Technical Evaluation of Gamma-Irradiation Pretreatment on Quality Preservation for Fresh Fish

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ABSTRACT

A comprehensive review and evaluation on the use of gamma-irradiation for preserving fresh fish quality has been made. The advantages and limitations of using gamma-irradiation of less than 1 M rad have been re-evaluated and compared with previous tests at the Halifax laboratory in terms of physical, organoleptic and some post process quality assessments. Cod, mackerel, and scallop were chosen as the models for lean, fatty and shell fish respectively. The irradiation process can prevent bacterial spoilage in fish, particularly when chilling and/or handling practices are inadequate, but the potential catalytic influences on enzymatic and chemical deterioration during the post-mortem period should also be considered. Some considerations and reservations concerning the changes in overall quality for irradiated fish are discussed. Before more research is completed, the gamma-irradiation process should not be used for shellfish, fatty fish and various prepared and frozen fish products made from Canadian Atlantic species.

Évaluation technique du prétraitement par irradiation du poisson frais aux rayons gamma pour en préserver la qualité

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Résumé

Ce rapport présente une étude détaillée ainsi qu'une évaluation de l'application des rayons gamma à la préservation de la qualité du poisson frais. Les avantages et les défauts techniques de l'utilisation des rayons gamma de moins d'un micron ont été, au laboratoire d'Halifax, réévalués et comparés à des tests antérieurs, en termes d'évaluation de la qualité sur les plans physiques, organoleptiques et autres aspects postérieurs au traitement. On a choisi la morue, le maquereau et les pétoncles pour différentes recherches variées, comme modèles d'échantillons de poissons maigres et gras, et de fruits de mer. Le processus d'irradiation peut prévenir la détérioration du poisson par les bactéries, surtout lorsque la manutention et le refroidissement sont inadéquats, mais son influence catalytique sur la détérioration causée par les enzymes et les produits chimiques devrait également être considérée surtout si le poisson y est soumis post mortem. On y discute également de certaines considérations et de certaines mises en garde portant sur les modifications apportées à la qualité globale quand l'irradiation sert à conserver la fraîcheur du poisson. Avant de poursuivre la recherche plus avant, il faudra ne pas se servir du processus d'irradiation par les rayons gamma des fruits de mer, du poisson gras, et des produits du poisson préparés et congelés des espèces de l'Atlantique canadien.

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INTRODUCTION

The Canadian Fish Processing Industry has intensified efforts in recent years in upgrading the quality of fresh fish and in marketing, especialy in North America. Seafood irradiation was the subject of various studies in the Halifax laboratory of the Department of Fisheries and Oceans in the 1960s, and an extended pilot test in the Nova Scotia fishing industry (Ackman, et al, 1966; Laycock & Regier, 1970; Power, et al, 1964 a & b, 1966; Laycock & Longard, 1973; Hashish, et al, 1966; Ostovar, et al, 1967 and 1971). It is one of several experimental approaches for enhancing fish quality and attaining longer shelf life of fresh fish products (Ke, 1982).

The irradiation of fish products has been comprehensively reviewed and commented on by Giddings (1984). The application of irradiation to various fish products are as follows: (1) Pasteurization of certain fresh finfish and shellfish (75-250 K rad); (2) sanitization of frozen products and dehydrated high-protein derivatives (0.25-1 M rad); (3) destruction of insect eggs and larvae (less than 0.10 M rad); and (4) sterilization of prepared fishery products for long-term, non-refrigerated shelf-life (3-4 M rad).

Market life extension of selected fresh fish and shell fish held in iced and refrigerated storage, as well as overall quality consideration, are the focus of this report. The reported results of a number of different authors have been summarized. This report details the various experiments carried out in the Halifax laboratory.

2. EXPERIMENTAL EQUIPMENT AND METHODS

The source of gamma radiation used in the studies to be described was a 15,216 curie cobalt-60 Gammacell designed and built by Atomic Energy of Canada Ltd. (Rice and Smythe, 1960). It consisted of an annular cage holding the cobalt-60 source, surrounded by a lead shield with a long cylinder which can be moved vertically through the center of the source. In the center section of this cylinder was the sample chamber; the upper and lower sections of the cylinders were lead and served as a shield. The sample was placed in the sample chamber and the cylinder lowered until the chamber was in the center of the source. A timing mechanism was used to raise the cylinder automatically after any desired exposure time. Other similar types of -irradiation units were also used for pretreating some fish samples. The dose was controlled by varying the length of time of irradiation (Power, et al, 1964 & 1966).

Bacterial counts (Power, et al, 1964) were made by blending the fillets with twice their weight of water in a sterile Waring blendor for 1 minute and then making dilutions of this homogenate in physiological saline solution. Single plates were poured from each dilution. Pseudomonads and achromobacters comparative investigations were made based on the procedure of Laycock and Regier (1970).

The analyses for trimethylamine, total volatile bases (TVB), thiobarbutonic acid volume (TBA), free fatty acid (FFA) etc, were performed as outlined by Wayewoda and Ke, 1980 (Ke et al, 1982). Samples of iced and frozen meat for glycogen analysis were digested with 30% KOH, the glycogen precipitated with ethanol and determined according to Seifter, et al, (1950).

