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TECHNOLOGICAL AND IRRADIATION CONDITIONS FOR RADAPPERTIZATION OF CHICKEN PRODUCTS USED IN THE UNITED STATES ARMY RALTECH TOXICOLOGY STUDY

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Abstract

TECHNOLOGICAL AND IRRADIATION CONDITIONS FOR RADAPPERTIZATION OF CHICKEN PRODUCTS USED IN THE UNITED STATES ARMY RALTECH TOXICOLOGY STUDY.

The paper describes the processing and irradiation conditions for the preparation of approximately 140 000 kg of meat for a multigeneration animal study of the wholesomeness of ionizing radiation sterilized chicken meat. This study was initiated by the US Army in 1976 at Raltech Scientific Services, Inc. in St. Louis, Missouri, United States of America. Four meat diets were prepared for the study as follows: (a) *Frozen control chicken*: Boneless, enzyme-inactivated (heated to an internal temperature of 73–80°C) chicken was canned and frozen. (b) *Thermally processed chicken*: Boneless, enzyme-inactivated chicken was canned and thermally treated to commercial sterility ($F_0 = 6$). (c) *Cobalt-60 irradiated chicken*: Boneless, enzyme-inactivated, canned in vacuo chicken was sterilized by gamma irradiation from cobalt-60 (45 to 68 kGy at $-25 \pm 15^\circ\text{C}$) and stored without refrigeration. (d) *Electron-irradiated chicken*: Boneless, enzyme-inactivated chicken was vacuum packed in flexible pouches and sterilized by 10 MeV electron irradiation (45 to 68 kGy at $-25 \pm 15^\circ\text{C}$) and stored without refrigeration. Representative samples of the irradiated and control chicken meat were analysed for their chemical and organoleptic qualities during a 2-year period, and for 7 years for lipid oxidation changes. Shelf stability was demonstrated by no increase in non-protein nitrogen and pH during storage. Irradiated samples had lower peroxide values and thiobarbituric acid reactive oxidation products than non-irradiated samples. The free fatty acid contents of the chicken fat of the thermal control and of the irradiated samples were directly related to the length of storage. The four chicken products received acceptable ratings for colour, odour, flavour, texture, and overall acceptance by trained panels over a 2-year period.

1. INTRODUCTION

During the period of June 1, 1976 through June 30, 1983 a large comprehensive toxicological study of chicken meat sterilized by ionizing radiation was conducted by the Raltech Scientific

Services¹ (Raltech), a division of the Ralston Purina Company, St. Louis, MO. The Raltech study was sponsored and monitored by the U.S. Army under a research contract until September 30, 1980, then completed under the monitoring and supervision of the U.S. Department of Agriculture (USDA).

Twenty separate studies were involved in the evaluation of the nutritional and toxicological properties of irradiation sterilized chicken meat and these studies required production of over 140 000 kg of precooked chicken meat. The product preparation and irradiation processing followed the official protocol prepared by the U.S. Army Medical R&D Command [1]. The protocol was reviewed and efforts coordinated with the FDA, USDA, and the National Academy of Sciences, Committee on Food Irradiation [2]. The study final reports are available from the National Technical Information Service [3].

This paper summarizes the key technological and irradiation processing parameters, including shelf-stability and chemical and sensory properties, of the four chicken meat groups used in the Raltech toxicological studies. A detailed description of the product technology, industrial processing, irradiation by ⁶⁰Co gamma rays and electrons, and post irradiation evaluations was described in a technical report by Wierbicki [4].

2. PRODUCT PROCESSING

2.1. Total quantity

Table I lists the quantity of the chicken meat of the four groups produced by Oscar Mayer & Co. in Madison, WI during 1976 through 1978. The total quantity of 135 405 kg of the enzyme-inactivated chicken meat (called "wholesomeness chicken meat") of the four groups (FC, TP, GAM, and ELE) represents about 96% of the total production; four percent of the meat was used as the samples retained by the U.S. Army Natick Research and Development Center (NLABS), rejected after post-irradiation inspection, and during packaging operation.

2.2. Processing

Fresh chicken broilers or friers, 3 to 3.5 lb carcass weight, were obtained, packed on ice, one day after slaughter, from USDA inspected poultry plants. Over 230 000 chilled, eviscerated broilers and friers were needed to produce the total quantity of the chicken meat shown in Table I.

¹Reference to brand name or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

TABLE I. PRODUCTION OF THE "WHOLESOMENESS CHICKEN MEAT" AT OSCAR MAYER AND COMPANY, INC.

Contract no. NLABS	Production no.	Production dates	Raw Meat kg	Enzyme-inactivated, kg:			
				FC (F)	TP (T)	GAM (G)	ELE ¹ (E)
DAAG17-76-C-0042	1	April-May 76	57.2	6 435	5 677	5 749	6 052
DAAK60-77-C-0024	2	Feb.-Apr. 77	57.2	10 459	9 652	10 196	9 778
DAAK60-78-C-0023	3	Feb.-Apr. 78	57.2	9 925	10 425	9 581	9 448
Modification DAAK60-78-C-0023	3A	April-May 78	57.2	12 755	6 535	6 320	6 320
TOTAL, kg			228.8	38 674	32 287	31 846	31 598
Grand total, enzyme inactivated meat:			135 405 kg				

¹ Codes used by Raltech for the experimental diets containing 35% of the meat in the total diet and are defined as follows:

FC: Frozen Control Chicken, Boneless, enzyme-inactivated (heated to an internal temperature of 73-80°C) chicken was canned and frozen.

TP: Thermally Processed Chicken, Boneless, enzyme-inactivated chicken was canned and thermally treated to commercial sterility ($F_0 = 6$).

GAM: Cobalt-60 Irradiated Chicken, Boneless enzyme-inactivated, canned in vacuo chicken was sterilized by gamma irradiation from Cobalt-60 (45 to 68 kGy at $-25^\circ \pm 15^\circ\text{C}$) and stored without refrigeration.

