TECHNOLOGY OF IRRADIATION PRESERVED MEATS

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RADAPPERTIZATION, or irradiation sterilization of meats and other protein foods is the subject of this paper. Radappertization is a new processing method applicable to precooked (enzyme inactivated) foods that are hermetically sealed (either in metal cans, flexible pouches or metal or plastic trays) and involved irradiation to sterilizing doses of either gamma rays (from a cobalt-60 or cesium-137 source (19) or by X-rays and electrons (24). The process is particularly applicable to precooked meat, poultry, fin fish and shellfish, as well as to dry foods, animal feed and spices. The resulting radappertized products are free from all food spoilage microorganisms and organisms of public health significance, including the pathogens such as C. botulinum, salmonellae, trichinae, etc. The radappertized products can be stored without refrigeration for long periods of time (years), the limiting factor being the integrity of the primary packaging material. Although radappertized products are ready-to-eat, they can also be warmed before table serving; additional culinary preparation, using a variety of recipes, can be applied to radappertized foods in the home, restaurant or dining hall to vary their taste and flavor.

TECHNOLOGY of the process has been developed by U.S. National Food Irradiation Program conducted by the U.S. Army at the Quartermaster Food & Container Institute in Chicago 1953-1962 and at the U.S. Army Natick R&D Command (NARADCOM) after 1962 . Several review papers summarize our main information in the field (9, 13, 32, 35). At present, negotiations are in progress to transfer the Food Irradiation Program from the U.S. Army to the U.S. Department of Agriculture, effective 1 October 1980. It may result in change of the scope and emphasis of the program. Therefore, in this paper I shall emphasize those areas of meat preservation by sterilizing doses of ionizing radiation which should be investigated in the future, if not by Natick scientists then by others, of interest to the meat industry.

RADAPPERTIZATION PROCESS. Fig. 1 gives the processing steps for irradiation sterilization (radappertization) processing of meats and other foods.

Product preparation. Most products do not need special preparations. The normal commercial practice can be used such as curing of ham, bacon and other cured meats, roasts of beef, pork, lamb, beef steaks, pork sausage, etc. However, in uncured meats addition of small amount of NaCl, below the salty taste (0.5 to 1.0%) along with 0.3% condensed phosphates is useful for improving flavor, texture, juiciness, overall acceptance and the yield of the products. Examples are given in Tables 4 and 8 and in published papers (4,5,25,26,27,35). The use of salt and phosphate allows also to produce different "cut and formed" items, such as meat rolls (4,16,17,27), ham (33,37), restructured beef steaks, pork and lamb chops, ground products (pork, lamb and beef patties; chicken burgers) (Table 3). Addition of phosphates is beneficial not only for increasing the water holding capacity (25,27), but also for controlling lipid oxidation (6) and some antibacterial effects (8).

Table 1: Minimal irradiation sterilizing (12D) doses in kGy (1 Gy = 100 Rad)

Food	Irrad. Temp. (°C)	Method of Est. 12D dose[1] Extreme Value[2]	Spearman-Karber[3]
Beef	-30±10	41.2	43.4
Chicken	-30±10	42.7	44.3
Ham	-30±10	31.4	38.1
Pork	-30±10	43.7	39.2
Codfish cake	-30±10	31.7	32.4
Corned beef	-30±10	26.9	24.4
Pork sausage	-30±10	25.5	26.5
Bacon	5 to 25	--	25.2

Source: D.B. ROWLEY, NARADCOM. [1]Based on recoverable botulinal cells and an assumed one most resistant strain/can. [2]Based on an assumed exponential spore death rate with an initial shoulder. [3]Based on an assumed exponential spore death rate without an initial shoulder.

Enzyme inactivation. For long time storage, proteolytic enzymes must be inactivated which is achieved by precooking the food to internal temperature of 70 to 75°C (26,35). Lower temperatures than 70°C for example, to produce "rare" beef steaks or roasts, can be used for the product which will be distributed without refrigeration and consumed within short period of time after processing, for example, within 1 to 6 months. Quality of beef steaks processed to 60°C received high quality scores and were preferred for juiciness and flavor over the steaks heated to 75°C (5) (Table 8). A methodology is available to determine the residual proteolytic activity in meats as affected by temperature and other processing variables (18). This technique can be used to predict shelf-stability of irradiated meats at specific temperatures, based on the residual proteolytic activity.