The guidelines and standards for physical grading and organoleptic evaluations are found in previous Halifax laboratory reports (Power, et al, 1964 & 1966; Ke, et al, 1978 & 1982; Wayewoda, et al, 1980).

The fish samples used in the investigations were from Nova Scotia waters, iced well and taken without delay to the Halifax laboratory, usually with a caught age of less than 12 hours before treatment. The samples were near ice temperature (0-2°C) when placed in the Gammacell for irradiation and the increase in temperature during treatment was less than 4°C, as estimated from similar material equipped with copper-constantan thermocouples. The greater part of this temperature increase is probably due to thermal conduction and radiation from the lead shell of the irradiation unit; only a small part can be attributed to the effect of gamma radiation. An iced control and a frozen control were prepared identically to the irradiated sample and kept at 0-2°C and -26°C, respectively.

3. RESULTS AND DISCUSSION

The results of total bacterial counts in various samples iced for up to 21 days after irradiation treatment are compared with the iced and frozen control in Table 1. The data clearly indicates that gamma-irradiation is very effective in preventing the growth of microorganisms in these fish samples. It has been well documented that bacterial spoilage in terms of TMA formation, as shown in Fig. 3, can be effectively reduced by irradiation pretreatments (Power, et al, 1966; FAO/IAEA, 1970; Hovart, et al, 1976; Giddings, 1984; Ouwerkerk, 1982). Pseudomonads were reduced by 2 to 3 log orders by irradiation, and achromobacters and gram-positive isolates predominated in the immediate post-irradiation flora. Little difference could be detected in either types or relative proportions of organisms occurring during storage of unirridated fish of different quality. Pseudomonads outgrew achromobacters and dominated the spoilage flora in all cases (Table 2). After spoilage, however, the growth rate of pseudomonads declined markedly. In irradiated fish, achromobacters predominated throughout storage. In fish of better initial quality, bacterial numbers were 1 to 2 log orders higher at spoilage than their unirradiated counterparts and in the poorer quality of irrradiated samples. The increased number of organisms was accompanied by a radical change in the character of the predominant achromobacters.

The glycogen content did not change in the frozen scallop muscle in 38 days (Fig. 1). Glycolysis in the iced samples considerably reduced the glycogen in about 14 days, although about 0.1 % remained even after 38 days. This rate is very much slower than that observed in cod held 2-3 days at 0°C. Samples treated with 400,000 rads showed little difference from the iced samples, but the inital glycogen level in the 800,000-rad treated samples was only about 0.2%. In the second series, glycogen values after 3 days storage were 0.80 and 0.67% respectively, for the frozen, and unirradiated-iced samples, and 0.28, 0.29, and 0.51% respectively, for iced samples irradiated at levels of 75,000, 150,000, and 300,000 rads. This again indicates that irradiation did not damage the glycolytic mechanism, the warming during treatment probably accounting for the greater glycolysis occurring in the irradiated samples as compared with the iced sample.

The results of taste testing are shown in Fig. 2. The points are shown only for the samples irradiated, showing a reasonable scatter of results. With the numerical scoring system used, ranging from 100 (perfect) to 0 (very badly spoiled), a score of 40 or lower denotes unacceptability.

There was little change in the frozen control which remained at top quality throughout 30 days' storage at -26°C, although some loss of the bland, fresh, seawater tang of the freshly frozen material was observed at 23 days. The iced, unirradiated controls were judged to be spoiled after 10-16 days. Stale, slightly sour odours and flavours were noticeable in these samples at 10 days (Tables 3 & 4); very stale, sour, ammonia-like flavours and odours were predominant at 16 days. The odours were especially objectionable when the bags were opened immediately after steaming. The onset of spoilage at 10 days was substantiated by an increase in TMA content to a level of 8 mg N/100 g (Fig. 3), followed by a rapid rise to 37 mg N/100 at 16 days, signifying advanced spoilage. These TMA values are in agreement with those found in cod fillets, with reported TMA levels of 4 to 15 in spoiling fillets and 15 to 30 or more in the spoiled material.

Texture changes in the cooked irradiated fillets were less pronounced than the flavour changes (Table 4). Unlike scallops, where irradiation levels in excess of 150,000 rad imparted a spongy, mushy texture (Table 3), haddock fillets receiving doses of 125,000 and 250,000 rad were mealy in texture following irradiation, and gradually developed a slight toughness and stringiness on iced storage.

Examination of the raw fillets indicated the development of objectionable odours and appearance just prior to unacceptability of the cooked product by the taste panel. This had also been observed with irradiated scallops (Table 3). In all fillets, controls and irradiated samples alike, repulsive odours described as sour, sweet-putrid, and trimethylamine-like, were noted approximately one week before the cooked samples were judged unacceptable.