ELE: Electron-Irradiated Chicken, Boneless, enzyme-inactivated chicken was vacuum packed in flexible pouches and sterilized by 10 Mev electron irradiation (45 kGy to 68 kGy at $-25^\circ \pm 15^\circ\text{C}$) and stored without refrigeration.

The broiler carcasses were hand deboned into lean meat and skin with subcutaneous fat and were hung on a moving conveyor. Mechanically deboned meat from the residual carcasses was not used in the formulation of the meat product for this study. Table II gives the proximate composition of the lean meat and the chicken skin. The lean meat represented about 82% and the skin 18% of the deboned raw material.

Thus, the meat formula for the processed chicken meat consisted of 18% skin and 82% lean meat. For each 100 kg chicken meat and skin mixture were added 0.75 kg salt (sodium chloride) and 0.30 kg sodium tripolyphosphate (TPP) to reduce the loss of

TABLE II. PROXIMATE COMPOSITION OF RAW CHICKEN MEAT AND SKIN

Component	No. samples	Mean \pm SD (%)		
		H ₂ O	Protein	Fat
Lean Meat	30	72.78 \pm 1.68	20.12 \pm 2.52	7.07 \pm 2.52
Skin	20	49.59 \pm 4.76	9.29 \pm 1.80	40.47 \pm 6.54

natural juices during enzyme-inactivation [5]. Also, 3 kg of crushed ice or cold water was added to each 100 kg meat formula to facilitate dissolution and distribution of the additives within the product. The added water was removed by evaporation during the enzyme inactivation process.

The meat, skin, and additives, mixed under vacuum, in 1 600 lb batches, were tightly stuffed into cellulose casings, laid horizontally on wire screened trucks and then enzyme inactivated by heat and steam in the smokehouse chambers, without smoking. One smokehouse (cookhouse) load was about 6 000 lb of the product. Drip loss was prevented by starting the chamber temperature at 46-52°C which assured the formation of a protective protein skin on the surface of the chicken rolls. Only moisture was lost during the process. At a final chamber temperature of 90°C the internal temperature of the chicken rolls was between 73 and 80°C and the yield was 87% of the total meat formula. Fig. 1 presents typical time and temperature parameters used for the enzyme inactivation process under industrial conditions. The chicken meat for the packaging in flexible pouches (ELE) was formed prior to the enzyme-inactivation processing by stuffing it into casings placed into stainless wire cages of 9.0 X 12.5 X 91.5 cm in size. A total of 61 cookhouse loads were processed with the yield of the enzyme-inactivated product to the raw product of 86.7 \pm 0.7% [4].

2.3. Packaging

The FC, GAM, and TP products were packed in metal cans, No. 404 X 309, 10.8 cm in diameter and 9.0 cm in height. The cans were made from 80 to 90 basic weight, No. 25 tinplate, coated overall inside with an epoxy-phenolic enamel with aluminum pigment in accordance with Federal Specification PPP-C-29E, Canned Subsistence Items, Packaging and Packing [4]. The lids contained the can sealing compound designated as a blend of cured and uncured butyl rubber. Reliability of the commercially available tinplate containers were determined for the packaging of irradiation processed foods and described elsewhere [6, 7]. The cans were filled with 595 \pm 7 g enzyme-inactivated product and sealed under highest attainable vacuum before collapse of the cans, which was -635 to -686 mm Hg. The cans were filled to about 84% of the can inside volume, thus allowing accommodation of hydrogen gas produced

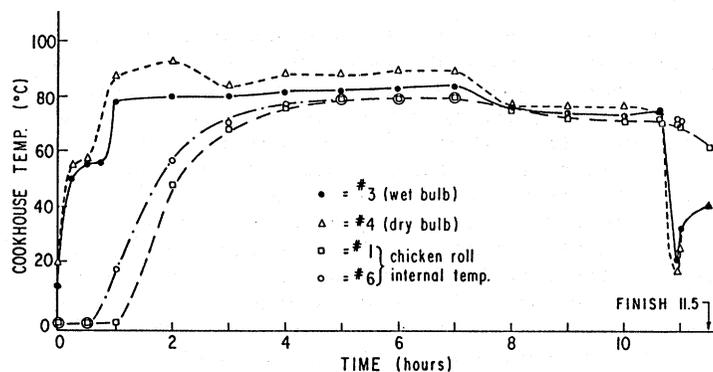


FIG.1. Enzyme inactivation process of chicken meat rolls.

in the can by irradiation as a result of radiolysis of water in the food and the food components [8, 9, 10].

After can closure, 24 cans (14.3 kg) of the FC product were packed in fiberboard shipping cases, arranged in a pattern of 4 cans in length, 3 cans in width, and 2 cans in depth with fiberboard separators between the individual cans. The packed shipping cases with the cans of the chicken meat were then stored in -23 to -40°C freezers until shipment in the frozen state to Raltech, where they were maintained in the frozen state until use as frozen control chicken meat in the toxicological studies.

For the TP chicken meat group, the product after the can closing was heat sterilized in commercial autoclaves at 115.6°C to the sterility level of $F_0 = 6$, by certified retort operators [4, 11]. Thermal sterilization of the TP chicken meat in this study was less severe than usually carried out by industry who operate their autoclaves at 121°C. The use of the retort temperature of 115.6°C [11] resulted in the end product which still could be sliced for sensory evaluation; retorting at 121°C resulted in a considerable loss in texture of the product [4]. Representative samples of the retorted product were subjected to incubation tests as required by the USDA inspection for the canned meats. The finished product was packed in shipping cases and shipped, nonrefrigerated, directly from the processing plant in Madison, WI, to Raltech, where it was stored, nonrefrigerated, until use.

The GAM chicken meat, after canning, packing, and freezing, was shipped frozen to Natick, MA where it was frozen stored before irradiation using ^{60}Co gamma facility of the U.S. Army Natick R&D Center.