Vacuum packaging. Commercially available metal cans, including the can enamels and end-sealing compounds, are available for packaging of irradiated foods (16). Flexible packaging, with proper food-contacting films, are also available (17) and can be modified or improved, if necessary. The main requirement is the reliability of the primary container to be sealed under high vacuum and maintain good seal. For metal cans, the "high vacuum" needed is min. 25 inches (13.9kPa) after sealing before irradiation, which will decrease to about 15-20 inches (37.3kPa) vacuum after irradiation due to the formation of hydrogen gas as a result of irradiation (23). For flexible pouches of 11.5 x 17.8 cm in size, containing 100 to 125 grams meat, used in our laboratory, the "high vacuum" means the amount of the headspace after evacuation and sealing not to exceed 0.5cc. For flexible pouches of other dimensions, the allowable residual headspace gas volume has to be determined. The "low vacuum" results in discolored and rancid food after irradiation. With good vacuum, even for such foods as bacon, there is no oxidative rancidity and no peroxide formation by irradiation (39). Packaging of meats for irradiation in metal or plastic trays needs more experimental work. Initial work on a chicken dish (Chicken Cacciatore) gave a better product than thermally sterilized (Table 5). However, on opening of the tray, expert technologists could detect a rancid odor, which was not detected after reheating the dish for serving. It is due to the low vacuum sealing of the trays, only 5 inches (80.9kPa), before the trays collapsed. Several possibilities are available for future improvement: stronger body trays, nitrogen flush, packaging in plastic bags first, followed by packaging in trays, etc.

Irradiation in the frozen state. It is essential that the vacuum packaged product is frozen to -30° to -40°C and irradiated in frozen state. This prevents off-flavor developments by reducing production of radiolysis products by the high doses of irradiation(21). The result is an improved flavor and acceptance of the products (4,20,27,35). The formation of the radiolysis products starts at temperatures about -20°C (21). Therefore, it is essential that during irradiation processing the temperature in the center of the container does not increase over -20°C at the end of the processing. Whereas some foods are not so sensitive (ham, corned beef), others (turkey, chicken) can show detectable quality decrease when irradiated at -20°C (Table 4). Irradiation sterilizing doses for several foods are given in Table 1. Adjustment in the 12D sterilizing doses with change in the product temperature during irradiation is possible (10), as demonstrated on chicken breasts in Table 4. The efficiency of irradiation to destroy food spoilage microorganisms is well known (12) and the determination of the 12D doses for irradiation sterilization is well documented (1,2,3).

Post-irradiation storage and shelf-stability. After irradiation with the sterilizing doses, the foods can be stored and distributed without refrigeration. The length of storage depends on the enzyme inactivation temperature and the storage temperature. In the course of the product development and continuous product improvement, most of our storage data were limited to 25 months storage. Initial work has been published (11). The product has to be precooked to internal temperature of 70 to 75°C to be shelf-stable for 2 years (or longer) at 21°C (11,26,27,35). Storage at 38°C causes decrease in sensory qualities (softening of texture, discoloration), as well as consumer acceptance after 9 to 12 months (11) (Table 7). Storage at lower temperatures than 21°C increases the storage time. Irradiated smoked ham, enzyme inactivated to 70°C, which received high sensory ratings after 14 months storage at 21°C(34), was still highly acceptable after 36 months at 21°C and 7 years at 10°C storage. In another experiment on ham, which was enzyme inactivated to 68°C, the product started to decrease in sensory ratings below acceptable range after 12 months storage at 21°C. There is definitely a need to determine the storage stability of different irradiated meats at different temperatures as affected by the degree of precooking (enzyme inactivation temperature) of the products. In the examples on the quality of irradiated meats cited here (Tables 2,3,4,5,6,8), as well as referred to published papers, two methods of sensory evaluations were used: (a) Technological panel for color, odor, flavor and texture, using the 9-point quality scores (33,38), and (b) Consumer panel, using the 9-point hedonic scale for preference (22). The ratings above 5 are indicative of products of food quality that can be expected to gain acceptance by a broad spectrum of consumers.