The changes in quality indicators such as TVB, TMA, peroxide values, FFA, TBA, total bacterial counts (TBC), and organoleptic

scores, selected from various tests are shown in Fig. 4. As indicated in Tables 1 and 2, the bacterial deterioration in quality during iced holding tests was effectively reduced by irradiation treatment. The TMA and TVB which result from both enzymatic and bacterial action give a positive indication as do the organoleptic scores and TVB. However, the catalytic effect of irradiation on lipid oxidation and hydrolysis must be viewed as a main disadvantage for the process, particularly in the treatment of fatty fish (Ackman, 1966, Ke, 1978). The drip loss and the bonded water change were also effected, but the results were considered to be somewhat inconclusive.

The results of another series of experiments in which fillets were pretreated with 0.5 M rad dose gamma irradiation are shown in Table 5. A three-class grading system (Wayewoda and Ke, 1980; Ke, et al, 1983) was used for the overall quality assessment. Grade A is top quality, Grade B is of acceptable quality and Grade F is unacceptable or reject quality. Physical evaluation and an organoleptic panel and/or laboratory tests were employed to determine grades. Samples of three types of fish: cod (lean), mackerel (fatty), and scallops (shellfish) were selected to compare the effect of irradiation on different types of seafood.

Part A in Table 5 shows comparisons for fish of both grade A and B during iced holding tests up to 14 days with 0.5 M rad irradiation pretreatments. Except for a slight improvement in quality for the irradiated mackerel fillets, there were no differences in quality for both cod and scallops for 14-day iced storage. Part B in Table 5 shows the results of Grade A fish only during identical iced storage after the irradiation process. The decreases in the percentage of freshness (Grade A) of the irradiated cod and the control were the same going from about 98% to 25% for 14-day storage in ice. However, the irradiated scallop and mackerel samples indicated a higher percentage of Grade A loss than the non-irradiated controls. As a matter of fact, no irradiated scallop and mackerel could be graded highly after 7 days on ice, mainly due to odour, colour, as well as texture changes (Tables 3 & 4).

Part C in Table 5 gives the results of fish samples held at 13°C (no ice) after irradiation treatment. This shows the major advantage of gamma-irradiation pretreatment for quality preservation on both lean and fatty fish samples. The irradiated cod fillet was held for 4 days with about 20% rejected while the non-irradiated control had 95% rejected under the same conditions. The effectiveness of preventing quality and freshness loss for unchilled fish is positively demonstrated with these results.

Since auto-oxidation is catalyzed by the ionic irradiation process (Ke, et al, 1978), frozen quality in terms of rancidity development and bonded water loss is affected by irradiation pretreatment, especially for high fat-containing mackerel and flavour-oriented scallop samples as shown in Table 5 (Section D). For cod fillets, there was no difference between the irradiated mackerel and scallops deteriorated far quicker in frozen storage than did the controls. Therefore, the negative effects on the quality of fatty fish and shellfish must be considered when irradiation is recommended for various frozen and prepared fish products.

We have recently reviewed and re-evaluated the accumulated scientific knowledge pertaining to quality preservation by irradiation. We conclude that modern handling technology is adequate to control problems created by spoilage microorganisms and that the gamma-irradiation pretreatment for fish is an addition to the methods of control of some fishborne pathogens and is not hazardous to health. With the limited information and experience from our pilot tests of using -irradiation on fresh fish in the Atlantic Area, low dose (less than 0.5 M rad) radorization may be applied as a pretreatment operation for some species of fresh lean fish. The irradiation process should not be used when freezing fatty fish and shellfish. However, the advantages of extending shelf-life and inhibiting bacterial deterioration for fresh fish through irradiation treatment when the chilling and handling operation is inadequate have been demonstrated. We also feel that more research is required to understand the quality implications of applying irradiation to prepared fish products.

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TABLE 1. SPC (BACTERIAL COLONIES/GRAM) IN SAMPLES WITH AND WITHOUT GAMMA-IRRADIATION TREATMENT

(a) Scallop

Icing (Days)	Iced Control	Frozen Control	Irradiated Samples 0.40	Irradiated Samples 0.80 M rad
1	2,100	2,800	10	10
4	4,800	2,000	150	10
8	12,900	3,200	78	900
15	12,600	4,000	180	8,750
18	460,000	2,800	6,300	1,500,000

(b) Haddock

Icing (Days)	Iced Control	Frozen Control	Irradiated Samples 0.075	Irradiated Samples 0.150	Irradiated Samples 0.250 M rad
1	11,000	21,000	5,200	21	24
6	201,000	3,000	6,600	8,100	120
10	10,500,000	2,700	2,500,000	116,000	21,300
16	40,200,000	15,000	12,300,000	8,400,000	144,000

(c) Cooked Lobster Meat

Icing (Days)	Iced Control	Frozen Control	Irradiated Samples 0.075	Irradiated Samples 0.150	Irradiated Samples 0.250 M rad
1	6,900	7,500	120	100	100
7	129,000	6,000	100	100	100
14	45,000,000	6,300	240,000	126,000	78,000
21	510,000,000	5,600	90,000,000	3,300,000	2,100,000

TABLE 2. TOTAL BACTERIAL COUNTS OF PREDOMINANT ISOLATES OF HADDOCK FILLETS BEFORE AND AFTER 100 KRAD OF IRRADIATION

Sample			% of Bacteria Flora								
			Pseudomonads								
Irradiated (M rad)	Icing (Days)	Total Count (log No)	I and II	III and IV	Pultre-faciens	Achromo-bacter	Flavo-bacterium	Micrococci	Bacillus	Coryne-forms	Vibrio
0	2	4.88	19	5	2	45	15	4	2	4	2
0.100	1	3.05				52			45	3	
0	5	5.20	11	2	7	60	3	6	2	8	1
0.100	5	4.05	1			53	1	12	13		
0	9	5.70	30		11	49	2	1		5	1
0.100	9	4.08	4		4	75		13	2		2

* From the report of Laycock & Rogier (1970).