The ELE chicken meat was packed in flexible packaging. The enzyme-inactivated, chilled, rectangular chicken blocks were cut into 1-in (26 mm) thick slices and vacuum packed in preformed

flexible packaging. The flexible packages were 165 mm X 208 mm in size, fabricated with 0.025 mm polyiminocaproyl (Nylon 6) as the outside layer, 0.0090 mm aluminum foil as the middle layer, and 0.051 mm polyethylene terephthalate-medium density polyethylene as the food contacting layer [4]. The reliability of this flexible packaging for irradiation sterilization of prepackaged foods, using either ^{60}Co gamma rays or electrons was demonstrated in previous experiments [12]. Medium density polyethylene, used as the food contactant in this flexible packaging does not produce extractives as the result of irradiation, over the levels designated by FDA, when in contact with nonirradiated foods [13, 14]. Single 1-in thick ELE chicken meat slices, in average 241 g product per slice, were packed into the flexible prefabricated pouches and sealed under maximum attainable vacuum of 28.5 to 29 in (-724 to -737 mm Hg). The evacuation time was preset so as to result in not more than 4 ml headspace gas in any pouch after sealing, as indicated by the method of Shappee and Werkowski [15]. The vacuum sealing of the filled pouches was accomplished at the rate of 32 pouches per min using the Swissvac, Model CVEP 100 vacuum sealing machine [4]. After vacuum packaging and sealing, the sealed pouches that passed visual inspection were held in a -2.2 to 5°C cooler overnight prior to assembly in the irradiation boxes. After being retained in the cooler overnight, each pouch was inspected for maintenance of the vacuum and tight adherence of the pouch to meat slice. The pouches that were observed with leaks in the seals or pinholes in the body of the pouch lost vacuum during this period in the cooler. The samples showing "poor vacuum" were rejected and the pouches opened, the meat repacked and resealed, and the inspection cycle repeated. Twelve filled and vacuum sealed pouches (four pouches in length, three pouches in width, and one pouch in depth) were placed into one "irradiation box" of proper dimensions [4]. Five irradiation boxes containing meat were than packed in a shipping box, the box sealed and placed into a -23 to -40°C freezer until shipment, in the frozen state, to the NLABS for electron irradiation.

In comparison with the GAM chicken meat that were vacuum packed in metal cans, the ELE chicken meat was exposed to much less residual air in the package. This was brought about as a result of the latter being sealed under higher vacuum and being kept overnight at a refrigerated temperature before freezing, thus allowing aerobic bacteria in the ELE packaged meat to consume the residual oxygen in the headspace and the air trapped by the meat.

Processing and packaging of the chicken meat in this study was carried out under continuous USDA inspection. At the time of packaging the enzyme inactivated chicken meat never exceeded the temperature of 10°C [4].

3. IRRADIATION PROCESS

3.1. The sterilizing dose used

At the time of the irradiation of the chicken product from the first procurement, May-June 1976, the 12-D irradiation sterilizing dose for chicken was still not determined. However, based on the data available for other foods the 12-D dose was estimated to be not higher than 45 kGy. Therefore, this sterilizing dose was selected as the minimum dose for processing the chicken product for this study. A 50% dose spread was added to provide a reasonable economical dose range for irradiation sterilization that might be carried out under industrial conditions. Consequently, the dose range selected for irradiation was 45 kGy minimum to 68 kGy maximum. The Microbiology Group at the U.S. Army Natick R&D Center was requested, at the same time, to determine by an inoculated pack study with Clostridium botulinum spores, the 12-D dose for this chicken product. This was accomplished, and the irradiation sterilizing dose (under the 12-D concept) for the chicken product used in this study was determined to be 42.7 kGy at the product temperature during irradiation of $-30^{\circ} \pm 10^{\circ}\text{C}$ [16]. An area of concern in irradiation sterilization processing of foods is that viruses are more radiation resistant than the most-resistant bacterial spores (e.g., C. botulinum types A and B) [17]. For example, some members of the Moraxella-Acinetobacter group of bacteria are also more radiation resistant than C. botulinum spores [18]. These bacteria and viruses are, however, far more sensitive to heat [17, 19] and were inactivated during the heat inactivation of enzymes (Fig. 1).

3.2. ^{60}Co irradiation of GAM chicken meat

The GAM chicken meat, packed in cans, was tempered in a liquid N_2 cooler ($-40^{\circ}\text{C} \pm 5^{\circ}\text{C}$) and irradiated, in the frozen state, at the U.S. Army Natick ^{60}Co Irradiation Facility which had 2.5 million curies source strength in 1976. The facility has been described by McDonald [20]. Irradiation was performed in batches of eight cases per run, with each case containing 24 cans, or a total of 114.4 kg product per run. The case carrier was mapped for the dose distribution within the batch to ensure the minimum and maximum absorbed dose spread required. For compliance the cases of the product located in the minimum dose position in the carrier were monitored during irradiation. The carrier containing 8 cases of the product was equipped with liquid N_2 line to control temperature in the carrier between -45°C and -30°C during irradiation as described by McDonald [20]. Table III gives a summary of ^{60}Co irradiation of the GAM product. As the data indicate, the minimum dose received in the "minimum dose" location in the carrier was 46 kGy. The maximum dose was 68 kGy and the average dose 56 kGy. The ferrous-cupric sulfate chemical dosimeter was used to measure the dose absorbed as described by Jarrett and Halliday [21].

TABLE III. SUMMARY OF ^{60}Co IRRADIATION OF GAM CHICKEN MEAT

Prodn. no.	Date	Dose rate Gy/min	Transient dose Gy	Run time min.	kGy ¹ Received	Run ² no.
1	May-June 1976	6.70×10^2	1.95×10^2	68.37	46.0	1 - 52
2	Apr.-May 1977	5.94×10^2	1.70×10^2	77.15	46.0	53 - 142
3	March 1978	5.26×10^2	1.50×10^2	87.17	46.0	143 - 182
3A	Apr.-May 1978	5.21×10^2	1.48×10^2	88.01	46.0	183 - 283

¹ Dose received in the "minimum dose location" in the carrier.

² Each run (batch) consisted of 8 cases of the product being irradiated, 14.3 kg product per case.