Reduction of nitrite in cured meats. Radappertization process allows to reduce greatly the incoming nitrite in cured meats. Elimination of nitrite entirely is possible, at least for some foods, such as bacon and corned beef. Table 6 summarizes results of our investigations in the field, part of which has been published (13,33,34,35,36,38) or is presented at this Congress (7,30,39).

QUALITY OF IRRADIATION PRESERVED MEATS

Reference to quality of meats preserved by sterilizing doses of ionizing radiation has been made already in discussing the radappertization process (Tables 3,4,5,7,8). The high quality of some

Table 2. Quality of irradiated meats used in NASA space flights

Product	kGy at -30°±10°C	Preference Tests			NASA Space Flights
		No. Tests	No. Raters	Av. Score	
Ham	37	5	143	7.36	Apollo 17, 1972
Beef Steaks	43	2	64	6.95	Apollo-Soyuz, 1975
Corned Beef	25	2	64	6.95	"
Turkey Slices	37	2	64	6.35	"

Table 3. Sensory properties of irradiated chicken patties

Sample	Treatment	Sensory properties (M±SD) (n=10):			
		Color	Odor	Flavor	Texture
1[1]	Ir[2]	6.8±0.4	5.7±0.9	6.0±0.9	6.2±1.1
2	Ir	6.4±1.3	6,4±1.0	5.9±1.5	6.9±0.7
3	Ir	6.9±1.0	6.5±1.4	6.4±1.3	6.6±1.2
4	Ir	6.7±0.9	6.0±1.1	6.2±1.0	6.8±0.8
4C	Nonir.	6.4±1.3	6.9±0.9	6.6±1.0	6.5±1.2

[1] 1 = 100% white meat, NaCl (0.75%), Na Asc/Eryth. (250/250 mg/kg); 2= 82% white meat, 18% skin, NaCl, Na Asc/Eryth.; 3 = 100% white meat, NaCl Na Asc/Eryth, NaTPP (0.3%); 4 = 82% white meat, 18% skin, NaCl Na Asc/Eryth, NaTPP; 4C = Nonirrad. control, stored at -29°C for 30 days, same additives as No. 4.
[2] 45 kGy at -40°±5°C, stored 30 days at 21°C.

Table 4. Sensory quality of chicken breast.[1]

Sample Code	Irradn kGy at °C	Technological Panel N=12):				Pref.[2] scores
		Color	Odor	Flavor	Texture	
79/53[3]	Control[4]	7.1	7.4	7.2	6.9	7.1
	41 at -20	7.0	6.6	6.5	7.0	6.1[5]
	43 at -40	6.9	6.3	6.1	6.6	6.5
	45 at -60	7.0	6.8	5.7	7.0	6.7
LST(<.05)	NSD	NSD	NSD	NSD	NSD	SD
76/24[6]	45 at -30	6.3	6.0	6.2	6.3	--

[1]Marinated in 1.5% NaCl +0.5% NaTPP solution overnight in a cooler before enzyme inactivation; [2]Consumer panel (n=36) of the chicken breasts deep fat fried before serving; [3]Initial evaluation after 10 days storage at 21°C; [4]Nonirradiated control, stored at -29°C; [5]Sig. less preferred to other samples; [6]Enzyme inactivated chicken breasts stored for 3 years at room temperature (20-25°C in winter, 30-32°C in summer).

Table 5. Quality of chicken dish (Chicken Cacciatore), vacuum packed in metal trays and processed by 3 different methods.

Process	Sensory Quality (n=12):			
	Color	Odor	Flavor	Texture
Thermal, F_o=6	5.3±1.9[a]	6.6±1.1[a]	5.5±1.5[a]	5.2±1.9[a]
Frozen Control	7.6±0.8[b]	7.2±1.2[a]	7.4±0.8[b]	7.2±1.1[b]
45 kGy at -40°C	7.0±0.8[b]	6.6±0.8[a]	6.3±1.1[a]	6.7±1.2[b]
LSD (<.05)	1.2	1.0	1.1	1.3

Means with the same letter within the column are not sig. different.