TABLE 3. CHANGES IN TASTE AND TEXTURE CHARACTERISTICS AFTER COOKING OF CONTROL AND IRRADIATED SCALLOP MEAT STORED IN ICE.

	Irradiation level (rads)									
	0		75,000[b]		150,000[b]		400,000[c]		800,000[c]	
Days Icing	Taste	Texture	Taste	Texture	Taste	Texture	Taste	Texture	Taste	Texture
1	Sweet	Dry-soft, tender					Neutral some off-flavours	Sl. spongy	Definite off-flavour*	Gummy, rubbery*
4	Tasteless-to-sweet	Typically firm, sl. fibrous sl. rubbery	Tasteless-to-sweet	Typically firm, sl. fibrous sl. rubbery	Tasteless	Some softness	Neutral-to burnt	Spongy	Scorched, burnt	Gummy, soft
7	Acid-sweetish	Some loss of firmness	Neutral	"	Neutral	Soft	Burnt, scorched*	Spongy tough*		
14	Sl. sour-to bitter*	Spongy	Neutral	"	Sl. off-flavours	Spongy soft	"	"		
21	Sour, bitter	Unpleasant soft, mushy*	Neutral	"	Musty, sl. burnt	"				

From Power, et al, 1964.

TABLE 4. CHANGES IN TASTE AND TEXTURE CHARACTERISTICS AFTER COOKING OF CONTROLS AND IRRADIATED HADDOCK FILLETS STORED IN ICE[a].

	Irradiation level (rads)							
	Untreated		75,000 rad		125,000 rad		250,000 rad	
Days After Filleting	Taste	Texture	Taste	Texture	Taste	Texture	Taste	Texture
1	more or less tasteless	tender, sl. dry	more or less tasteless	sl. mealy	sl. stale sl. burnt	mealy	sl. stale sl. burnt	mealy
6	sl. stale	sl. mealy	more or less tasteless	dry some mealiness	sl. burnt	mealy, stringy	sl. burnt	mealy, stringy
10	stale, sl.[b]	mealy sl. tough	more or less tasteless	sl. dry	sweet- burnt	mealy stringy	sweet- burnt	mealy, stringy
16	sour, NH_3 very stale	mealy	more or less tasteless	sl. dry	sweet- burnt sl. stale	mealy, stringy	sweet- burnt sl. stale	mealy, stringy
23			some off- flavours	sl. dry	sweet- burnt sl. stale stronger irr.odours	mealy, stringy	sweet- burnt sl. stale stronger irr.odours	mealy, stringy

[a]The frozen control fillets maintained the initial tender, slightly dry texture and bland-to-neutral flavour to 30 days at -26°C.

[b]Unacceptable or becoming unacceptable.

From Power, et al, 1964.

TABLE 5. GRADING OF (A) FISH SAMPLES PRETREATED WITH GAMMA-IRRADIATION (0.5 M RAD) AND (B) THE NON-IRRADIATED CONTROL

Fish sample		Iced holding % Grade A & B*	2	4	7	14 days
(A) Icing storage tests						
Cod fillet	A		100	100	98	98
	B		100	98	100	96
Mackerel fillet	A		100	96	90	92
	B		98	100	96	80
Scallop meat	A		98	100	90	81
	B		100	100	98	94
(B) Freshness evaluation tests		Iced holding % Grade A*	2	4	7	14 days
Cod fillet	A		98	75	30	0
	B		100	60	10	0
Mackerel fillet	A		60	40	0	0
	B		90	60	20	0
Scallop meat	A		70	20	0	0
	B		100	96	50	0
(C) Holding tests at 13°C		Hold at 13°C % reject grade*	2	4	7	14 days
Cod fillet	A		10	20	40	75
	B		70	95	100	NA
Mackerel fillet	A		20	30	45	80
	B		80	100	NA	NA
(D) PPQ evaluation		Frozen at -26°C % Grade A only*	1	3	6	12months
Cod fillet	A		90	95	80	60
	B		95	80	70	50
Mackerel fillet	A		50	15	0	0
	B		80	60	30	0
Scallop meat	A		60	10	0	NA
	B		95	85	60	NA

* Three grades system was used as follows: A-excellent; B-acceptable; F-reject grade.

**Data selected from previous reports (Power, et al, 1964; Laycock, et al, 1970; Ke, et al, 1978, 1982, 1983).

LEGENDS TO FIGURES

Fig. 1. Glycolysis in iced irradiated scallop meat 0.4 M (-----)and 0.8 M rad (-.-.-) and non-irradiated frozen control and iced control (_____) (Power, et al, 1964[a]).

