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COMBINATION PROCESSES IN FOOD IRRADIATION

PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM
ON COMBINATION PROCESSES IN FOOD IRRADIATION
JOINTLY ORGANIZED BY THE
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TECHNOLOGICAL FEASIBILITY OF PRESERVING MEAT, POULTRY AND FISH PRODUCTS BY USING A COMBINATION OF CONVENTIONAL ADDITIVES, MILD HEAT TREATMENT AND IRRADIATION

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Abstract

TECHNOLOGICAL FEASIBILITY OF PRESERVING MEAT, POULTRY AND FISH PRODUCTS BY USING A COMBINATION OF CONVENTIONAL ADDITIVES, MILD HEAT TREATMENT AND IRRADIATION.

Radappertization, or irradiation sterilization of meats and other protein foods (poultry, seafoods) 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 involves irradiation to sterilizing doses of either gamma rays (from a cobalt-60 or caesium-137 source) or by X-rays and electrons. 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 food spoilage micro-organisms 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 (years), the limiting factor being the integrity of the primary packaging material. Irradiation sterilization of cured meats allows complete elimination or a drastic reduction of incoming nitrite to the levels needed only for characteristic colour and flavour of the items while providing protection against *C. botulinum* by irradiation. The irradiated-cured products with the low levels of added nitrite are free from residual nitrite and nitrosamines, including nitrosopyrrolidine in fried bacon. In recent co-operative research with the US Department of Agriculture, it was shown that irradiation also destroys pre-formed nitrosamines in bacon. The technology of the process was developed by the US National Food Irradiation Program and the US Army from 1953 to 1980. The US Army spearheaded the development of this new technology to the point where the food irradiation potentials have become meaningful within the broad scope of national and international interests. Therefore, it was highly appropriate that, effective 1 October 1980, the responsibility for the programme at this stage was transferred to the US Department of Agriculture which has been designated as the leading agency for the US Federal food and nutrition programmes.

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IMPROVEMENT OF MICROBIOLOGICAL QUALITY OF FISH AND POULTRY PRODUCTS BY COMBINATION PROCESSES (Session V)

INTRODUCTION

Irradiation of foods by sterilizing doses of ionizing radiation, or radappertization, is the topic of this paper, a topic that fits into the overall agenda of this symposium, since radappertization is a combination process of irradiation, mild heat treatment, packaging, and selected food additives needed for obtaining the characteristic colour, flavour, texture and taste of the resulting products that consumers are used to in non-irradiated food products.

The radappertized products can be stored without refrigeration for long periods (years), the limiting factor being the integrity of the primary packaging material. Technology of the radappertization process was developed under the US National Food Irradiation Program conducted by the US Army at the Quartermaster Food and Container Institute in Chicago from 1953 to 1962 and since 1962 to October 1980 at the US Army Natick Research and Development Laboratories (Natick Labs). The Army spearheaded the development of this new technology to the point where the food irradiation potentials have become meaningful. Therefore, it was appropriate that, effective 1 October 1980, the responsibility for the programme at this stage was transferred to the US Department of Agriculture (USDA), which has been designated by the US Congress as the leading agency for the US Federal food and nutrition programmes. The USDA agency designated to continue the US National Food Irradiation Program is the Eastern Regional Research Center (ERRC) in Philadelphia, Pennsylvania, one of the regional laboratories of the USDA's Science and Education Administration. The food irradiation is a part of the Food Safety Laboratory of the ERRC. Its activity will extend also to low-dose irradiation of foods and agricultural produce of interest to the United States food industry and agriculture.

I joined the Food Irradiation Research Group of the Food Safety Laboratory at the ERRC to continue food irradiation research in high-dose applications and to apply the low-dose irradiation to foods most promising for industrial adoption and consumer interests. The progress made in food irradiation the world over, under the patronage and leadership of the International Atomic Energy Agency (IAEA), will be very beneficial and will be widely used in future food irradiation efforts in the USA.

On joining the USDA-ERRC I wish to acknowledge two scientists from Natick Labs who contributed so much to the progress of food irradiation in the United States and, I believe, the world over: Dr. Edward J. Josephson who directed the food irradiation programme at Natick Labs from 1961 to 1972 and his successor, Dr. Ari Brynjolfsson who was in charge of the programme until its transfer to USDA. Particularly noteworthy are the last 10 years in food irradiation research at Natick Labs where, under the inspiration, leadership, and personal participation of Dr. Brynjolfsson,

PRODUCT PREPARATION ⟶ ENZYME INACTIVATION

VACUUM-PACKAGING ⟶ FREEZING TO -40°C ⟶

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

FRIGERATED 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.

FIG. 1. Radappertization processing of foods.

considerable basic radiation chemical data were generated which laid the basis for the chemiclearance principle that allows extrapolation and interpolation wholesomeness clearances from the tested and approved foods to other, as yet not approved foods of similar chemical composition subjected to similar irradiation treatment.

