RADIATION PRESERVATION OF MEATS AND SEAFOODS[1]

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Preservation of foods by gamma irradiation has been the subject of intensive research in the United States during the past 12 to 15 years. Early pioneering work was accomplished by investigators at the Massachusetts Institute of Technology, Electronized Chemicals Corporation and the General Electric Company. This early research definitely pointed the way toward application of ionizing radiation in preserving foods. Many types of foods were irradiated with varying success. Problems associated with a loss or change in color, flavor, texture, aroma and consistency became evident. Nevertheless, those problems appeared to be amenable to solution.

In 1953 and 1954 the U. S. Army, through the Quartermaster Food and Container Institute (QMFCI), initiated and has continued to support research on problems associated with this new means of food preservation. The Army was interested in this method of food preservation as one capable of improving the dietary regimen of personnel in the forward, intermediate and rear echelon areas as well as for logistic reasons.

Simultaneously with the program sponsored by the QMFCI, the Office of the Surgeon General supported research on the wholesomeness of foods processed by this means of preservation.

Consequently, a very tightly knit research group was assembled. It is true that while almost 90% of the research was carried on in college or university laboratories, the exceedingly good liaison between individual contractors and the QMFCI made it possible to obtain up-to-date progress reports from individual laboratories. It was thus possible to keep abreast of current findings and alter the research as new information became available.

Early in 1963, the Radiation Laboratory at Natick, Massachusetts was dedicated. Prior contractural research, having revealed the necessary protocol to follow in preserving food by this method, formed the basic design and modus operandi of the Laboratory. It is not to be implied that all problems attending this preserving method are solved. There is much to be revealed regarding the chemistry of flavor compounds produced in products as a result of the application of ionizing radiations. Elucidation of these reactions under carefully controlled conditions will do much to bring the process to fulfillment.

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The Department of Food Science and Technology at Oregon State University has been engaged in research on preserving foods by means of ionizing radiations since 1954 the findings of which are reviewed in this paper. This laboratory was among the first to do large scale panel preference testing. Early in the history of ionizing radiations, spurred on by the pioneering work of Proctor and Goldblith (1951), the accepted dose for sterilization of meat and meat products was established at 2 and 3 megarad (Mrad). Products so treated and immediately subjected to microbiological analysis were shown to be sterile. In our laboratory it was found that meat so treated was indeed sterile if plates were poured with nutrient agar. It was noticed in 1955 that if irradiated samples were stored in cans at temperatures of 70°F, the cans soon developed into hard swells. Upon plating on tryptone-glucose-yeast extract agar, a radiation resistant organism was discovered, (Anderson et al., 1956). This organism later named Micrococcus radiodurans has excited scientific inquiry in laboratories throughout the world. The possibilities for determining the mechanisms of resistance of the organism open exciting vistas with respect to radiation protection in humans. This is just one example of the by-products of research dealing with preservation of foods by ionizing radiations.

Microbiologists, food scientists, and others have leaned heavily upon the microbiological standards applicable in the canning industry. With the application of similar probability curves to the destruction of the highly toxic organism, Clostridium botulinum, by radiation, the irradiation dose required for sterilization of foods, specifically meats, was raised from 2-3 to 4.5 Mrad (Morgan, 1958). Concurrently with the increased dosage, flavor, color and textural changes in the products so treated have been magnified (Schultz et al., 1956b).

RADIATION-PASTEURIZATION

Low dose radiation (1 Mrad or less) or radiation-pasteurization which kills or inhibits spoilage and other undesirable bacteria and eliminates about 98% of all microorganisms present (Morgan, 1958), appears to be readily applicable to the pasteurization of certain fishery products and fresh meats. Radiation-pasteurization can extend the refrigerated shelf life of many seafoods three- to five-fold. Fishery products such as cod, halibut, flounder, crab, shrimp and oysters, are particularly amenable to radiation-pasteurization (Schultz et al., 1962b).

Since all products do not react to ionizing irradiation in precisely the same manner, the radiation flavor threshold must be established for each product to be radio-pasteurized. The threshold dosage is the highest radiation level that can be employed without resulting in detectable flavor changes. Flavor changes are difficult to detect in radiated-pasteurization products screened by the flavor threshold method. Although radio-pasteurization can be used quite effectively to extend storage life, it does not imply that such products can be stored without caution. Radiated-pasteurized seafoods must be held at temperatures of 38°F or below because Cl. botulinum Type E can sporulate, produce toxin at temperatures around 42°F and exhibit its lethal effects (Schmidt et al., 1962).