Fig. 2a. Organoleptic scores of gamma-irradiated haddock fillets (0, 0.125 & 0.250 M rad) and frozen control (-26°C) (*Power, et al, 1964[b]).

Fig. 2b. Organoleptic scores of scallop meat: frozen control (-26°C) (A), irradiated at 0.075 M rad (B), 0.150 M rad (C), 0.300 M rad (D), iced control (E), 0.40 M rad (F), and 0.800 M rad (G).

Fig. 2c. Organoleptic scores for -irradiated and control samples of cooked lobster claw and tail meats stored in ice for various periods (*Dyer, et al, 1966).

Fig. 3. TMA change in irradiated and control sample during iced holding tests (3A). Scallop meat, (A), iced control, (B, C, and D) irradiated treatments at 0.075, 0.150, and 0.400 M rad, and (E) frozen controls (3B) lobster meats.

Fig. 4. Various quality changes in irradiated fish samples (0.5 M rad) during holding tests in ice (*Ke, et al, 1978; Kumta, et al, 1970); control (_____); irradiated (----------).

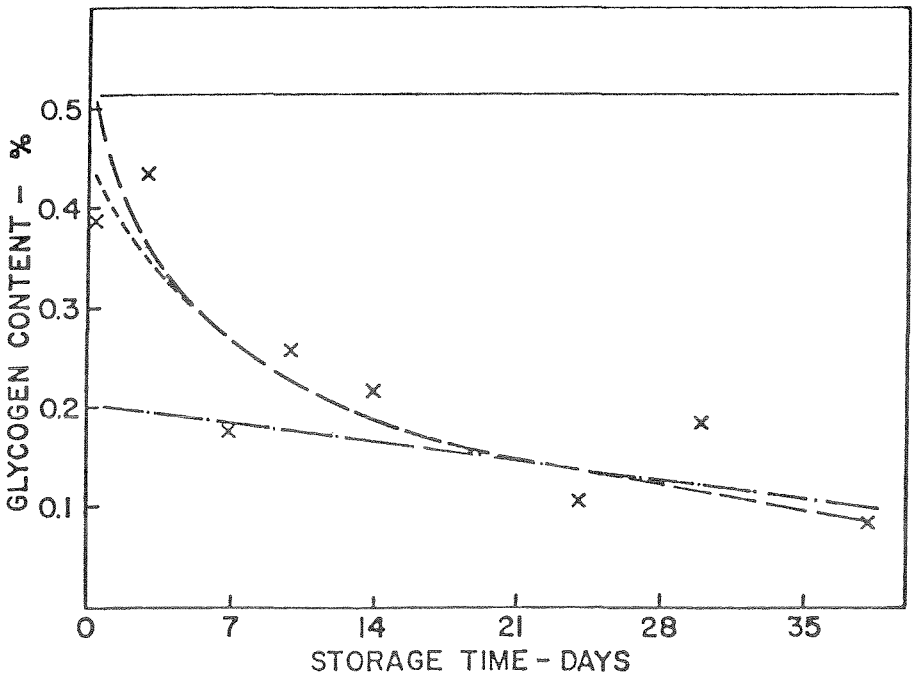


Fig. 1 Glycolysis in iced irradiated scallop meat of 0.4 Mrad (----), and 0.8 Mrad (-·-·-) with the non-irradiated (Power et al., 1964a) frozen control (——) and ice control (— —).