2. RADAPPERTIZATION PROCESS

2.1. Processing steps for radappertization

Figure 1 presents the processing steps for radappertization processing of meats and other foods. Only the most critical technological parameters, supported by new research data, on radappertization of meats, poultry and seafood items are presented and discussed, since much information has already been published [1–5].

2.1.1. Product preparation

Most products do not need special preparations. Normal commercial practice can be used, such as curing of ham, bacon, and other cured meats, roasts of beef, pork, lamb, beefsteaks, pork sausage, etc. However, in uncured meats the addition of a small amount of NaCl, below the salty taste (0.5 to 1.0%), along with 0.3% condensed phosphates, is useful for improving flavour, texture, juiciness, overall consumer acceptance, and the yield of the products [6–9]. In addition, the use of salt and phosphate allows the production of different "cut-and-formed" items, such as meat rolls, ham, restructured beefsteaks, pork and lamb chops, and ground products (pork, lamb, and beef patties; chicken burgers). Condensed phosphates, such as

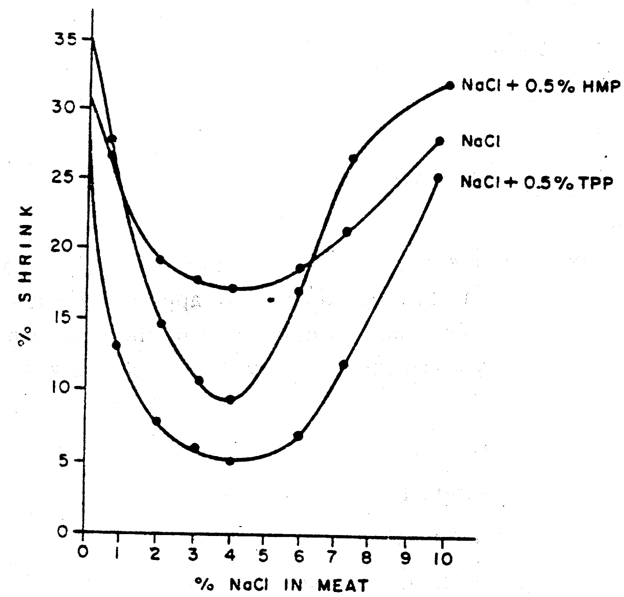

FIG.2. Effect of condensed phosphates (TPP and HMP) in combination with NaCl on the shrinkage of beef semi-membranosus muscle at 70°C. Shults, G.W. et al. [6].

sodium tripolyphosphate (TPP) in combination with salt (NaCl) decreases the loss of natural juices of meats during cooking, as shown in Fig.2, for heating ground beef at 70°C with added 0.5% TPP or HMP (hexametaphosphate) with varying salt concentrations [6]. TPP and sodium pyrophosphate (PP) are the most efficient phosphates for increasing the water-holding capacity of meats, poultry and fish proteins and, consequently, for reducing loss of the natural juices (reduction of shrink) of these protein foods during cooking. Our investigations at Natick Labs showed that 0.3% additions of TPP or PP are sufficient for optimal effects. Addition of phosphates is also benefical for controlling lipid oxidation in radappertized foods, particularly in combination with sodium ascorbate or sodium erythorbate in amounts of 300 to 600 mg/kg.

2.1.2. *Enzyme inactivation*

For prolonged storage, proteolytic enzymes must be inactivated, which is achieved by precooking the food to an internal temperature of 70 to 75°C [10–12]. Temperatures lower than 70°C (for example, to produce "rare" beefsteaks or roasts), can be used for the products distributed without refrigeration and consumed within a short period after processing, within one to six months.

The quality of beefsteaks processed to 60°C and 75°C received high-quality scores as shown in Table I.

The data presented in this table for colour, odour, flavour and texture were obtained by sensory taste testing of reheated, enzyme-inactivated beefsteaks by a trained technological panel using the following 9-point quality scores:

Scale		*Quality*
9	=	excellent
7	=	good
5	=	fair
3	=	poor
1	=	extremely poor

Other examples are given in this paper on the quality of radappertized foods using either the technological panel for appraisal of the four quality attributes using the scale given above, or by using the 9-point hedonic scale for preference [13] by a consumer panel with the following quality rating:

Rating		*Quality*
9	=	like extremely
7	=	like moderately
5	=	neither like nor dislike
3	=	dislike moderately
1	=	dislike extremely

Ratings above 5 by either panel are indicative of products of good quality that can be expected to gain acceptance by a broad spectrum of consumers.