3.3. Electron irradiation of ELE chicken meat

Electron irradiation of ELE chicken meat has been performed using U.S. Army NLABS 10 MeV Electron Accelerator (LINAC), as described by Rees and Caspersen [22]. ELE chicken meat, packed in fiberboard shipping cases was stored in a liquid N_2 storage box ($-45^\circ\text{C} \pm 5^\circ\text{C}$) before irradiation. Each shipping box contained five "irradiation boxes", each containing 12 packaged 1-in slices of ELE chicken meat, with an average of 241 g product per package. Two sequentially numbered "irradiation boxes" were placed into one polystyrene foam box (to keep the samples frozen during irradiation) for electron irradiation processing, representing one irradiation run (total 5.784 kg product per run). Details on the irradiation processing were described in Wierbicki's technical report [4]. In order to obtain the dose spread from 45 to 68 kGy the machine had to be set for the average dose of 59 kGy, 3 kGy higher than the average dose used for ^{60}Co irradiation of GAM chicken meat. The chemical ferrous-cupric sulfate dosimeter was attached outside of the polystyrene foam boxes to cross-check the accuracy of the dosimetry [21]. For each irradiation run the energy of the electron beam used was automatically measured and recorded. The electron beam energy, as taken from the irradiation records [4], was 9.7 to 10.0 MeV. A total of 5 462 runs of electron irradiation of ELE chicken meat was performed, comprising 136 472 pouches of the packed product for a total net weight of 32 957 kg [4].

3.4. Product temperature control during irradiation

In the course of ^{60}Co irradiation of 31 846 kg (Table I) GAM chicken meat, 54 cans were equipped with the thermocouples and the temperature of the product before and after irradiation was recorded. The product temperature before irradiation was

-39.5° ± 3.3°C and after irradiation -15.3° ± 3.2°C. This represented a temperature rise of 4.3°C for each 10 kGy absorbed gamma ray energy. During electron irradiation, 641 samples were checked for the product temperature, which was -40° ± 2.9°C before irradiation and -9.9° ± 1.8°C after irradiation. This represented a temperature rise of 5.1°C for each 10 kGy of electron energy absorbed [4].

For the electron irradiation, the temperature rise was about 0.8°C greater than for ⁶⁰Co irradiation since no cooling could be provided during electron irradiation. For the best quality radappertized product, the product temperature after irradiation should be -20°C or lower [23]. This was not achieved during irradiation of these chicken products and was a deliberate decision made to obtain radappertized products under less than "ideal" conditions for toxicological studies.

3.5. Post-irradiation inspection

After irradiation, the GAM and ELE groups of the irradiated chicken product were moved to a noncontrolled area for defrosting at room temperature (21 to 25°C), for inspection of each can (GAM) and each pouch (ELE) for the absence of induced radioactivity [24], for packaging integrity, vacuum of the cans (undestructive), and marking of the samples (production no., samples no., dose, run no., and date of irradiation). Samples showing any sign of damage, or missing markings, particularly the qualitative "go-no-go" dosimeter (red after irradiation), were removed and destroyed. The inspected samples were repacked, palletted and shipped without refrigeration to Raltech for nonrefrigerated storage until the toxicological studies were performed.

4. PRODUCT EVALUATION

4.1. Radiolysis products

Radiolysis products in the four groups of the enzyme-inactivated chicken products used in the Raltech toxicological studies (FC, TP, GAM, and ELE), along with the frozen samples of raw chicken meat, have been reported separately in a comprehensive technical report by Merritt [25]. The radiolysis products were determined on duplicate samples for each chicken meat group initially and after storage for 12, 24, and 36 months. The raw chicken meat and the frozen control enzyme-inactivated chicken meat (FC group) were stored in -29°C freezers. The irradiation sterilized chicken meat (GAM and ELE) and the thermally sterilized chicken meat samples (TP) were stored in a 21°C room. The same storage temperatures were used for the FC, GAM, ELE, and TP chicken samples for the chemical and sensory quality evaluations at the NLABS. The subject report by Merritt [25] also contains radiolysis product information on radappertized beef, pork, ham, and bacon with

TABLE IV. CHEMICAL COMPOSITION OF ENZYME-INACTIVATED CHICKEN MEAT

Composition	No. samples	Product Group:			
		FC	TP	GAM	ELE
H ₂ O, (%)	12	65.4 ± 0.7	65.3 ± 1.0	65.1 ± 0.8	65.3 ± 0.3
Protein (%)	12	20.2 ± 0.6	19.9 ± 0.7	20.0 ± 0.4	20.4 ± 0.4
Fat (%)	12	12.4 ± 1.1	12.7 ± 1.2	13.0 ± 0.9	12.6 ± 0.3
Ash (%)	12	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.9 ± 0.0
NaCl (%)	12	0.85 ± 0.05	0.87 ± 0.05	0.85 ± 0.08	0.87 ± 0.05
P (mg/100g)	12	265 ± 9	263 ± 9	260 ± 10	266 ± 12
NPN ¹	8	0.36 ± 0.02	0.35 ± 0.03	0.38 ± 0.02	0.38 ± 0.02
pH	8	6.39 ± 0.10	6.33 ± 0.08	6.40 ± 0.08	6.39 ± 0.08

¹ NPN = Nonprotein nitrogen as % total N.

computer analysis of the commonality of the radiolysis products in the five different meats.

4.2. Chemical composition

Table IV presents the chemical composition of the four groups of the enzyme-inactivated chicken meat (FC, TP, GAM, and ELE) as determined using the AOAC standard methods for food analyses [26]. The samples analyzed were withdrawn from all three production lots of the product and subjected to the analyses initially and after 6 and 12 months of storage; detailed tabulations of the results are available [4]. The data, as summarized in Table IV, indicate a very homogeneous product from group to group submitted to Raltech for toxicological studies. There were no changes of these chemical quality indexes during the storage of the items for 2 years [4]. The nonprotein nitrogen (NPN) is an index of proteolytic enzyme activities in protein foods. The NPN content was the same in the samples stored for 2 years (0.34 ± 0.02%) [4] as before storage (Table IV). The fact that there were no changes in the NPN content with the storage time without refrigeration in the irradiated products (GAM and ELE) indicate that the preirradiation enzyme-inactivation treatment as shown in Fig. 1 was effective for the purpose.