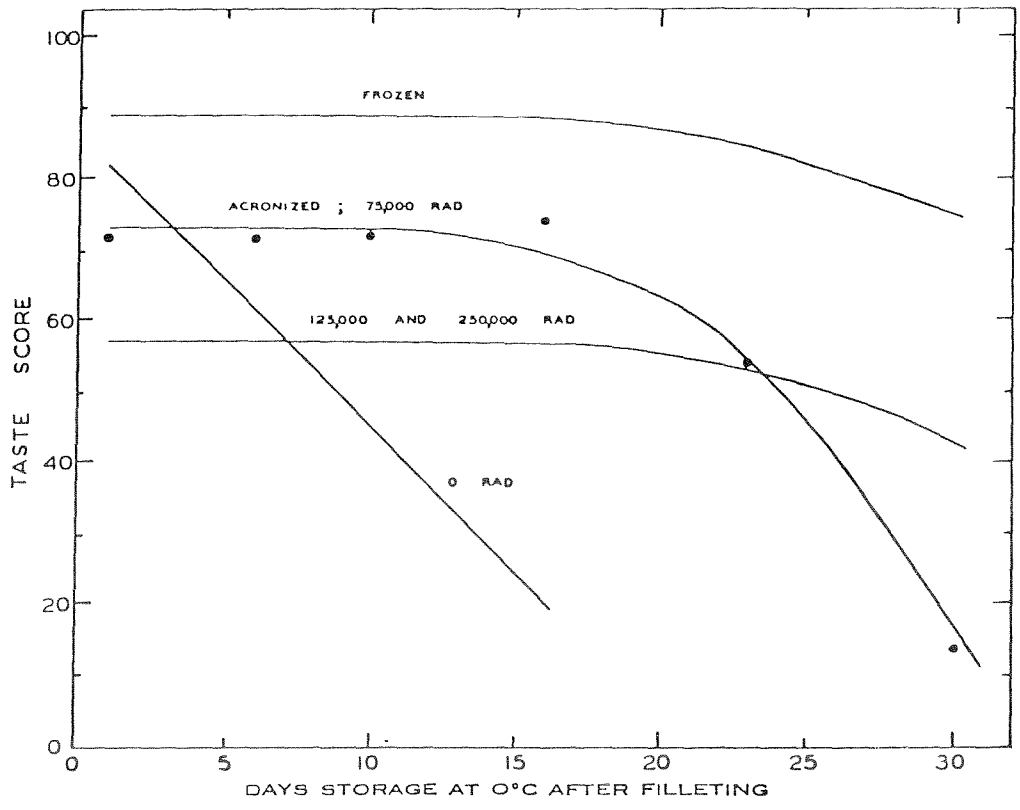


Fig. 2a. Organoleptic score various r-irradiated haddock fillets (0, 0.125 and 0.250 Mrad) and the frozen control of -26^{o}C (Power et al., 1964b).

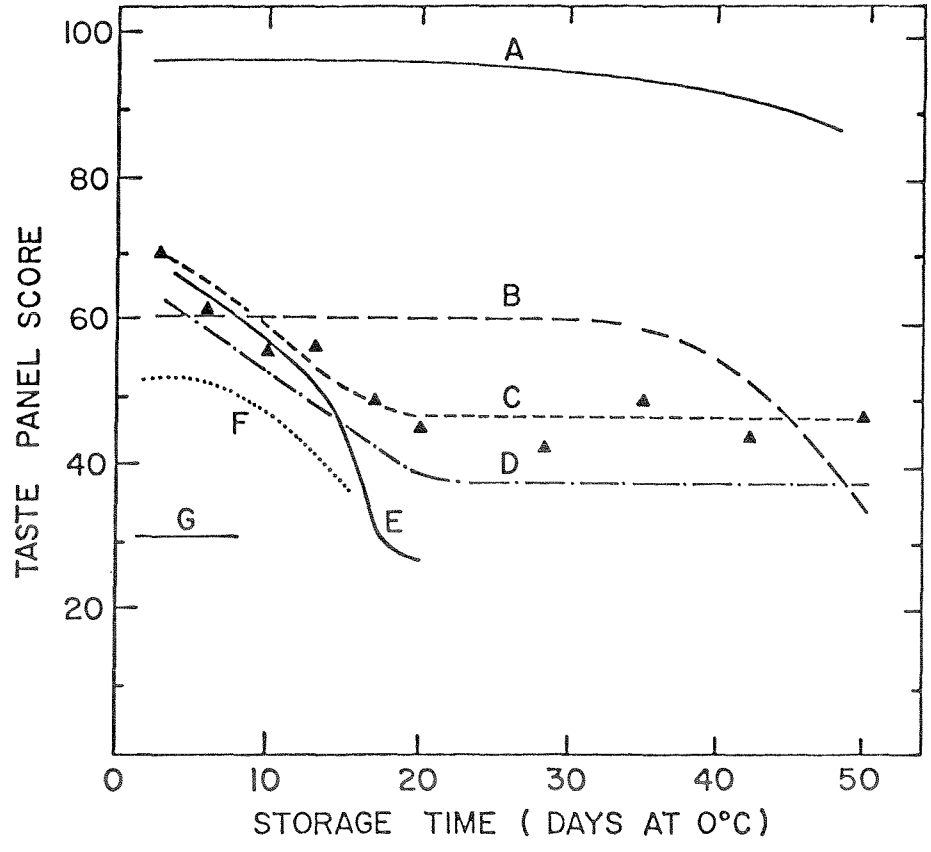


Fig. 2b. Organoleptic score of iced scallop meat of the frozen control at -26°C (A), irradiated of 0.075 Mrad (B), 0.150 Mrad (C), 0.300 (D), iced control (E), 0.40 Mrad (F), and 0.800 Mrad (G).