Continuing the subject of the enzyme-inactivation temperature (precooking), the overall experience allows all products to be subdivided into three categories regarding the optimal quality of the products after radappertization:

(1)	Beef, lamb	70 to 75°C
(2)	Pork	75 to 80°C
	Poultry	75 to 80°C
	Seafood	75 to 80°C
(3)	Smoked bacon	53°C

TABLE I. EFFECT OF ADDITIVES AND ENZYME INACTIVATION TEMPERATURE ON SENSORY QUALITY OF IRRADIATED (41 kGy AT −40°C) BEEFSTEAKS

Additives	Enzyme inactivation temperature (°C)	Sensory quality (2 X n = 12)			
		Colour	Odour	Flavour	Texture
None	75	7.53	7.38	6.87[a]	7.40
0.75% NaCl	75	7.53	7.27	7.16	7.34
0.75% NaCl + 0.3% TPP	75	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.

TABLE II. METAL CANS
Irradiation dose: 30 to 75 kGy; Irradiation temperatures: 5, −30, −90°C

Components	Requirements
1. Tinplate: (a) 400 X 400 X 1110 (b) 404 X 700	100# MRT2−25# Electrolytic tinplate 95# LTU-25# Electrolytic tinplate
2. Sideseam	Conventional 2−98 solder
3. Enamel	(a) Epoxy-phenolic with aluminium pigment (b) Epoxy type with aluminium pigment and wax
4. End-sealing compound	(a) Blend of cured and uncured butyl rubber (b) Blend of neoprene and butadiene-styrene

TABLE III. SUMMARY OF HEAD-SPACE GAS ANALYSIS IN CANS OF FROZEN CONTROL (FC) AND GAMMA-RAY IRRADIATED (GAM) ENZYME INACTIVATED BEEF

Gas	Group	n	Avg.	SD
O_2	FC	39	2.7[a]	3.6
(%)	GAM	42	0.9	0.5
N_2	FC	39	80.9[a]	5.9
(%)	GAM	42	45.5	6.1
H_2	FC	39	0.0[a]	
(%)	GAM	42	36.3	6.2
CO_2	FC	39	14.0[a]	6.2
(%)	GAM	42	16.4	3.4
CH_4	FC	39	0.0[a]	
(%)	GAM	42	0.7	0.1
CO	FC	39	0.0	–
(%)	GAM	42	0.0	--

[a] Signifying an overall level of 99%.

Selection of the temperature and method for the enzyme-inactivation depends on (1) the product's identity; (2) its initial quality after irradiation; and (3) intended storage time and temperature.

2.1.3. Vacuum-packaging

Commercially available metal cans, including the can enamels and end-sealing compounds, are available for packaging irradiated foods [14]. In Table II, the technological requirements for the metal cans, which performed satisfactorily in our development of irradiated foods, are given. Flexible packaging, with proper food-contacting films, is also available [15] and can be modified or improved, if necessary. The main requirement is the reliability of the primary container being sealed under high vacuum and maintaining a good seal. For metal cans, the "high vacuum" needed is minimum 25 in. (13.9 kPa) after sealing before irradiation, which will decrease to about 15 in. (37.3 kPa) vacuum after irradiation owing to the formation of hydrogen gas as a result of irradiation [16].

TABLE IV. QUALITY OF CHICKEN DISH (CHICKEN CACCIATORE), VACUUM-PACKED IN METAL TRAYS AND PROCESSED BY THREE DIFFERENT METHODS

Process	Sensory quality (n = 12) Colour	Odour	Flavour	Texture
Thermal. $F_0 = 6$	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 ($P < 0.05$)	1.2	1.0	1.1	1.3

[a,b] Means with the same letter within the column are not significantly different.

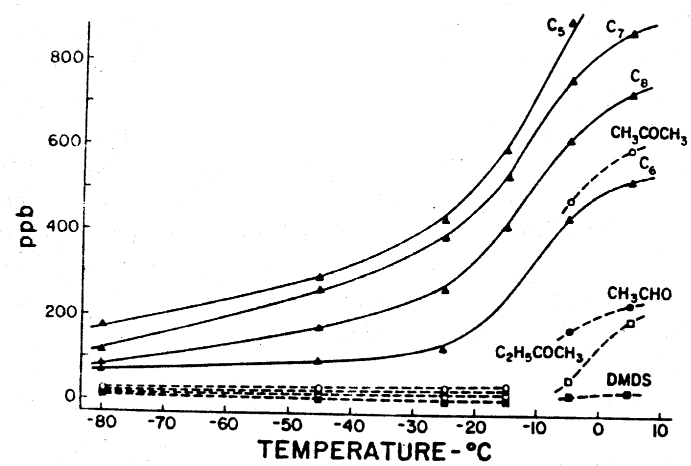

FIG.3. Effect of irradiation temperature on the amount of various radiolysis products formed in beef irradiated with 47 kGy. Merritt, C., Jr. [17].

In Table III, the headspace gas analysis in metal cans is given for vacuum-packed (13.9 kPa) non-irradiated frozen control (FC) and gamma-irradiated, 47 kGy of −30° ± 10°C (GAM) enzyme-inactivated beef. Formation of hydrogen gas, small increase in CO_2 and depletion of the residual oxygen are characteristic for irradiation of vacuum-packed foods.