Table 6. Reduced additions of nitrite to irradiated meats

Product	Nonirrad Meats mg/kg $NaNO_2$	Irradiated Meats Min. req. mg/kg $NaNO_2$	Recommended mg/kg $NaNO_2$ 1/	kGy at -30 ± 10^oC	Product Quality
Bacon	120	None	--	30	Slightly different color and flavor.
		20	40		Color, flavor and taste like in normal commercial bacon
Ham	156	25	50	32	Color fading
		25/25 2/	50/25 2/		Color stabilized.
		None	--		Ham-like product, texture excellent, color different.
Corned Beef	156	25	50	26	Regular quality product.
		None	--		Color different, otherwise acceptable.
Frankfurters	156	50	75	32	Good quality product, normal color and flavor.
		None	--		Acceptable, different flavor and color.

1/ Extra additions of nitrite to accommodate less efficient processing equipment than used in our research.
2/ 25 mg/kg $NaNO_3$ addition is needed to prevent fading of color.

Table 7. Preference ratings of pork sausage with the storage time

Treatment	Storage Temp ^oC	Months of Storage: ½	1	4	9	16
Nonirrad.	-29^o	6.9	-	6.8	7.6^a	6.3
24 kGy at 5^oC	21	5.9	6.4	6.5	6.4	5.5
24 kGy at -30^oC	21	6.2	6.9	6.3	6.3_b	6.0_b
24 kGy at -30^oC	38	5.7_b	6.8_b	5.9	4.4^b	4.4^b
Thermal[c]	Ambient	4.9^b	3.7^b	4.1^b	--	--

[a]Significantly ($P<0.05$) preferred over other samples

[b]Significantly less preferred than other samples

[c]Military item, canned in brine, thermally sterilized, history unknown.

Table 8. Effect of additives and enzyme inactivation temperature on sensory quality of irradiated (41 kGy at -40^oC) beef steaks

Additives	Enz. Inact. Temp. ^oC	Sensory quality (2 x n=12): Color	Odor	Flavor	Texture
None	75	7.53	7.38	6.87^a	7.40
0.75% NaCl	"	7.53	7.27	7.16	7.34
0.75% NaCl+0.3% TPP	"	7.53	7.19	7.11	7.58
0.75% NaCl+0.3% TPP	60	7.56	7.39	7.07	7.46
same additives	75	7.49	7.17	6.98	7.42

a Significantly different from other two samples

Fig. 1 - Irradiation Sterilization Processing of Foods

PRODUCT PREPARATION ⟶ ENZYME INACTIVATION ⟶

VACUUM PACKAGING ⟶ FREEZING TO -40^oC ⟶

IRRADIATION (X)(Z) with 12D DOSE ⟶ NON-REFRIGE-

RATED STORAGE ⟶ SHIPPING ⟶ DISTRIBUTION

(X) 5 to 10 Mev electron irradiation of flat packages 1.7 to 3.4 cm in thickness.
(Z) Cobalt-60 gamma irradiation of packaged foods of any thickness

products is attested by the fact that NASA used four irradiated foods (Table 2) in their space flights which received high appraisal by American and Soviet astronauts. Another irradiated meat, "cut-and-formed" pork chops, is being presently evaluated by NASA for addition to the irradiated foods for the future space flights. However, there is still need for further investigation regarding sensory quality of irradiation sterilized meats.

Color. Irradiation of heat denatured uncured meat pigment, metmyoglobin, reduces the pigment to deoxymyoglobin, changing the meat color from brown to pinkish red (14,15,29). The color is unstable and upon exposure of the meat to air and light, fades rapidly and returns to the original brown color of cooked meat. This color change is advantageous in some products, like no-nitrite bacon (38,39), not apparently objectionable in beef, lamb and poultry products, but might be objectionable in pork. The consumer will have to be educated about the color of uncured irradiated pork, not to confuse the reddish color with undercooked pork products. In cured meats, irradiation causes some decrease in the intensity of the characteristic pink color and formation of an unknown brownish red color (15). Upon exposure to air and light, the color of irradiated cured meats, particularly ham, undergoes further decrease in the intensity (color fading). Addition of nitrate, along with nitrite, during curing of ham, prevents the color fading to a large degree (33,38), but not eliminate it entirely. Research in this area is inconclusive (15) and more research is needed.