4.3. Headspace gas composition

Irradiation produces gases in packaged irradiation sterilized foods in the headspace of the cans. The gases produced may result in bulged or swelled cans. Therefore, since users of canned food will normally interpret a swelled can as a sign of

TABLE V. HEADSPACE GAS COMPOSITION IN CANS OF ^{60}Co -
IRRADIATED, NONIRRADIATED AND THERMALLY
PROCESSED PRODUCTS

GAS ¹	GAM ³		FC ⁴		TP ³
	Initial ²	12 Months	Initial ²	12 Months	Initial ²
H ₂	24.5	25.3	0	0	0
N ₂	62.8	60.6	88.7	89.6	93.3
O ₂	1.1	0.9	1.5	1.7	1.4
CO ₂	11.6	12.9	10.0	9.3	5.4
CH ₄	0	0.4	0	0	0
Co	0	0.1	0	0	0

¹ As percent of total headspace gas.

² Samples frozen stored for 2 months before analysis.

³ Stored at 21°C.

⁴ Frozen stored at -29°C.

bacterial spoilage, the cans filled with food for irradiation should not be filled to more than 84% of the can volume. Hydrogen gas is the dominant gas produced by the radiation process [8, 9] as a result of radiolysis of water and the food components [10,27].

The headspace gases were analyzed for hydrogen (H₂), nitrogen (N₂), oxygen (O₂), carbon dioxide (CO₂), methane (CH₄), and carbon monoxide (CO) in the headspace gas removed from the packages by water displacement by the method of Pratt et al. [8, 9]. The headspace gas composition for the GAM, FC, and TP products packed in metal cans is given in Table V. As the data indicate, the frozen control (FC) and thermally processed chicken meat (TP) contain no hydrogen in the headspace. To the contrary ^{60}Co irradiated product (GAM) contained about 25% hydrogen. After 12 months storage traces of methane and carbon monoxide were also detected in the headspace gas of the GAM product. Similar headspace compositions were found for electron irradiated samples [4]. However, very little (<1-ml) headspace gas could be collected from the ELE chicken samples to allow accurate quantitative determinations. Determination of hydrogen in the headspace gas of irradiated foods packed in metal cans, may have the potential to be used to identify whether a product was irradiated or not.

TABLE VI. EFFECT OF PROCESSING AND STORAGE ON FAT OXIDATION

Fat oxidation index	FC ¹		GAM ²		ELE ²		TP ²	
	Initial ³	81 Mon.						
PV ⁴	38.1	1.6	11.3	0.6	14.1	0.9	0	1.1
TBA ⁵	4.4	1.6	0.2	0.2	2.0	0.3	0.2	0.2
FFA ⁶	0.7	0.9	0.9	4.6	0.9	5.0	1.1	3.4

¹ Stored frozen at -29°C.

² Stored at 21°C.

³ 3 month old samples (first evaluation).

⁴ PV = peroxide value as milliequivalent O₂/1000 g fat.

⁵ TBA = Thiobarbituric acid value in mg malonaldehyde/1000 g meat.

⁶ FFA = Free fatty acid as % oleic acid in the extracted fat.

4.4. Lipid oxidation indexes

Three fat oxidation indexes were determined to study the changes in lipid oxidation in the four groups of the product (FC, GAM, ELE, and TP), initially and after 6, 12, 24, 53, and 81 months of storage: (a) peroxide value (PV), which is an index for the primary lipid oxidation products, using iodometric techniques (where the PV is reported in milliequivalents of oxygen per 1 kg extracted fat) [26]; thiobarbituric acid value (TBA) which is the index of secondary oxidation products of polyunsaturated fatty acids containing two or more double bonds [28] (expressed in mg of malonaldehyde per kg sample) [29]; and free fatty acids (FFA) (expressed as percent of oleic acid in extracted fat from the food sample), using standard AOAC method [26].

Table VI summarizes the data for the PV, TBA, and FFA in the four groups of the chicken products, initially, and after 81 months of storage. This data best illustrates the effect of the further processing (⁶⁰Co and electron irradiation and thermal retorting) of the enzyme-inactivated chicken meat, when comparisons are made with the frozen control (FC). The data also shows the effect of long-term nonrefrigerated storage of the irradiated (GAM and ELE) and thermally sterilized (TP) chicken meat. In raw chicken meat before enzyme inactivation, the PV and TBA were below the 2.0 units [4]. Enzyme inactivation increased the PV and TBA, in the product as shown by the high initial data for the frozen control (FC) samples; prolonged frozen storage significantly reduced these fat oxidation indexes. Irradiation of the enzyme-inactivated chicken meat, packed *in vacuo*, greatly reduced, both PV and TBA values; storage for 81 months decreased these fat

oxidation indexes to about a zero level. Thermal retorting destroyed both the PV and TBA fat oxidation indexes. This effect of the thermal processing of canned foods is well documented [30].

Irradiation and thermal retorting slightly increased the FFA and a further, significant increase took place during prolonged nonrefrigerated storage of these chicken products (Table VI). Since the enzyme-inactivation procedure (and in case of the TP chicken meat, the further thermal processing) destroyed (inactivated) the triglyceride hydrolyzing enzymes (lipases), the increase in the FFA in the GAM, ELE, and TP products represents an autooxidation of the lipids during storage at nonrefrigeration temperatures. In fact, the increase in the FFA in the fat of GAM, ELE, and TP chicken meat is directly related to the storage time, thus allowing approximate determination of the length of time the products were stored without refrigeration within 1 year accuracy. The increase in FFA for GAM and ELE chicken products was 0.524% and for the TP product 0.404% per year of nonrefrigerated storage [4].

