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The Safety and Wholesomeness of Irradiated Foods

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Numerous studies support the safety and efficacy of treating selected foods with ionizing radiation to control insects or foodborne pathogens and to accomplish other beneficial results. The outcome of this food processing technique can be affected by various parameters such as radiation dose ; dose rate ; temperature and atmosphere during irradiation ; and duration, temperature and atmosphere during storage. As with any other food processing technique, proper conditions must be used. However, the results of many years of study have demonstrated the wholesomeness of irradiated foods. I will have time to cite only a few examples of such studies.

During the course of this lecture I will stress a few important points. The first of these is that the process of irradiation is incapable of imparting radioactivity to foods, and irradiated foods are not radioactive. Food cannot become radioactive from exposure to gamma rays from cobalt-60 or cesium-37, from x-rays of 5 MeV or lower energy, of from accelerated electrons with energy levels below 10 MeV-(becker, 1983).

The emphasis of this presentation will on animal tissue represented by red meat and poultry meat. One reason is that this is the area of out research and of our principal interests. Another reason is that irradiation of fresh and frozen poultry meat to control foodborne pathogens was recently approved by the Food Safety and Inspection Service of the U.S. Department of Agriculture. The approval encompasses a maximum radiation dose of 3.0 kGy and a minimum dose of 1.5 kGy. The data reported here support the safety of that process.

Meat is irradiated for one of four purposes : 1) control of foodborne pathogens, 2) shelf-life extension of fresh and frozen meats, 3) production of sterile meats for immuno-compromised patients, and 4) production of shelf-stable meats suitable for storage at room temperature for relatively long periods of time. Each of these purposes imposes a number of conditions for the preparation and use of the product. For example, only shelf-stable products do not require refrigeration.

However, it is important to note another important principle, namely that irradiation of foods cannot substitute for proper sanitation, packaging, refrigeration, cooking and prompt and sanitary serving.

If irradiation is to be used as a food processing procedure, it is clear that it will have to compete in the market place with other food processing methods both technically and economically. Therefore, for this technology to be appropriate, it must control the

traget spoilage and pathogenic organisms, and it must not adversely affect the wholesomeness of the food product. Any effects on the nutritional value and the organoleptic properties of the treated food must be within acceptable limits. The market place will define what sensory changes are acceptable, but nutritional changes must be defined by chemical and biological analyses of the treated product, as it will be consumed.

Irradiation of red meat and poultry can provide products to the consumer in which the risk of encountering a foodborne pathogen is greatly reduced or completely eliminated. The effects of radiation on microorganisms, nutrients and sensory properties depend on absorbed radiationdose, Irradiation temperature, irradiation atmosphere, dose rate, storage time and temperature before consumption, and method of cooking.

The public health reason for the irradiation of poultry is to provide the public with products having significantly reduced probability of being contaminated with foodborne pathogens such as Salmonella. The potential for increased food safety with the use of this technology is illustrated by a study conducted by Thayer et al.(1991) with Salmonella typhimurium on mechanically deboned chicken meat. In the figure, the area in blue at the top of threedimensional graph should be noted. Going from right to left on the bottom scale, it is noted that, at the maximum radiation dose of 1.8 kGy, 4 logs, or 99.99%, of the Salmonella typhimurium were killed at a temperature of +20℃ and 3 logs, or 99.9% at −20℃. with regard to this, two points need to be kept in mind. First, that the USDA, Food safety & Inspection Service has recommended a minimum dose of 1.5 kGy and a maximum dose of 3.0 kGy. Second, that there is a small, but significant, effect of irradiation temperature on the survival of the pathogen. Since raw chicken is rarely consumed in the U.S., it is fair to inquire about the fate of the 0.1% of the bacteria that might survive a radiation dose of 1.8 kGy delivered at −20℃. If it is assumed that the product has been properly refrigerated before cooking, then something rather extraordinary happens when the product is cooked. When unirradiated chicken meat is cooked briefly at 60℃, a cooking temperature which is considerably less than normal, there is a 99.9%(3 log) destruction of bacteria due to heating. But when those salmonella have been irradiated to a dose of 1.8 kGy prior to exposure to heat, an additional 6 logs of the pathogens are killed on heating to 60℃, a probability of survival of 1 in 1 trillion. This greatly increased sensitivity to heat does not occur if heating takes place before irradiation. Thus, a very great amount of safety can be achieved by even relatively low doses of ionizing radiation.

The following discussion concerns three toxicological studies of radiation-pasteurized chicken and one of radiation-sterilized chicken meat.