For the flexible pouches of 11.5 X 17.8 cm in size, containing 100 to 200 g meat, the "high vacuum" means the amount of the headspace gas after evacuation and sealing should not exceed 0.5 cm³. For flexible pouches of other dimensions, the allowable residual headspace gas volume has to be

TABLE V. MINIMAL IRRADIATION STERILIZING (12D) DOSES IN kGy (1 Gy = 100 rad)

Food	Irrad. temp. (°C)	Method of establishing a 12D dose[a] Extreme value[b]	Spearman-Karber[c]
Beef	−30 ± 10	41.2	43.3
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, Natick Labs (Personal communication).

[a] Based on recoverable botulinal cells and an assumed one most resistance strain can.

[b] Based on an assumed exponential spore death rate with an initial shoulder.

[c] Based on an assumed exponential spore death rate without an initial shoulder.

determined. The "low vacuum" results in discoloured and rancid food after irradiation. With good vacuum, even with fatty foods such as bacon, there is no detectable oxidative rancidity and peroxide formation by irradiation. Packaging of meats for irradiation in metal or plastic trays needs more experimental work. An initial experiment on a chicken dish (Chicken Cacciatore) resulted in a better product than the thermally sterilized item (Table IV). However, on opening the tray, expert technologists could detect a rancid odour, which was not detected after reheating the dish for serving. The initial off-odour is due to the low vacuum sealing of the trays, only 5 in. (80.9 kPa), before the trays collapsed. Several possibilities are available for future improvement: stronger body trays, nitrogen flush, or high vacuum-packaging in plastic bags first, followed by packaging in trays.

2.1.4. Irradiation in the frozen state

It is essential that the vacuum-packaged product for irradiation sterilization be frozen to between −30° and −40° and irradiated in the frozen state. This prevents off-flavour development by reducing production of radiolysis products by the high doses of irradiation. A drastic increase in the formation of the radiolysis products starts at temperatures above −20°C, as shown in

TABLE VI. SENSORY QUALITY OF CHICKEN BREASTS[a] RADAPPERTIZED AT THREE DIFFERENT TEMPERATURES WITH ADJUSTED 12D DOSE

Sample code	Irradiation (kGy at °C)	Technological panel (n = 12)				Preference[b] scores
		Colour	Odour	Flavour	Texture	
79/53[c]	Control[d]	7.1	7.4	7.2	6.9	7.1
	41 at −20	7.0	6.6	6.5	7.0	6.1[e]
	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
LSD (<0.05)	NSD	NSD	NSD	NSD	NSD	SD
76/24[f]	45 at −30	6.3	6.0	6.2	6.3	–

[a] Marinated in 1.5% NaCl + 0.5% NaTPP solution overnight in a cooler before enzyme inactivation.

[b] Consumer panel (n = 36) of the deep-fat-fried chicken breasts.

[c] Initial evaluation after 10 days' storage at 21°C.

[d] Non-irradiated control, stored at −29°C.

[e] Significantly less preferred to other samples.

[f] Enzyme-inactivated chicken breasts stored for three years at room temperature (20–25°C in winter, 30–32°C in summer).

Fig.3 for high-dose irradiated beef [17]. Irradiation in the frozen state (−40° ± 10°C) results in improved flavour and acceptance of the irradiated products [2, 3, 7, 18, 19].

Because of the drastic increase of the radiolysis products produced in radappertized foods irradiated above −20°C, it is essential that during irradiation processing the temperature in the centre of the container does not exceed −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. However, it should be emphasized that the irradiation in the frozen state alone is not sufficient for some radappertized foods to obtain end items of good quality without combination with other technological factors, the most important of which are: (a) small amounts of added phosphate and salt; (b) enzyme-inactivation (precooking); and (c) vacuum-packaging. Irradiation in the frozen state, at −40°C and below, is also very important to prevent destruction of water-soluble vitamins, such as thiamine [2–4, 20]. Considering the cost of freezing vacuum-packed,

Production size (pouches)	Sample size[a] for incubation tests at:		Sample size[a] for microbiological sterility tests at:	
	35° ± 2°C	55° ± 2°C	35° ± 2°C	55° ± 2°C
8 to 150	8	8	4	4
151 to 500	14	14	7	7
501 to 1 200	20	20	10	10
1 201 to 10 000	32	32	16	16
10 001 to 35 000	50	50	25	25
35 001 to 50 000	80	80	40	40

[a] Samples randomly selected. Space Food Prototype Production Guide [26].

enzyme-inactivated foods for radappertization and of keeping the foods frozen during irradiation, the quality desired by specific foods should be considered and proper irradiation temperature selected. In our experiments, to meet the sensory quality desired by the United States consumers, the irradiation temperature for most products during irradiation should be maintained at −40 ± 5°C on the surface with the temperature in the centre of the products at the end of radappertization not higher than −20°C.

