *Salmonella* in egg powder by gamma irradiation. J. Food Prot. 53:111-114.

Mulder, R. W. A. W. 1976. Radiation inactivation of *Salmonella panama* and *Escherichia coli* K 12 present on deep-frozen broiler carcasses. Eur. J. Appl. Microbiol. 3:63-69.

Mulder, R. W. A. W. 1982. *Salmonella* radicidation of poultry carcasses. Report 363. Spelderholt Institute for Poultry Research, Beekbergen, The Netherlands. 158 p.

Mulder, R. W. A. W., S. Notermans, and E. H. Kampelmacher. 1977. Inactivation of salmonellae on chilled and deep frozen broiler carcasses by irradiation. J. Appl. Bacteriol. 42:179-185.

Previte, J. J., Y. Chang, and H. M. El-Bisi. 1970. Effects of radiation pasteurization on *Salmonella*. I. Parameters affecting survival and recovery from chicken. Can. J. Microbiol. 16:465-471.

Proctor, B. E., R. P. Joslin, J. T. R. Nickerson, and E. E. Lockhart. 1953. Elimination of salmonella in whole egg powder by cathode ray irradiation of egg magma prior to drying. Food Technol. 7:291-296.

Schaffner, D. F., M. K. Hamdy, R. T. Toledo, and M. L. Tift. 1989. *Salmonella* inactivation in liquid whole egg by thermoradiation. J. Food Sci. 54:902-905.

Thayer, D. W. 1988. Chemical changes in food packaging resulting from ionizing irradiation. pp. 181-194. In Hotchkiss, J. H. (ed.), ACS Symposium Series. No. 365 Food and Packaging Interactions. American Chemical Society, Washington, D.C.

Thayer, D. W. and G. Boyd. 1991a. Effect of ionizing radiation, dose, temperature and atmosphere on the survival of *S. typhimurium* sterile, mechanically deboned chicken meat. Poultry Sci. (In Press)

Thayer, D. W. and G. Boyd. 1991b. Survival of *Salmonella typhimurium* ATCC 14028 on the surface of chicken legs or in mechanically deboned chicken meat when gamma irradiated in air or vacuum at temperatures of -20 to +20 C. Poultry Sci. (In Press)

Thayer, D. W., G. Boyd, W. S. Muller, C. A. Lipson, W. C. Hayne, and S. Baer. 1990. Radiation resistance of *Salmonella*. J. Indus. Microbiol. 5:373-380.

Thayer, D. W., J. P. Christopher, L. A. Campbell, D. C. Ronning, R. R. Dahlgren, G. M. Thomson, and E. Wierbicki. 1987. Toxicology studies of irradiation-sterilized chicken. J. Food Protection. 50:278-288.

Urbain, W. M. 1986. Food irradiation. Academic Press, Inc. New York.