Eekelen et al. in 1971 reported the results of a multi-generational study of albino rats that had consumed radiation-pasteurized chicken as 35% of total dry matter in their diet. The diets included a non-irradiated control, a diet with chicken irradiated to 3 kGy, and a diet with chicken irradiated to 6 kGy the diets were feed to 10 male and 20 female rats in the F_0, F_1, and F_2 generations. Two litters were reared in each of the three generations. A complete sub-chronic 90-day feeding study was conducted with the second litter of the third generation. The overall result of this study was that no deleterious effects were found in rats that were fed the irradiated chicken.

Eekelen et al. in 1972 reported the results of a chronic two-year feeding study of albino rats fed a

stock rat feed, non-irradiated chicken, or gamma-irradiated chicken. The experimental diets contained chicken at 35% of total dry matter, irradiated to either 3.0 kGy or 6.0 kGy. Each of the diets was fed to 60 male and 60 female rats. The general appearance and behavior, mortality, growth, food intake, and hematological factors and clinical constituents of the blood and urine were determined. The animals were sacrificed at 2 years and examined for any pathological effects. No treatment-related effects were found.

Til et al. in 1971 reported the results of a one-year study of beagle dogs fed non-irradiated chicken or chicken that had been irradiated to an absorbed dose of either 3.0 or 6.0 KGy. Each test group consisted of four male and four female dogs which were fed the test diet at a level of 35% dry matter. No treatment-related deleterious effects were noted in appearance, behavior, growth, hematology, urology, and gross or microscopic pathology upon autopsy of the dogs at 52 weeks.

Thayer et al. in 1987 reported the results of nutritional, genetic, teratogenic and multigeneration feeding studies of frozen enzyme inactivated chicken meat, thermally sterilized chicken meat, gamma-sterilized, enzyme-inactivated chicken meat, and electron-sterilized, enzyme-inactivated chicken meat. These studies were initiated by the U.S. Army in 1976 and were completed under the supervision of the U.S. Department of Agriculture in 1984. One-hundred-thirty-five-thousand-four-hundred and five kilograms of chicken was required for the preparation of the four diets used in these studies. The deboned irradiated chicken received a radiation dose of 45 to 68 kGy administered in vacuo at an initial temperature of −40℃ and an average temperature of −25℃. This irradiation dose was obviously far in excess of the 3.0 kGy maximum currently approved in the U.S. for the treatment of poultry. Test animals were fed chicken at a level of 35% dry matter, except that teratology studies inclused groups that were fed chicken at a level of 70% dry matter.

Teratology studies were conducted with mice, hamsters, rats and rabbits. Four genetic toxicology studies were conducted : a test for mutagenic activity using the salmonella / mammalian microsome mutagenicity assay, a test for sex-linked recessive lethal mutations in Drosophila melanogaster, a test for heritable translocations in CD-1 mice, and a dominant lethal essay with pregnant mice. In the last test the positive control failed to induce a response and, thus, could not be evaluated. No evidence of genetic toxicity or of teratogenic effects was observed.

Two significant chronic feeding studies were completed during the study : a 40-month chronic feeding and breeding performance study with beagle dogs and a 2-year chronic toxicity, oncogenicity and multigeneration reproductive study with CD-1 mice.

Beagle dogs were fed the test of control diets beginning in utero until death or secrifice at 36 months postweaning of females and 40 months postweaning of males. The 20 female F_0 dogs were bred on successive estrus periods with 10 males to produce the maximum number of litters before the end of the study. The F_1 weanlings were maintained on the diets for six months. Observations were made during the study of general appearance and behavior, mortality, growth, food intake, and hematological and urological factors in each of the beagles. Very extensive gross and microscopic pathological examinations were conducted at the edath or sacrifice of each of the animals. No overt signs of toxicity due to ingestion of any of the diets were observed. Males fed the gamma-irradiated chicken had a lower body weight

than those fed the frozen control chicken. However, the latter animals were considered obese. The F_0 femles fed the gamma-irradiated meat had greater fecundicity. Neither treatment-related abnormalities nor evidence of reproductive toxicity were observed.

Albino CD-1 mice were placed on one of the four diets and maintained on that diet for 10 weeks prior to the birth of the F_0 litters. At that time 115 pairs were selected for each diet group, except for the frozen control diet for which 175 pairs were selected. In brief, the animals were exposed to the test or control diets beginning in utero and continuing until natural death or scheduled termination. The same types of analyses were performed as described earlier for the beagle study. The overall conclusion of this study was that there was no evidence of treatment-related abnormalities in the animals.

In Summary-- Although it must be remembered that the chicken in these studies was processed in vacuo at cryogenic temperatures, nevertheless, the ingestion of chicken meat sterilized with radiation doses 20 times those currently approved by the U.S. Food and Drug Administration did not cause genetic toxicity, teratogenic effects, or chronic toxicity in the animals tested.