Texture. As shelf-stable items, irradiation sterilized foods receive consistently high appraisal for texture, particularly in comparison with the thermally processed items. Irradiated meats can be dry-packed and, as such, they are very suitable for portion-controlled, convenience-type meat products. Only irradiation can be used for production of shelf-stable large-size meat products, such as whole beef, lamb or pork roasts, whole hams, or meat rolls (13,16,27,28,35). However, irradiation with the high doses has some effect on texture which is of two categories: (a) softening of the overall texture; and (b) decomposition of the connective tissue. On the positive side, irradiation has a tenderizing effect, thus allowing the use of lower grades of beef, for example, to make tender roast beef or beef steaks. On the negative side, irradiation can cause overtenderizing leading to a mushy texture; and excessive degradation of the connective tissue may result in friable texture. However, these textural changes can be controlled and made beneficial by skilled meat technologists by selecting proper raw material and proper methods of the enzyme inactivation. This provides a flexibility and opportunity for meat industry to make specific meat products with desired textural characteristics.

Flavor and odor. Flavor of meat products preserved by irradiation is the main area where most research and product development will have to be done in the future. Fatty foods, such as bacon (raw and prefried) and pork sausage are least sensitive to the flavor changes, provided the foods are irradiated in vacuum sealed containers; otherwise they turn rancid on irradiation. Cured meats are less sensitive to the flavor changes than uncured meats. Among uncured meats, whole-muscle items (roasts, steaks), "cut-and-formed" beef, pork and lamb chops are less sensitive to flavor changes than the emulsion-type products. This indicates that the residual oxygen in the system is responsible, at least partially, for these flavor changes. Addition of phosphates, small amount of sodium chloride (0.5 to 1.0%) to uncured meats improve the flavor. Use of the antioxidants, as well as mixing of the meat formula under vacuum, eliminates the lipid oxidation and improves the flavor (6). The low flavor scores in our first experiments on irradiated frankfurters (30) might be due to the fact that the frankfurters emulsion was not subjected to final mixing under vacuum. The characteristic flavor of specific meats might be improved by addition of commercial flavor preparations, as we have observed by using 1 and 2% "chicken flavor" of Stange Co. in irradiated chicken rolls. Definitely, use of different condiments and spices improve the products, like for example, barbecue sauce in various meats and chicken products we have experimented with. There are many choices for skilled food technologists in industry to improve flavor and overall quality of irradiation sterilized meats. In some irradiated ham and corned beef, vacuum packed in flexible pouches and stored non-refrigerated for over 2 years, we have observed a bitter-metallic after-taste; no such after-taste was noticed in ham vacuum packed in metal cans and stored over 4 years. A possibility of an effect of the plastic films in contact with the food during long periods of time on the after-taste of the products should be investigated. It should be emphasized that the flavor changes discussed here refer in comparison with the non-irradiated, hermetically sealed, frozen-stored meat products. In comparison with the shelf-stable thermally processed canned meats, the irradiated meats were superior, not only in texture, but also in color, odor and texture. Irradiation reduces also the packaging and storage space 15 to 40% by eliminating water or brine needed for thermal processing (28). Irradiation in the frozen state greatly reduces destruction of nutrients, such as thiamine (31), and prevents destruction of the amino acids in meat proteins in comparison with thermal processing (35).

CONCLUSIONS

1. Irradiation sterilization of precooked meats and other protein foods is the most promising processing method for production of shelf-stable convenience foods which, on the plate of the consumer, closely resemble the foods prepared from fresh items.
2. Irradiation sterilized meats, experimentally developed so far, range in quality from highly acceptable to marginally acceptable. More research and development is needed on improving the flavor of the marginally acceptable meats and some possiblities are indicated in this paper to do so.
3. Irradiation preserved meats are definitely superior to thermally processed meats, the only other shelf-stable ready-to-eat meat products now available to the consumer.