4.5. Sensory quality

4.5.1. Expert panel evaluation

Ten permanent and four alternate members at the NLABS, were trained as "expert" evaluators for color, odor, flavor, and texture for the four groups of chicken meat used in this study [4]. The product, sliced into 1/4-in (6 mm) slices were served to the panelists, either cold or after reheating in a covered pan held over hot water (85 to 95°C). Scores were obtained by rating the four quality attributes using the following rating scale:

<u>Rating</u>	<u>Quality</u>
9	Excellent
8	Very Good
7	Good
6	Below Good - Above Fair
5	Fair
4	Below Fair - Above Poor
3	Poor
2	Very Poor
1	Extremely Poor

TABLE VII. EFFECT OF DIFFERENT PROCESSING AND STORAGE ON COLOR, ODOR, FLAVOR, AND TEXTURE OF ENZYME-INACTIVATED CHICKEN MEAT (Served Cold, Expert Panel, n = 10)

Time of storage	Product group	Sensory Scores:			
		Color	Odor	Flavor	Texture
Initial ¹	FC	6.4 ± 0.6	6.1 ± 0.7	5.6 ± 1.3	5.5 ± 1.3
	GAM	5.9 ± 0.9	5.5 ± 1.2	4.9 ± 1.0	4.7 ± 1.4
	ELE	5.9 ± 1.1	5.7 ± 1.4	5.3 ± 1.3	5.2 ± 1.7
	TP	5.7 ± 0.9	5.7 ± 1.0	5.0 ± 1.2	4.4 ± 1.7
F:		0.67	0.46	0.63	0.95
LSD:		NSD	NSD	NSD	NSD
24 Months	FC	5.9 ± 1.9	6.2 ± 2.1	6.1 ± 1.9	6.3 ^a ± 1.3
	GAM	5.6 ± 1.6	5.2 ± 1.8	4.9 ± 1.9	5.0 ^{a,b} ± 1.6
	ELE	5.6 ± 0.8	5.3 ± 1.4	5.0 ± 1.2	5.3 ^a ± 1.4
	TP	5.3 ± 1.1	6.0 ± 1.6	4.8 ± 1.2	3.9 ^b ± 1.2
F:		0.30	0.81	1.44	5.18
		NSD	NSD	NSD	1.25

¹ First evaluation after 3 months storage.

LSD = Least significant difference.

NSD = No significant difference.

a,b = Means in the same column with different subscript letters are significantly different (P < 0.05).

Ratings of 5 and above indicated acceptable products. Ratings of 5 and 4 indicated the products were of marginal quality, whereas the rating of 3 (poor) and below indicated that the product might not be accepted by the consumers who are particularly demanding of this particular quality attribute. The four groups of the product (FC, GAM, ELE, and TP) were subjected to sensory evaluation for color, odor, flavor, and texture by the expert panels initially and after 6, 12, and 24 months of storage. The means (M) and standard deviations (SD) of the data obtained for each attribute, and for the least significant differences (LSD) between the means of the four groups of the product were evaluated using the statistical method of Duncan [31]. The results of the expert panel sensory taste testing of the four groups of chicken meat used in the Raltech toxicological studies were published in 13 tables in

TABLE VIII. EFFECT OF FURTHER PROCESSING ON COLOR, ODOR, FLAVOR AND TEXTURE OF ENZYME-INACTIVATED CHICKEN MEAT

Product group	Overall sensory scores ¹ :			
	Color	Odor	Flavor	Texture
FC ²	6.45 ^b ± 0.44	6.68 ^b ± 0.48	6.40 ^b ± 0.47	6.11 ^c ± 0.42
GAM ³	6.28 ^b ± 0.73	6.04 ^a ± 0.53	5.43 ^a ± 0.38	5.40 ^b ± 0.58
ELE ³	6.30 ^b ± 0.73	5.98 ^a ± 0.58	5.40 ^{a,b} ± 0.56	5.35 ^b ± 0.54
TP ³	5.35 ^a ± 0.89	5.73 ^a ± 0.49	5.26 ^a ± 0.48	5.35 ^a ± 0.64
M ± SD:	6.10 ± 0.72	6.11 ± 0.52	5.62 ± 0.48	5.30 ± 0.55
LSD:	0.73	0.53	0.49	0.56

¹ All data combined: 4 storage times X 2 preparations for serving (n = 80 for each product group).

² Frozen stored at -29°C.

³ Stored without refrigeration at 21°C.

a, b, c = Means in the same column with different subscript letters are significantly different (P < 0.05).

Wierbicki's technical report [4]. Representative findings are summarized in Tables VII and VIII. In Table VII, ratings are given for the chicken meat served cold (held in a refrigerator for 3 days in unopened containers before serving), initially and after 24 month storage. Similar data were obtained on the samples served reheated and on other withdrawals (after 6 and 12 month storage) [4]. As the data indicate, during the initial evaluation there were no significant differences between the four groups for all four quality attributes. However, the frozen control samples (FC), which were not further processed after enzyme-inactivation (cooking), scored slightly higher than the chicken samples of the other three groups (GAM, ELE, and TP). After 24 months storage only the samples of thermally retorted meat (TP) received significantly lower scores for texture. In Table VIII the scores received in all tests at different times on the four groups of chicken meat were pooled together to more accurately determine the overall effect of further processing on the enzyme-inactivated chicken meat, by ⁶⁰Co gamma irradiation (GAM), electron irradiation (ELE), or thermal retorting (TP), since only the processing affected the quality [4]. The data represent the pooled results of the total of 80 scores received by each product group for each attribute. The data indicate that FC samples received the highest ratings for all attributes.

TABLE IX. PREFERENCE SCORES¹ OF WHOLESOMENESS CHICKEN MEAT SERVED COLD TO A CONSUMER PANEL (n = 32 Panelists)

Product group	Initial evaluation:		Production no. 2:	
	Production no. 2	Production no. 3	6 Months	12 Months
FC ²	6.37 ^b ± 1.60	6.00 ^b ± 2.27	6.16 ^c ± 1.39	6.19 ^b ± 1.80
GAM ³	5.00 ^a ± 1.64	5.15 ^a ± 2.13	4.28 ^a ± 1.63	5.28 ^a ± 1.97
ELE ³	4.62 ^a ± 1.77	4.81 ^d ± 2.32	4.06 ^a ± 1.34	5.06 ^a ± 1.97
TP ³	5.03 ^a ± 1.80	5.94 ^b ± 2.09	5.03 ^b ± 1.71	5.25 ^a ± 1.95
LSD: ⁴	0.70	0.76	0.61	0.66

¹ 9-point hedonic scale: 9 = like extremely; 5 = neither like-nor dislike; 1 = dislike extremely.