Incidental evidence of the wholesomeness of irradiated foods is provided by the routine use of feeds by toxicology groups in order to obtain better and more reproducible results. Swallow reported in 1991 that "the process is in routine use in preference to autoclaving for pasteurization or sterilization of the whole diet of laboratory animals, where it is necessary to maintain colonies with reduced bacterial load, although irradiation of high-fat diets is not recommended owing to the development of oxidative rancidity." He further reported that forty generations of 2000 mice, at the Patterson Institute for Cancer Research in Mancherster, England, have been fed diets irradiated to 50 kGy without evidence of genetic, teratogenic or any other abnormalities.

Chi *et al.* reported in 1986 that a feeding trial with human volunteers was conducted in China in which 21 male and 22 female volunteers consumed approximately 62-71% of their total caloric intake as irradiated food for a period of 15 weeks. The diet included rice irradiated to 0.37 kGy and stored for three months; rice irradiated to 0.4 kGy and stored for 2 weeks before consumption; meat products, such as pork sausage, irradiated to 8 kGy and stored at room temperature for 2 weeks before consumption; and 14 different vegetables irradiated to 3 kGy and stored at room temperature for 3 days before consumption. A double blind design was used for the study that included meaurements of total caloric intake, monthly biochemical and physical examinations and sensory evaluations of the food. The diet was well received, and there were no adverse findings associated with the consumption of the irradiated foods.

In the U.S., a frequently voiced concern is the potential effect of food irradiation on critical nutrients in food. Fox et al. reported in 1989 the effects of gamma-radiation at doses up to 6.65 kGy on the content of thiamin, niacin, and riboflavin of chicken breasts and on the content of thiamin, niacin, pyridoxine and cobalamin of pork chops. Thiamin was the only vitamin for which significant losses were observed within this dose range. Further, the rate of loss of thiamin in chicken was approximately one-half that in pork. They concluded that the vitamin losses from chicken at doses up to 3 kGy and from pork up to 1 kGy were not of nutritional significance.

The large scale toxicology study of radiation-ster-

ilized chicken, described earlier, provided a unique opportunity to compare the effects of four different processing techniques on nutrients in chicken meat.

The 135, 405 kg of deboned chicken was enzyme-inactivated by heating it to an internal temperature of 73-80℃ and frozen, thermally sterilized, electron-sterilized or gamma-sterilized.

The frozen control and the three treatment samples were analyzed for 19 amino acids and the results compared by statistical methods. At the $P=0.05$ level there were no significant differences between the four samples in the percentages of the individual amino acids.

Analytical values for fatty acids, crude fat, peroxide value and thiobarbituric acid(TBA) value for each of the processed chicken meats used in the study were determined. No significant differences were detected in the means for the percentages of the individual fatty acids, free fatty acids, crude fat and peroxide values in the treated meats form those of the control meat. The TBA values of the treated meats were significantly lower than that of the control meat. Because of the relatively high polyunsaturated acid content of the chicken meat(~21%), higher peroxide and TBA values and lower linoleic and linolenic acid contents would have been expected in the irradiated meats, had the processing been performed at atmospheric pressure and at ambient temperature.

The four chicken meat samples were analyzed for riboflavin, pyridoxine, niacin, pantothenic acid, biotin, folic acid, choline, vitamin A, vitamin D, thiamin, vitamin K, and vitamin B_{12}. The content of thiamin in the thermally processed chicken was 1.53 ppm and was 1.57 ppm in the gamma-processed chicken. These values were significantly lower than those found in the frozen control and the electron-sterilized chicken, which were 2.31 and 1.98 ppm, respectively. The loss of thiamin from radiation-sterilized chicken processed in vacuo and at cryogenic temperatures, was not greater than that from chicken irradiated to 6.6 kGy at 0℃.

Some concerns have been raised about irradiated products other than meats. A persistent concern is the potential loss of vitamin C from fruits of vegetables irradiated to control insects. This issue is complicated because fruits and vegetables are living tissue.

Ascorbic acid is sensitive to oxidative processes that are prevalent during cooking or irradiation in the presence of air. Even at doses below 1 kGy, such as is approved in some countries for the control of insects, some ascorbic acid is converted to its oxidized dehydro form(Roamni *et al.*, 1963). Dehydroascorbic acid, however, is fully as active as a vitamin as the reduced form. Unfortunately, many investigators did not use assay methods capable of detection the oxidized from of the vitamin and, therefore, reported erroneously high losses. During storage of irradiated potatoes, much of the dehydroascorbic acid is converted back to the reduced form. However, some losses appear to be irriversible in selected products, especially at radiation doses greater than 1 kGy (Thayer *et al.*, 1991). These losses do not appear to be significant at doses of less than 1 kGy intended for the control of insects in fruits.