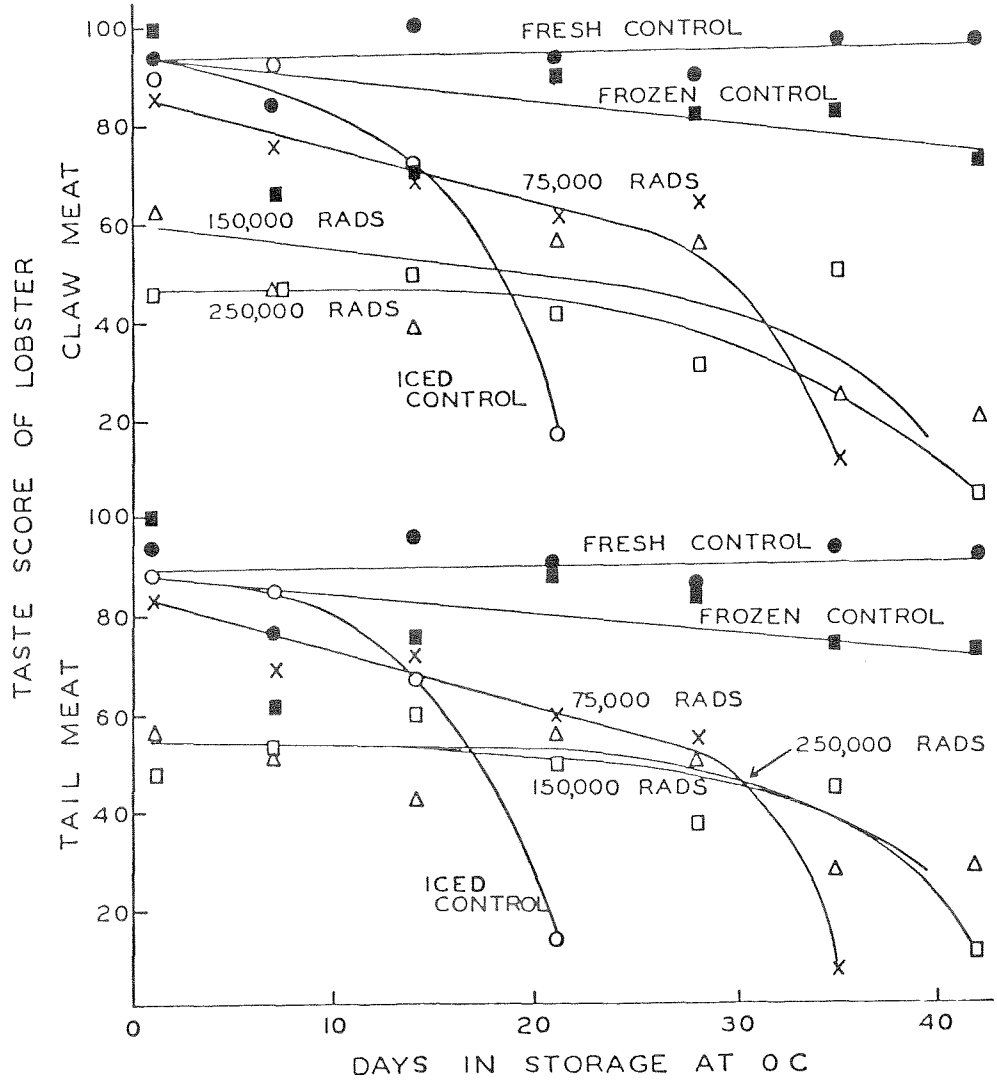
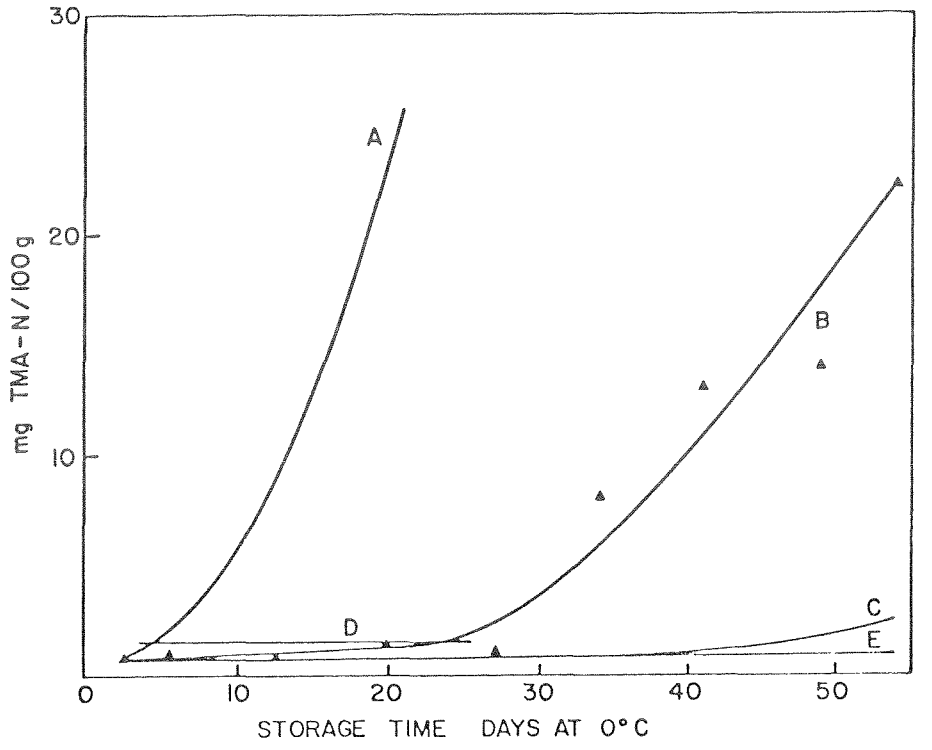


Fig. 2c. Organoleptic scores for r-irradiated and control samples of cooked lobster claw and tail meats stored in ice for various period. (Dyer et at., 1966)