The rate of proteolysis of radiated-pasteurized raw beef loin muscle stored at 34°F was recently studied by Mohasseb (1962). After 88 days of storage, she found that the electrophoretic pattern and the throsine-tryptophan indices of the glycine soluble nitrogenous material of the pasteurized beef closely approximated those of the control stored for 18 days. Moreover, further comparison indicated that radiated-pasteurization caused a three-fold delay in the breakdown of proteins to peptides followed by a ten-fold delay in the splitting of the peptides into amino acids. Since enzymes are more resistant to radiation than are microorganisms, autolysis eventually becomes a problem after the microorganisms have been inhibited or destroyed by radiation. The same situation also occurs with fresh radiated-pasteurized fishery products (Scholz et al., 1962).

The addition of aureomycin at levels ranging from 1 to 5 ppm to lean ground beef subsequently radiated at 0.1 Mrad resulted in considerable extension of the shelf life of the beef at 40°F (Cain et al., 1958a). Injecting pigs with 3-6 mg of oxytetracycline per pound live weight prior to slaughter followed by radio-pasteurization of the subsequent meat increased the storage life at 50°F three-fold over that of the non-treated control samples. Dipping pork cuts into an aqueous solution containing 100 ppm of oxytetracycline and then pasteurizing at levels of 0.1 and 0.3 Mrad significantly reduced the bacterial population. The complementary effect of oxytetracycline plus radiation was found to be more pronounced at the 0.1 Mrad level than at a dosage of 0.3 Mrad. Furthermore, there was a synergistic effect in coupling oxytetracycline with radiation since a combination of the two provided significantly greater protection against bacteria than either treatment alone (Cain et el., 1958a). Raw shrimp radio-pasteurized with 5 ppm of added chlortetracycline remained in good condition throughout a ten-week storage period at 38°F as contrasted to only five weeks for the radiated-pasteurized samples (Awad et al., 1963). Combining these two techniques and applying them to fresh meats and sea foods significantly extends storage life while offering the advantage of reducing the radiation-pasteurization dosage required for the same degree of preservation obtained by radiation alone.

Other work in our department has indicated that vitamin K_5 exerts a radiation sensitizing action upon certain microbes whereby lower levels of radiation apparently can be used to pasteurize meat products (Yang, unpublished data). Although we have not investigated the effects of radiation on trichina, it has been reported that a low radiation dosage ranging from 20,000 to 50,000 rads will inactivate this organism or sterilize the female which offers another advantageous application of low dose radiation (U. S. Army Quartermaster Corps, 1961).

RADIATION-STERILIZATION

In high dose irradiation, a dosage range of 2 to 4.5 Mrad is used for the sterilization of various food products. The actual level, however, is dependent upon the particular product to be treated (U. S. Army Quartermaster Corps, 1961). A radiation level of 4.5 Mrad is required for the sterilization of meats and seafoods (Morgan, 1958). Since an increase in radiation dosage results in decreasing acceptability of meat and fishery products, marked changes in the sensory attributes are readily noted when certain meats are irradiated at the sterilization level (Schultz et al., 1956b). More specifically, radio-sterilization affects the flavor of beef more adversely than pork. However, the change in the flavor of beef can be partially masked by the addition of various condiments to a gravy to be served with the beef (Schultz et al., 1960). Storage stability tests on both sterilized beef and pork have indicated that the radiation induced flavor tends to diminish with storage time (Cain et al., 1958a). A similar observation was reported by Scholz et al., (1962) in regard to the radiation flavor of crabmeat and shrimp.

Although radiation-sterilization was originally planned for the preservation of fresh beef, this proved to be impractical since the inherent proteolytic enzymes were found to be very resistant to radiation. On long-term storage of radio-sterilized fresh meats at 70°F, tyrosine crystals and some exudation of fluids were evident in about 9 months (Cain et al., 1958a). The meat takes on a bitter flavor thought to be due to the free tyrosine. The enzymatic reactions occur in all meats that have not been heated. It has been reported that a much greater irradiation dosage (5 to 10 fold) is required to inactivate the enzymes or to reduce their activity to an acceptable level than is necessary to inactivate the spore-forming bacteria (Proctor and Goldblith, 1951). Although the proteolysis of sterilized beef can be greatly retarded by storage at 34°F (Mohasseb, 1962), the method of using ionizing radiations for the sterilization of meats is now directed solely to the radiation of precooked or enzyme-inactivated meats.

Irradiated bacon is one product that has been judged acceptable by flavor panels. Early in 1956, we radiated mild cured bacon at a level of 3 Mrad. After 9 months storage at 70°F the fried bacon was judged at the same or slightly higher level of preference as the frozen control (Schultz et al., 1956a).