(1) ANELLIS, A., Berkowitz, D., Swantak, W. and Strojan, C. Radiation sterilization of prototype military foods: Low-temperature irradiation of codfish cake, corned beef and pork sausage. Appl. Microbiol. 24 (3):453 (1972).
(2) ANELLIS, A., Rowley, D.B. and Ross, E.W., Jr. Microbiological safety of radappertized beef. J. Food Protection 42 (12): 927 (1979).
(3) ANELLIS, A., Shattuck, I., Latt, T., Songpasertchal, S., Rowley, D.B., and Ross, E.W. Gamma irradiation at -30±10° of low level nitrite/nitrate ham. "Spore Research", p. 613. Academic Press, London, 1976.
(4) COHEN, J.S., Mason, V.C. and Wierbicki, E. Flavor and textural changes in radappertized chicken as affected by irradiation temperature, NaCl and phosphate addition. J.Fd. Sci., 42(4): 885 (1977).
(5) COHEN, J.S., Wierbicki, E. and Mason, V.C. Variables affecting the quality of irradiation-sterilized beef steaks. J. Fd. Sci. (in press)(1980).
(6) EL-MAGOLI, Salwa, Wierbicki, E., Heiligman, F. and Angelini, P. Optimization of technological procedures affecting quality of radappertized chicken rolls. J. Fd. Sci. (in press) (1980).
(7) FIDDLER, W., Gates, R.A., Pensabene, J.W. and Wierbicki, E. Nitrosamines in irradiated bacon. 26th EMMRW, Colorado Springs, CO, U.S.A. (1980).
(8) FIRSTENBERG-EDEN, R., Rowley, D.B. and Shattuck, G.E. Inhibition of Moraxella-acinetobacter cells by phosphates and sodium chloride. J. Fd. Sci. (in press) (1980).
(9) GRAHAM, H.D. Safety and wholesomeness of irradiated foods. "Safety of Foods," 2nd Ed., p. 546, AVI Publishing Co., Westport, Conn., 1980.
(10) GRECZ, N., Walker, A.A., Anellis, A. and Berkowitz, D. Effect of irradiation temperature in the range -196 to +95C on the resistance of spores of Clostridium botulinum 33A in cooked beef. Canad. J. Microbiol. 17:135(1971)
(11) HEILIGMAN, F. Storage stability of irradiated meats. Food Technol. 19 (5): 114 (1965).
(12) INGRAM, M. "Microbiology of Foods Pasteurized by Ionizing Radiation." International Project in the Field of Food Irradiation, Tech. Rpt. Series, Rpt.No. IFI R-R33, Inst. of Food Technol., Karsruhe, Germany, 1975.
(13) JOSEPHSON, E.S., Brynjolfsson, A. and Wierbicki, E. The use of ionizing radiation for preservation of food and feed products. "Radiation Research," p.96, Acad. Press, Inc., 1975
(14) KAMAREI, A.R., Karel, M. and Wierbicki, E. Spectral studies on the role of ionizing radiation in color changes of radappertized beef. J. Fd. Sci. 44(1): 25 (1979).
(15) KAREL, M., Kamarei, A.R. and Wierbicki, E. Changes in meat pigments as a result of radappertization. 26th EMMRW, Colorado Springs, CO. (1980).
(16) KILLORAN, J.J., Howker, J.J. and Wierbicki, E. Reliability of tinplate cans for packaging radappertized beef under production conditions. J. Food Processing and Preservation, 3:11 (1979).
(17) KILLORAN, J.J. Cohen, J.S. and Wierbicki, E. Reliability of flexible packaging of radappertized beef under production conditions. J. Food Processing and Preservation, 3:25 (1979).
(18) LOSTY, T., Roth, J.W. and Shults, G.W. The effect of gamma irradiation and heating on the proteolytic activity of meat samples. J. Agr. Food Chem. 21:275 (1973).
(19) MACDONALD, B.A. Gamma ray sterilization of meat. The First Internat. Cong. on Engr. and Food, Boston, MA, 9-13 Aug. 1976.
(20) MERRITT, C., Jr., Angelini, P., Wierbicki, E., and Shults, G.W. Chemical changes associated with flavor in irradiated meats. J. Agr. Food Chem. 23:1037 (1975).