Concern has been expressed that ionizing radiation creates free radicals, and that they may be present in the food at the time of ingestion. By their very nature, free radicals are extremely reactive, and hence short-lived, in most products at temperatures above 0℃. Taub et al. in 1978 reproted that even at −10℃ the lifetime of free radicals in meat is less than eight hours. Free radicals do not appear to present a threat

even in very dry products in which they are expected to have longer half-lives. Renner and Reichelt in 1973 reported the results of a three year study of rats fed milk powder irradiated to 45 kGy. No treatment-related effects were found.

It was feared that ionizing radiation might produce peroxides and hydroperoxides in high fat foods. It is well known, of course, that prolonged storage of such foods in contact with air and at room temperature gives rise to elevated peroxide and TBA values and leads to unacceptable sensory values, i.e. rancidity. High peroxide values were reported in irradiated herring by Gower and Wills in 1986. However, irradiated fatty fish have been fed to test animals without evidence of toxicological effects(Nadkarni, 1980). The total fat content of the radiation-sterilized chicken used in the studies described previously was 12-13%, and the products were stored at room temperature, but in vauo, following sterilization. The peroxide values of these irradiated meats were not elevated compared to non-irradiated , and there was no evidence of toxic effects from its long-term ingestion(Thayer et al., 1987 ; Thayer 1990).

Bhaskaram and Sadasivan at the National Institute of Nutrition, India in 1975 reported that children suffering from kwashiorkor developed an incidence rate of polyploidy of 0.8% after two weeks and 1.8% after four weeks ingestion of irradiated wheat. Vijayalaxmi, at the same institute, in 1975 and 1976 found an increased incidence of polyploid cells in mice and rats that had been fed irradiated wheat. These reports caused considerable concern in the scientific community. However, upon examination they were found to contain mutually contradictory data and to be at variance with well established knowledge of biology according to Kesavan and Sukhatame in 1976 and the U.S. Food and Drug Administration in 1986. An example of contradictory data was the report of 0% polyploidy in controls and test group children after removal of the treated diet by Bhaskaram and Sadasivan(1975), even though polyploidy is not unusual in human populations.

George et al. in 1976 found no evidence for increased numbers of polyploid cells in the bone marrow of rats that were fed for one to six weeks, within 24 hours of treatment, wheat that had been irradiated to a dose of 0.75 kGy.

Tesh et al. in 1977 reported the results of duplicate studies of rats fed a diet incorporating irradiated wheat. The diets contained 70% by weight of wheat flour that was irradiated to 0.75 kGy prior to milling. The diets were consummed by the rats within 2, 4, or 8 weeks from the date of irradiation. There was 5 males and 5 females in each diet group in each study. The number of polyploid configurations per 500 metaphases was counted for each animal. The authors concluded that there were no treatment-related effects on the number of polyploids per 500 metaphases, food consumption, body weight change, or incidence of mortality.

Chi et al. in 1986 specifically looked for any evidence of polyploid cells in human volunteers ingesting irradiated diets, They fond no such evidence ; however, the study design may have been inadequate for detection of abnormalities below the 1 percent level, because only 50 metaphase lymphocytes were examined for each subject.

Renner (1977) examined metaphase preparations of chromosomes from bone marrow cells of Chinese hamsters for evidence of mutagenic effects following the ingestion of a diet sterilized to 45 kGy. In the initial investigations 100 metaphases were counted

per animal. The incidence of chromosomal aberrations did not increase. An increased rate of polyploidy was observed in animals fed feed irradiated to a dose of 20 kGy or greater immediately following irradiation. No such effect was found at doses of 10 kGy or less, and when the feed was stored for 6 weeks. The ingestion of small amounts of 0.3% hydrogen peroxide with the unirradiated diet also produced an increased incidence of polyploidy. Because some of the polyploidy returned to the control level within a maximum of three weeks and because the effect was not dose-related, the author concluded that the result was not a mutagenic effect.

It may be helpful at this point to look briefly at the regulatory climate affecting food irradiation. There is not time for a detailed review, especially since well over 30 countries have now approved the irradiation of one or more foods with ionizing radiation. In the U.S., the regulations currently in effect regarding the irradiation of food are shown. The Food Safety and Inspection Service of the U.S. Department of Agriculture has specific jurisdiction over meat and poultry. No official or unofficial estimates of the amounts of meat and poultry irradiated are available at this time.

From the above-quoted evidence and from a wealth of further studies described in the sources quoted it can be stated that neither short nor multigeneration studies have produced evidence of toxicological or other adverse effects in mammals due to the ingestion of properly processed, irradiated foods. Hence it can be concluded that such foods are safe and wholesome.