2.2. Microbiological safety

C. botulinum spores are the most radiation-resistant microorganisms of concern in radappertization. The main purpose of irradiation, and its main contribution to the radappertization, is destruction of food spoilage microorganisms, including *C. botulinum* spores. The radappertization process has been centred on the dose needed to reduce the number of *C. botulinum* spores from 10^{12} to 10^0, which is the 12 D concept, where D is the dose required for 90% reduction of the spore population [21–25]. This concept has been accepted by the FAO, IAEA, and WHO.

Table V presents the 12 D doses for eight radappertized foods as determined by the Microbiology Group of Natick Labs. Note that the codfish cakes have a lower 12 D dose than the red meats (beef and pork) and the chicken. Beef, pork, and chicken, enzyme-activated, contained added 0.75% NaCl and 0.3% TPP. Without these additives, the 12 D dose is higher, 47 kGy, as determined for beef (versus 41.2 kGy). Ham, corned beef, pork sausage, and bacon

TABLE VIII. MINIMAL ADDITIONS OF NITRITE TO IRRADIATED MEATS

Product	Non-irrad. meats ($mg/kg\ NaNO_2$)	Irradiated meats: ($mg/kg\ NaNO_2$)	kGy at −30 ± 10°C	Product quality
Bacon	120	None	30	Slightly different colour and flavour.
		20		Colour, flavour, and taste like in normal commercial bacon
Ham	156	25	32	Colour fading;
		25/25[a]		Colour stabilized;
		None		In research state (texture excellent)
Corned beef	156	50[b]	26	Regular quality product;
		None		Colour different, otherwise acceptable
Frankfurters	156	50	32	Good quality product;
		None		Acceptable, different flavour, and colour

[a] 25 mg/kg $NaNO_3$ addition is needed to prevent fading of colour.

[b] 25 mg/kg $NaNO_2$ addition is sufficient if $NaNO_2$ is uniformly distributed during pumping.

contain higher amounts of added NaCl (1.5 to 2.5%) and other additives (ascorbate, nitrite, and spices). The 12 D doses for these foods are considerably lower than for their uncured counterparts (beef and pork). This indicates that the additives decrease resistance of *C. botulinum* spores to irradiation, thus indicating a combined process effect.

2.2.1. *Adjustment to the 12 D dose with changing the irradiation temperature*

The sensitivity of *C. botulinum* spores, and all bacteria, in general, to ionizing radiation increases with the decrease of the product's temperature during irradiation from +65 to −195°C. The following relationship can be used for predicting the radioresistance of *C. botulinum* spores in enzyme-inactivated ground beef for any irradiation temperature between +65 and −196°C [21]:

$$D_t = D_0 - 1.06\ t$$

where:

D_t = the D value in krad, at temperature t;
D_0 = the D value in krad at 0°C
1.06 = the increment of change in the D value with the change in the irradiation temperature in °C.

Since the D value for beef is one of the highest among the uncured meats (within the experimental error to calculate the D value), this equation can also be applied to other radappertized foods.

We have applied this formula for irradiating chicken breast in 404 × 309 cans (diameter = 10.7 mm), since in a can of this diameter, the inside temperature can be below −20°C when irradiated with the 12 D dose of 42.7 kGy (43 kGy) at −30°C ± 10°C. Table VI shows the results on the quality of radappertized chicken breasts irradiated at −20, −40, and −60°C (±5°C) with an adjusted 12 D dose. As the consumer preference scores indicate, irradiation of chicken breasts at the starting temperature of −60°C with 45 kGy might be beneficial over the irradiation with 41 kGy at −20°C. Such flexibility should be available in practice/application by industry.

2.2.2. *Estimated irradiation sterilizing dose*

Determination of the 12 D dose for each product and its modification will be a costly process for industry. Based on the 12 D doses determined on different foods (Table V), it is possible to estimate the required radappertization

TABLE IX. RESIDUAL NITRITE AND NITROSAMINES IN IRRADIATED (30 kGy AT −30°C) PRE-FRIED AND REGULAR BACON CURED WITHOUT AND WITH REDUCED ADDITIONS OF NITRITE

Added: $NaNO_2$	$NaNO_3$ (ppm)	A/E[d]	Pre-fried Res. $NaNO_2$	Pre-fried NDMA (ppb)	Pre-fried NPYR (ppb)	Regular bacon[c] Res. $NaNO_2$	Regular bacon[c] NDMA (ppb)	Regular bacon[c] NPYR (ppb)
0	0	275	n.d.[a]	n.d.[b]	n.d.[b]	n.d.[a]	n.d.[b]	n.d.[b]
0	0	550	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
20	0	550	n.d.	n.d.	1	n.d.	n.d.	n.d.
40	0	550	n.d.	n.d.	2	n.d.	n.d.	1
20	20	550	n.d.	n.d.	1	n.d.	n.d.	1

[a] n.d. = none detected, min. detectability, 0.5 ppm $NaNO_2$.

[b] n.d. = none detected, min. detectability, <1 ppb NA.

[c] Edible portion after frying.