² Frozen stored at -29°C.

³ Stored without refrigeration at 21°C.

⁴ LSD = Least significant differences: means in the same column with different subscript letters are significantly different (P < 0.05).

Further processing, either by irradiation or thermal retorting decreased the quality ratings. However, the ratings for color for the irradiated samples were not significantly different from the nonirradiated frozen control and for flavor by electron irradiation of the meat. There were no significant differences in the ratings between ⁶⁰Co and electron irradiated samples. The thermally retorted chicken meat (TP), scored significantly lower for color and texture than the irradiated and frozen control samples. However, all scores were high enough (over 5) to consider the products to be of acceptable quality.

4.5.2. Consumer panel evaluation

The "cold" and the "hot" chicken meat samples of the four groups of the product (FC, GAM, ELE, and TP) were evaluated for consumer acceptance using the 9-point hedonic scale of Peryam and Pilgrim [32]. The statistical treatment of the data used the randomized block method with 32 test subjects for means (M) and standard deviations (SD), least significant differences (LSD), and analysis of variance [31]. The test subjects were selected from a pool of about 800 volunteers who were employees at the NLABS. The subjects were not informed that two out of the four chicken samples served for each test were irradiation treated. Table IX gives the preference rating data for the four products when served cold to the panelist. Table X gives the ratings obtained when the chicken meat samples were reheated before serving.

TABLE X. PREFERENCE SCORES¹ OF WHOLESOMENESS CHICKEN MEAT SERVED REHEATED (HOT)
TO A CONSUMER PANEL (n = 32 Panelists)

Product group	Initial evaluation:		Production no. 2:	
	Production no. 2	Production no. 3	6 Months	12 Months
FC ²	6.88 ^b ± 1.45	6.69 ± 1.69	7.00 ^c ± 1.48	6.78 ^b ± 1.10
GAM ³	5.78 ^a ± 1.64	6.09 ± 1.80	6.22 ^{a,b} ± 1.70	5.37 ^a ± 1.84
ELE ³	5.91 ^a ± 1.91	5.97 ± 2.01	6.55 ^{b,c} ± 1.52	5.87 ^a ± 1.76
TP ³	6.31 ^{a,b} ± 1.60	6.25 ± 2.03	5.78 ^a ± 1.88	5.59 ^b ± 1.84
LSD ⁴ :	0.58	NSD	0.59	0.77

¹ 9-point hedonic scale: 9 = like extremely; 5 = neither like-nor dislike; 1 = dislike extremely.

² Frozen stored at -29°C.

³ Stored without refrigeration at 21°C.

⁴ LSD = Least significant differences: means in the same column with different subscript letters are significantly different (P < 0.05).

The means of the ratings of the reheated samples from production lot 3 in the initial evaluation did not reveal significant differences between the groups (Table X). In all other tests the frozen control chicken meat (FC) received significantly higher scores. Reheating slightly increased the preference scores in all instances, indicating that consumers prefer the chicken meat served after reheating. Initial evaluations were performed on the products from production No. 2 and No. 3 to confirm that the quality of the products can be reproduced from one production lot to another. The 6 and 12 month storage studies used only the chicken meat from production 2. The consumer panel rated thermally processed (TP) chicken meat either equally high or slightly higher in preference to the irradiated samples (GAM, ELE), in spite of the fact that TP samples received the highest number of comments for "poor texture" [4].

The preference scores received by irradiated chicken meat in Tables IX and X are in the acceptable range, even though irradiation doses were relatively high, an ave. 56 kGy for ⁶⁰Co and an ave. 59 kGy for electron irradiated samples. Improved preference scores were assigned by the same panel to a similar chicken product irradiated under better control of radiation dose (45 to 55 kGy) and temperature

TABLE XI. PREFERENCE RATINGS OF IRRADIATED¹

CHICKEN BREAST MEAT ROLLS

(Consumer Panel, n = 32)

Product preparation number	Additives, %:		Rating: ²
	NaCl	TPP	Mean \pm SD
1	0.0	0.0	5.1 ^a \pm 2.1
2	0.75	0.5	6.7 ^b \pm 1.4
3	0.75	0.0	6.3 ^b \pm 2.0
4	0.75	0.3	6.2 ^b \pm 1.9
4 ³	0.75	0.3	6.5 ^b \pm 1.8

Least significant difference (LSD, P < 0.05): 0.3

¹ 45 to 55 kGy at $-30^{\circ}\text{C} \pm 10^{\circ}\text{C}$.² 9-point hedonic scale: 9 = "like extremely," 5 = "neither-like-nor-dislike," 6 = "like slightly."³ Nonirradiated sample from product preparation 4.

($-30^{\circ} \pm 10^{\circ}\text{C}$) (Table XI) [4]. The preference scores given in Table XI indicate also the importance of the additives, NaCl and TPP, to the quality of irradiated products.

5. CONCLUSIONS

(a) Production of over 140 000 kg of enzyme-inactivated chicken meat under industrial conditions for the Raltech toxicological studies showed that the industry is capable of processing and packaging large quantities of products for irradiation treatment.

(b) Irradiation processing by ^{60}Co gamma rays and by 10 MeV electrons, of about 35 000 kg product by each of the irradiation source, showed that preservation of prepacked foods by sterilizing doses of ionizing energy is possible. However, packaging of the foods, under high vacuum with control of product temperature during irradiation are essential in obtaining products of acceptable quality.

(c) Enzyme-inactivated, vacuum packed chicken roll products preserved with sterilizing doses of ^{60}Co gamma rays and 10 MeV

electrons within the dose range of 45 to 68 kGy ($D_{\max}/D_{\min} = 1.51$) were shelf-stable and were of acceptable quality. The quality and acceptance of the products might be upgraded by reducing the irradiation sterilizing dose to the range of 43 to 56 kGy ($D_{\max}/D_{\min} = 1.30$).