(21) MERRITT, C.,Jr., Angelini, P. and Graham, R.A. Effect of radiation parameters on the formation of radiolysis products in meat and meat substances. J. Agr. Food Chem. 26:29(1978).
(22) PERYAM, D.R. and Pilgrim, F.J. Hedonic scale method for measuring food preferences. Food Technol. 11(9), Supp. 9 (1957)
(23) PRATT, G.B., Keeland, L.E., Heiligman, F. and Killoran, J.J. Irradiation induced gases in packaged foods. I. Identification and measurements. J.Fd. Sci. 32:200 (1967).
(24) REES, C.W. and Caspersen, J.M. Electron irradiation in the sterilization of meat. The First Internat. Cong. on Engrg. and Food, Boston, MA, 9-13 Aug. 1976.
(25) SHULTS, G.W., Russell, D.R. and Wierbicki, E. Effect of condensed phosphates on pH, swelling and water-holding capacity of beef. J. Fd. Sci., 37:860 (1972)
(26) SHULTS, G.W. and Wierbicki, E. Changes in non-protein nitrogen content and the sensory characteristics of beef steaks as affected by the meat treatment. Tech. Rpt. 75-8-FEL, U.S.Army Natick Laboratories, July 1974.
(27) SHULTS, G.W. and Wierbicki, E. Development of irradiated restructured lamb. 26th EMMRW, Colorado Springs, CO, USA (1980).
(28) SMITH, G.C. Irradiation of meat and meat products. Proceedings MIRC, p.57, March 1978.
(29) TAUB, I.A., Robbins, F.M., Simic, M.G., Walker, J.E. and Wierbicki, E. Effect of irradiation on meat proteins. Food Technol. p. 184, May 1979.
(30) TERRELL, R.N., Smith, G.C., Carpenter, Z.L., Heiligman, F., and Wierbicki E. Radiation preserved frankfurters: Curing ingredients and processing effects on physical, chemical and sensory traits. 26th EMMRW, Colorado Springs, CO., U.S.A. (1980).
(31) THOMAS, M.H., Atwood, B.M., Wierbicki, E. and Taub, I.A. The effect of radiation and conventional processing on the thiamin content of pork. J. Fd. Sci. (in press) (1980).
(32) WIERBICKI, E., Simon, M. and Josephson, E.S. Preservation of meats by sterilizing doses of ionizing radiation. "Radiation Preservation of Foods," Nat. Acad. of Sciences, NRC, Publication No. 1273,p.383, Washington, DC, 1965.
(33) WIERBICKI, E. and Heiligman, F. Shelf stable cured ham with low nitrite-nitrate additions preserved by radappertization. Proc. Int. Symp. Nitrite in Meat Prod., Zeist, p. 189. PUDOC, Wageningen (1973).
(34) WIERBICKI, E., Heiligman, F. and Wasserman, A.E. Cured meats with reduced nitrite preserved by radappertization. 20th EMMRW, Dublin, p. 101 (1974).
(35) WIERBICKI, E., Brynjolfsson, A., Johnson, H.C. and Rowley, D.B. Preservation of meats by ionizing radiation. 21st EMMRW, Bern (1975).
(36) WIERBICKI, E., Heiligman, F. and Wasserman, A.E. Irradiation as a conceivable way of reducing nitrites and nitrates in cured meats. Proc. 2nd Int. Symp. Nitrite in Meat Products, Zeist, p.75, PUDOC, Wageningen (1976).
(37) WIERBICKI, E., Howker, J.J. and Shults, G.W. Effect of salt, phosphates and other curing ingredients on shrinkage of lean pork meat and the quality of smoked processed ham. J. Fd. Sci. 41(5): 1116 (1976).
(38) WIERBICKI, E. The importance and feasibility of irradiated low nitrite meat products. Activities Report of the R&D Associates, 31(2): 70 (1979).
(39) WIERBICKI, E. and Heiligman, F. Irradiated bacon without and with reduced addition of nitrite. 26th EMMRW, Colorado Springs, CO., U.S.A.(1980).