[d] 1:1 mixture of Na-ascorbate/Na-erythorbate.

dose for similar foods by extrapolation. We have successfully done so with the smoked turkey slices for NASA. The product was cured by pumping 5% weight of the turkey raw meat with a curing solution containing 2 kg NaCl, 750 g TPP, 29.4 g $NaNO_2$, and 244 g sodium ascorbate dissolved in 25 kg water. The further processing consisted of smoking and cooking to 75°C, vacuum-packaging, and irradiation. The additives and the process were similar to those applied for smoked ham for which the 12 D dose is 31.4 kGy at −30 ± 10°C (Table V).

Therefore, we have selected the radappertization dose for the smoked turkey breasts to be 32 kGy at −40 ± 5°C, to precede the following tests for microbiological safety:

	Number of pouches			
	Incubation tests at:		Sterility tests at:	
Irradiation dose	35°C	55°C	35°C	55°C
32 kGy at −40 ± 5°C	14	14	14	14
22 kGy at −40 ± 5°C	14	14	14	14

TABLE X. AEROBIC PLATE COUNT (APC) IN COMMERCIALLY PACKED, NON-IRRADIATED AND LOW-DOSE IRRADIATED BACON AFTER REFRIGERATED STORAGE AT 5°C FOR 78 d, AS DETERMINED IN LEAN AND FAT PORTIONS OF THE PRODUCT

Added:		APC (cells/g)			
		Non-irradiated		7.5 kGy at 5°C	
$NaNO_2$ (ppm)	$NaNO_3$	Lean	Fat	Lean	Fat
0	0	$>3 \times 10^6$	$>3 \times 10^6$	10^a	10^a
0	0	$>3 \times 10^6$	3×10^7	10	10
20	0	7.8×10^6	7.4×10^6	10	10
40	0	2.6×10^6	1.1×10^7	10	10
20	20	$>3 \times 10^6$	$>3 \times 10^6$	10	10

[a] 10 = Negative at 1:10 dilution.

The incubation tests continued for 14 days. Since no swollen pouches were observed at the end of incubation, microbiological sterility tests were performed (APC, anaerobic plate count and test for the *C. botulinum* toxin). The sterility tests were negative and, consequently, the 32-kGy minimum irradiation dose for the smoked turkey slices was adopted.

The 22-kGy dose was used to check the safety margin for the product. Our experience during the 12 D determinations has shown that the "commercial sterility" (no swells, no toxin) is achieved with about 9 D sterilizing values. The 3 D values is the safety margin accounting for about 10 kGy (1 Mrad).

This approach is recommended for further considerations and studies by microbiologists, Codex Alimentarius experts, and the health authorities in individual countries responsible for developing and enforcing "Good Manufacturing Practices" to radappertized foods. We should not put the burden on food industry to determine the 12 D radappertization dose any time small changes are made in their specific product formulations.

2.2.3. Production microbiological safety tests

Table VII presents the sampling procedure for random withdrawal of samples from a production lot of radappertized foods for confirming the microbiological safety. This example is taken from the Production Guide used for processing irradiated meats for NASA [26].

TABLE XI. EFFECT OF NITRITE TO PREVENT COLOUR FADING IN REHEATED HAM, EVALUATED IMMEDIATELY AND 2 HOURS AFTER EXPOSURE TO AIR AT 21°C (n = 16)

Added[d] NO_2/NO_3 (ppm)	Non-irradiated		32 kGy at −40°C	
	0	2 (h)	0	2 (h)
25/0	7.8	6.4	6.9[a,b]	4.6
50/0	7.5	6.4	6.3[a]	4.6[a]
75/0	7.6	6.4	7.1[a,b]	5.2[a,b]
25/25	7.6	6.4	7.8[b]	6.3[b,c]
25/50	7.4	6.4	7.8[b]	6.5[c]
$P < 0.05$	NSD	NSD	SD	SD

[a,b,c] No significant difference between means with the same letter.

[d] Other additives: 2.4% NaCl, 0.3% sodium tripolyphosphate and 550 ppm sodium ascorbate-isoascorbate 1:1 mixture.

If the "incubation tests" showed a single swollen pouch, the entire lot was rejected and additional R + D work was applied (such as increasing the irradiation dose). If the "incubation tests" were negative, "the microbiological sterility tests" were performed. Only when both tests were negative was the product of the production lot declared microbiologically safe. Additional tests, of course, required checking each sample for the packaging integrity, be it a flexible pouch or metal can.

This is another example for consideration for the development of processing procedures for radappertized foods by the Codex Alimentarius and the health authorities of individual countries.

2.3. Reduction and elimination of nitrite

Irradiation sterilization of cured meats allows a drastic reduction of incoming nitrite to the levels needed only for characteristic colour and flavour of the items, while providing protection against *C. botulinum* by irradiation [27–31]. Table VIII gives the minimal additions of nitrite to irradiated-cured meats in comparison with the nitrite levels used in the non-irradiated products at present used by industry.