Preheating beef to an internal temperature of 160°F prior to radio-sterilization inhibits or inactivates the proteolytic enzymes and eliminates or significantly retards the degradation of the meat proteins (Bautista et al., 1961; Cain et al., 1958b; Thompson et al., 1961). Later work along these lines indicated that the adverse changes occurring during storage in the sensory attributes of beef and pork could largely be prevented by heating the meat to an internal temperature of 170°F prior to irradiation (Artar et al., 1961; Korten et al., 1962). The application of intermittent irradiation may also be of value for sterilizing beef. When lean ground beef was exposed to radiations for eight periods of approximately 12 minutes each to give a total dosage of 2.0 Mrad, significantly less radiation flavor developed as well as resulting in a marked decrease in survivors of radiation resistant M. radiodurans when compared with beef subjected to the same amount of radiation but upon shorter exposure (Cain et al., 1956).

Although a combination of antibiotics and radio-pasteurization was previously mentioned to be an effective means to preserve meat, such is not the case with radiation-sterilization. At a sterilization dosage of 4.65 Mrad, the tetracycline antibiotics were completely or almost completely destroyed when added at a level of 5 ppm to the meat (Cain et al., 1958a).

Enzyme-inactivated irradiated (4.5 Mrad) cod fish cakes have been scored by taste panels as "being better" than the frozen controls (nonradiated) even after 6 months storage at 70°F (Schultz et al., 1962b). Clams, oysters and scallops also appear to have promise as radiated-sterilized fishery products retaining little radiated odor and flavor (Schultz et al., 1962a).

While the problem of enzymatic degradation has been largely overcome by the use of heat treatments prior to irradiation, a side problem arose which is of considerable concern. This alludes to the problem of texture in precooked irradiated-sterilized meats. Such meat has a poor texture. Generally, the texture is termed liver-like. The meat loses its resiliency and rather than being chewable must be classed as mushy.

The influence of irradiation-sterilization on some of the muscle characteristics involved in meat texture has been the subject of considerable research in our laboratories during the past few years. El-Badawi (1963) found that beef soaked in an equal weight of distilled water for 72 hours at 38°F prior to heat inactivation of the enzymes and irradiation was much firmer in texture than comparable samples that were not soaked. Beef heated to an internal temperature of 160°F prior to radiation also resulted in meat having a firm texture. However, irradiation tends to reverse the effects of soaking or heating or a combination of the two treatments. When soaking, heating and irradiation were combined in one treatment, these factors exerted their effects individually and by different mechanisms.

Soaking the meat in water appears to cause a partial denaturation and a net loss of anions of some of the muscle proteins resulting in a shift in the isoelectric region of such meat to a higher pH. Thus, when the soaked meat is cooked, it is heated at a pH closer to its isoelectric point than the control meat. Such a situation promotes the coagulation or precipitation of the proteins which results in an increasing loss of moisture as heating proceeds. This loss of moisture alters the meat properties to exert a toughening effect on the meat (El-Badawi, 1963).

Heating the meat to an internal temperature of 160°F results in partial denaturation of the proteins followed by the formation of new, but more stable cross linkages between the polypeptide chains. In addition, heating releases large amounts of calcium, magnesium, potassium, and possibly some anions, which may result in a partial "salting-out" effect to contribute to the heat coagulation of the proteins. A combination of these effects is largely responsible for the heated meat's having a tighter or more "closed structure" and, thus, firmer texture than the non-heated meat (El-Badawi, 1963).

Irradiation exhibits a fragmentation effect upon beef muscle proteins. Hydrogen bonding electrostatic forces appear to hold these fragments together. The fragmentary alterations of the proteins, the incorporation of water within the fragments plus a slight liberation of the bound electrolytes to give a possible slight "salting-in" effect of the proteins, appear to be the major factors accounting for the irradiation effects on meat texture (El-Badawi, 1963).

The clearance in February, 1963 by the Food and Drug Administration of irradiated-sterilized (4.5 Mrad) bacon for public consumption is indeed a milestone. This is the first food product in the world to be cleared for sterilization by gamma irradiation. Others will follow. There are, in fact, petitions before the Food and Drug Administration relative to the use of ionizing radiations to kill larvae and insects in wheat and wheat products. The use of low dose radiation to inhibit the sprouting of potatoes has been cleared for several years by both Canadian and Russian officials (Armed Forces Food and Container Institute, 1963).

Although a considerable amount of progress has been made in the application of ionizing irradiation for the preservation of meat and seafoods, much work still needs to be completed especially at the sterilization level. Since irradiation-sterilization may induce gross flavor changes, non-enzymatic browning, oxidation, and free radical formation, additional studies must be undertaken to clarify the problems of radiated flavor and odor, the use of antioxidants, browning inhibitors, free radical acceptors, and oxygen scavengers in order to improve the quality of radiated-sterilized products.

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