(d) The approval by the health authorities of the radapertization process is needed before its industrial application. The U.S. Army—USDA Raltech toxicology studies on chicken were conducted to provide information for this purpose.

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REFERENCES

- [1] BAKER, R. W., CHANDLER, H. K., "Animal Feeding Study Protocol for Irradiation Sterilized Test Foods," U.S. Army Medical Research and Development Command Washington, DC, 1975. National Technical Information Service, Springfield, VA PB84-186998.
- [2] ABPS, NRC, "ABPS Report No. 66, Interim Report, Task Group on Feeding Study Protocols," Committee on Food Irradiation, National Academy of Sciences, Washington, DC (1975).
- [3] ERRC-ARS, "Irradiation Sterilized Chicken Toxicology Studies," National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, USA (1984).
- [4] WIERBICKI, E., Technical Report: "Irradiation Sterilized Chicken Products: Technology, Product Quality, Feasibility," ERRC-ARS Document No. 84. National Technical Information Service, Springfield, VA PB84-186998 (1984) 290.
- [5] SHULTS, G. W., WIERBICKI, E., J. Food Sci. 38 (1973) 991.
- [6] KILLORAN, J. J., Chemical and physical changes in food packaging material exposed to ionizing radiation. Radiation Research Reviews, Elsevier Publishing Company, Amsterdam, 3 (1972) 369.
- [7] KILLORAN, J. J., HOWKER, J. J., WIERBICKI, E., J. Food Process. and Preserv. 3 (1979) 11.
- [8] PRATT, G. B., KNEELAND, L. E., HEILIGAM, F., KILLORAN, J. J., J. Food Sci. 32 (1967) 200.
- [9] PRATT, G. B., KNEELAND, L. E., Irradiation Induced Headspace Gases in Packaged Radiation Sterilized Food. Amer. Can Company, Contract No. DA-19-129-AMC-119(N); Technical Report 72-55-F4, NLABS (1972).

- [10] SIMIC, M. G., J. Agr. Food Chemistry 26 1 (1978) 6.
- [11] COHEN, J. S., WIERBICKI, E., Transaction of ASAE 21 6 (1978) 1242.
- [12] KILLORAN, J. J., COHEN, J. S., WIERBICKI, E., J. Food Process. and Preserv. 3 (1979) 25-34.
- [13] Food and Drug Administration. The code of Federal Regulation 179 45: Packaging materials for use during the irradiation of prepackaged foods. Federal Register, 32 (1967) 8360.
- [14] KILLORAN, J. J., Packaging Materials for Use during the Ionizing Irradiation Sterilization of Prepackaged Chicken Products. ERRC-ARS Document No. 82. National Technical Information Service Springfield, VA PB84-186998 (1984) 180.
- [15] SHAPEE, J., WERKOWSKI, S. J., Study of Nondestructive Test for Determining the Volume of Air in Flexible Food Package. Technical Report 74-4-GP, NLABS (1972).
- [16] ANELLIS, A., SCHATTUCK, E., MORIN, M., SRISARA, B., QUALE, S., ROWLEY, D. B., ROSS, E. W., JR., J. Environmental Microbiol. 34 6 (1977) 823.
- [17] GRECZ, N., ROWLEY, D. B., MATSUYAMA, A. "The effect of irradiation on bacteria and viruses," Preservation of Food by Ionizing Radiation (JOSEPHSON, E. S., PETERSON, M. S., Eds), CRC Press, Inc. II. (1983) 167.
- [18] WELCH, A. B., MAXCY, R. B., Appl. Microbiol. 30 (1975) 242.
- [19] FIRSTENBER-EDEN, R., ROWLEY, D. B., SCHATTUCK, E. G., Appl. Microbiol. 39 (1980) 159.
- [20] MACDONALD, B. A., Gamma ray sterilization of meat. NLABS Manuscript, presented at the First International Congress on Engineering and Food, Boston, MA (1976).
- [21] JARRET, R. D., HALLIDAY, J. W., Dosimetry in support of wholesomeness studies. NLABS Manuscript, presented at the First International Congress on Engineering and Food, Boston, MA (1976).
- [22] REES, C. W., CASPERSEN, J. M., Electron irradiation in sterilization of meat. NLABS manuscript, presented at the First International Congress on Engineering and Food, Boston, MA (1976).
- [23] WIERBICKI, E., Technological feasibility of preserving meat, poultry, and fish products by using a combination of conventional additives, and heat treatment, and irradiation (Proc. Int. Symp. "Combination Processes in Food Irradiation," Colombo, Sri Lanka, 1980) IAEA, Vienna (1981) 81.
- [24] MARTIN, T. M., III, Health physics in food irradiation facilities. NLABS Manuscript, presented at the First International Congress on Engineering and Food, Boston, MA (1976).
- [25] MERRIT, C., JR., Radiolysis compounds in bacon and chicken. ERRC-ARS Document No. 83. National Technical Information Service, Springfield, VA 22161 PB84-187095 (1984) 466.
- [26] A.O.A.C., "Official Methods of Analysis", 12th ed. Assn. Offic. Anal. Chem., Washington, DC (1975).
- [27] TAUB, I. A., ROBBINS, F. M., SIMIC, M. G., WALKER, J. E., WIERBICKI, E., Food Technol. 33 5 (1979) 184.

- [28] DAHLE, L. K., HILL, E. G., HOLMAN, R. T., Arch. Biochem. Biophys. 98 (1962) 253.
 - [29] TARLADIS, B. G., WATTS, B. M., YOUNATHAN, M. T., J. Am. Oil Chem. Soc. 37 (1960) 44.
 - [30] PEARSON, A. M., LOVE, J. D., SHORTLOUD, F. B., Adv. Food Res. 23 (1977) 1.
 - [31] DUNCAN, D. B., Biometrics 11 (1955) 1.
 - [32] PERYAM, D. R., PILGRIM, F. J., Food Technol. 11 9 (1957).
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