The irradiated-cured products with the low levels of added nitrite are free from residual nitrite and nitrosamines, including nitrosopyrrolidine (NPYR)

TABLE XII. SENSORY QUALITY OF IRRADIATED (30 kGy AT −30°C) BACON

Added: $NaNO_2$	$NaNO_3$ (ppm)	A/E[a]	Sensory quality: Colour	Odour	Flavour	Texture
0	0	275	5.7 ± 0.8	6.9 ± 1.0	6.5 ± 1.0	6.3 ± 1.1
0	0	550	6.2 ± 1.5	6.8 ± 1.2	6.3 ± 2.3	6.5 ± 1.7
20	0	550	6.7 ± 1.1	6.9 ± 1.0	6.0 ± 2.0	6.8 ± 1.1
40	0	550	7.2 ± 1.0	6.9 ± 1.0	6.6 ± 1.4	6.7 ± 1.3
20	20	550	6.5 ± 1.4	6.9 ± 0.9	6.4 ± 1.9	6.3 ± 1.6
$P < 0.05$			NSD	NSD	NSD	NSD

[a] 1:1 mixture of Na-ascorbate/Na-erythorbate.

in fried bacon, as shown in Table IX. In co-operative research with the USDA Laboratory in Philadelphia [32] it was established that:

(a) Irradiation destroys residual nitrite;

(b) Irradiated bacon cured without nitrite, or with the reduced nitrite (20 to 40 mg/kg), is free from nitrosamines;

(c) Irradiated bacon with a commercial level of added nitrite (120 mg/kg) contains only one-third nitrosodimethylamine (NDMA) and NPYR in comparison with non-irradiated paired samples;

(d) Irradiation (30 kGy at −40°C) destroyed over 95% of NDMA and over 85% NPYR added to bacon, thus indicating that irradiation has a destructive effect on preformed nitrosamines.

In addition, irradiation destroys common spoilage microorganisms in bacon, for which an irradiation dose as low as 7.5 kGy is sufficient (Table X) [33].

Irradiation of vacuum-packed non-nitrite bacon, with a dose as low as 5 kGy, or with a sterilizing dose (25 to 30 kGy), restores the characteristic colour in the fresh bacon as desired by the consumer because of the irradiation-induced reduction of metmyoglobin to deoxymyoglobin of the meat pigments [34–35].

In bacon, corned beef, or frankfurters, the use of small quantities (20 to 50 mg/kg) of nitrite is sufficient for getting the characteristic colour desired

TABLE XIII. PREFERENCE OF IRRADIATED AND NON-IRRADIATED BACON BY CONSUMER PANEL
(randomized block, 5 of 5, 35 subjects)

Added:			Preference scores	
$NaNO_2$	$NaNO_3$ (ppm)	A/E[a]	Non-irrad.	30 kGy at −30°C
0	0	275	5.0 ± 2.1	5.9 ± 1.7
0	0	550	6.3 ± 1.4	5.3 ± 1.8
20	0	550	6.4 ± 1.8	5.9 ± 1.9
40	0	550	6.8 ± 1.7	5.9 ± 1.9
20	20	550	6.4 ± 1.9	5.5 ± 2.2
Duncan	<0.5 LSD		0.80	0.65

[a] 1:1 mixture of Na-ascorbate/Na-erythorbate.

TABLE XIV. SENSORY PANEL OF IRRADIATED (30 kGy AT −30°C) PRE-FRIED BACON
Technological panel (n = 10)

Added:			Sensory quality			
$NaNO_2$	$NaNO_3$ (ppm)	A/E[c]	Colour	Odour	Flavour	Texture
0	0	275	5.8[a]	6.7	6.5	6.6
0	0	550	6.0[a]	7.2	6.1	6.4
20	0	550	7.1[b]	7.0	6.7	6.6
40	0	550	7.2[b]	6.7	6.6	6.7
20	20	550	7.6[b]	6.8	6.7	6.7
Signif. diff.			SD	NSD	NSD	NSD

[a,b] Means with the same letters are not significantly different.

[c] 1:1 mixture of Na-ascorbate/Na-erythorbate.

TABLE XV. CONSUMER PREFERENCE OF PRE-FRIED IRRADIATED AND NON-IRRADIATED BACON PROCESSED WITHOUT AND WITH REDUCED ADDITIONS OF NITRITE (n = 35)

Added: $NaNO_2$	$NaNO_3$ (ppm)	A/E[d]	Preference scores: Non-irradiated	Preference scores: 30 kGy at −30°C
0	0	275	5.1 ± 2.2[a]	5.9 ± 1.6
0	0	550	5.5 ± 2.2[a,b]	5.9 ± 1.6
20	0	550	6.2 ± 2.0[b,c]	6.0 ± 1.6
40	0	550	6.3 ± 1.9[c]	5.7 ± 1.8
20	20	550	6.7 ± 1.8[c]	6.2 ± 1.6
Signif. diff. ($P < 0.05$)			SD	NSD

[a,b,c] Means with the same letters are not significantly different.