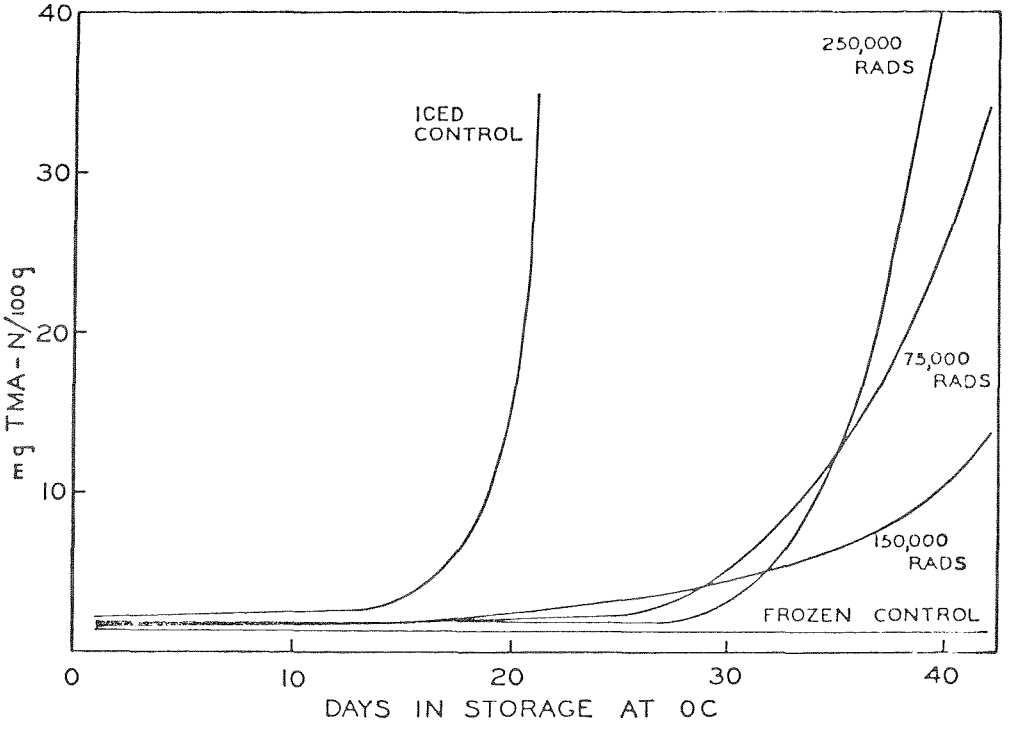
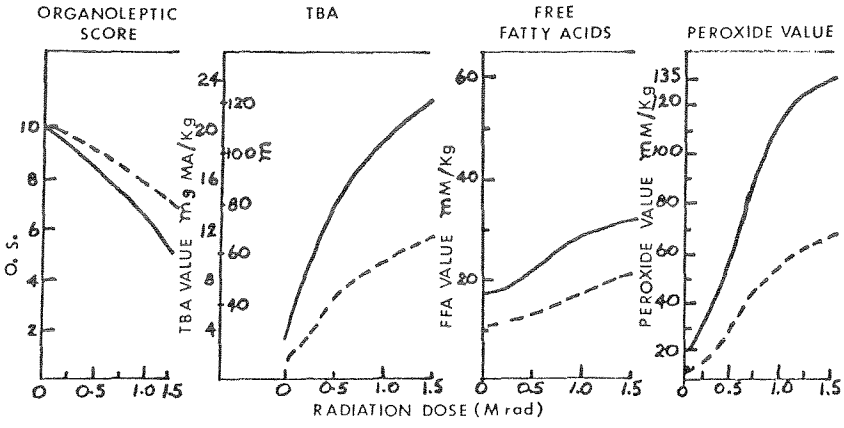


Fig. 3 TMA change in irradiated and control cample during icing holding tests. (3a) scallop meat curve A-iced control, curve B, C, and D for irradiated treatments at 0.075, 0.150, and 0.400 Mrad, and curve E, frozen controls. (3b) lobster meats.



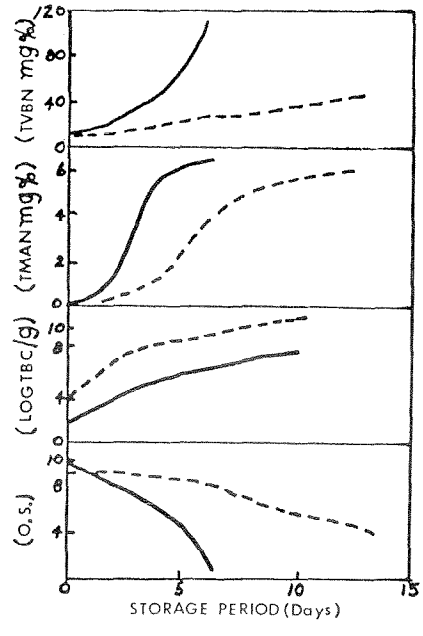


Fig. 4 Various quality parameters changes of irradiated fish samples (0.5 Mrad) during icing held tests. (KE et al., 1978; Kumta et at., 1970)