[d] 1:1 mixture of Na-ascorbate/Na-erythorbate.

by the consumer. However, in ham, an addition of a small amount of nitrate (25 mg $NaNO_3$/kg) is needed, together with 25 mg $NaNO_2$/kg, to prevent the colour fading after irradiation, as shown in Table XI [28–29].

Irradiated bacon, because of its nature, produced without nitrite, received high-quality scores for odour, flavour, and texture, and acceptable scores for colour (even though the colour of the bacon after frying is reddish-brown rather than pink), as shown in Table XII. Consumer scores for preference of irradiated bacon cured without nitrite were also in an acceptable range, as shown in Table XIII, which was one of numerous tests conducted at the Natick Labs [27, 28, 31, 33].

It is also of practical importance to mention that bacon does not need to be irradiated in a frozen state, even with a radappertizing dose, to obtain an acceptable product.

2.3.1. *Pre-fried bacon*

Pre-frying bacon to 40% of its raw weight before vacuum-packaging and irradiation results in a product with water activity (A_w) below 0.93. At this A_w, *C. botulinum* hazard is prevented. However, the viable microorganisms, including *Staphylococcus aureus*, are the bacterial contaminants acquired during packaging of pre-fried bacon [36]. To destroy these microorganisms a dose of only 5 to 10 kGy is sufficient as demonstrated in our unpublished recent research.

Tables XIV and XV give information about the high quality of irradiated pre-fried bacon [27–28]. The results given in these tables are self-explanatory. In our latest experiments on pre-fried bacon, equally high quality scores were obtained when the product was irradiated at refrigerated temperatures (5 to 10°C), thus eliminating the need to freeze the product before irradiation.

Returning to our general topic on combination processes in food irradiation, it appears that a combination of reduced water activity in the product prior to irradiation should receive more attention and more study in the future. Along the same line of thought, partial dehydration or desiccation, combined with low doses of irradiation, should receive more attention and research. In a study at Natick Labs by Agarwal, from the Bhabha Atomic Research Centre of India, it was shown that partially desiccated chickens and lamb meat rolls, followed by irradiation with 5 and 10 kGy at 5°C, resulted in acceptable products which were shelf-stable without refrigeration for three months, the longest storage time investigated [37]. The samples analysed were free from microbiological spoilage and *C. botulinum* toxin after a three-month storage at 21°C.

3. THE NEED FOR RADAPPERTIZED FOODS

There is a definite need for radappertized foods, as already demonstrated by radappertization of four foods for NASA space flight feeding, and hospital diets for sterile feeding environment in Europe [38] and, lately, in the United States by Martin Welt, Radiation Technology, Inc., in his September 1980 presentation at the 26th European Meat Research Congress in Colorado Springs [39]. The existence of canned foods and canning is a proof that there is a need for shelf-stable foods. Radappertization provides a great opportunity for canning industries the world over to increase their productions by (a) adding a series of new products (whole roasts of beef, pork, lamb, etc.); (b) portion-controlled dry-packed items (ground meat and poultry patties, restructured and whole muscle steaks and chops); (c) dry-packed chicken parts and solid-fill meat rolls; (d) reducing or eliminating water or brine solutions which are needed in conventional canning for heat penetration; (e) producing the items of higher nutritional value (less destruction of vitamins and essential amino acids by radappertization than by thermal retorting); (f) substantial savings in energy.

This is just a very broad review of the benefits of radappertization. It is to be hoped that the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI) will continue its work, including deliberations on radappertized foods, to bring this important application of ionizing radiation on food preservation to positive practical recommendations as was accomplished during the October 1980 Meeting in Geneva, Switzerland, on low-dose irradiated foods [40].

4. CONCLUSIONS AND RECOMMENDATIONS

(a) Radappertization is a feasible process, as demonstrated by 27 years of research and development work in the United States of America, supported by the US Congress and conducted by the US Army until 1 October 1980.

(b) Radappertization of meats, poultry, and seafood is a combination process of mild heat treatment, selective use of food additives, vacuum-packaging, and irradiation.

(c) Radappertization will ease the growing demand for safe and shelf-stable foods, both in the developed and in developing countries.

(d) Radappertization will extend the food canning industry by providing new and convenience-type products, better-quality existing canned and more nutritious products, produced at a lower expenditure of total energy needed for the processing, storage, and distribution of food.

(e) The universal clearance by health authorities of the radappertization process is needed before its industrial application. The long-term, multi-generation animal feeding studies on the wholesomeness of radappertized chicken, supported by extensive chemical studies on radappertized chicken, ham, beef, pork, and bacon in the USA, should provide a basis to clear radappertization as a process for all foods.

(f) The interest and assistance of the international agencies, such as the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Foods, the Codex Committee of Food Additives, and the Codex Alimentarius Commission, are needed for obtaining universal clearance for the radappertization process.

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