IRRADIATION PRESERVATION OF FOODS

I. Prolongation of the keeping quality of fresh fish by radiation pasteurization

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Studies on the prolongation of the keeping quality of fresh fish by radiation pasteurization were started some ten years ago. In the U.S.A. the radiation pasteurization of fish was taken in the U.S. Atomic Energy Commission's programme in 1960. In the same year Proctor *et al.* (1960) and Nickersson *et al.* (1960) published the results of their studies on the subject. Later investigation results have been reported in international congresses and symposiums dealing with the irradiation of foodstuffs (National Academy of Sciences 1965, International Atomic Energy Agency 1966, Kreuzer 1969). Comprehensive reviews on irradiation preservation of fish have been provided by Slavin *et al.* (1966), Hobbs and Shewan (1967), Ronsivalli *et al.* (1967), and Meyer-Waarden (1968). Among the most recent studies should be mentioned the works of Ampola *et al.* (1969), and Ehlermann and Münzner (1969 a, b, c). The purpose of pasteurization radiation is to destroy most of the bacteria causing the deterioration of fish. The results show that the shelf life under refrigeration of some 30 species of the studied fish and other seafoods, which include the more common commercial species of fish, can be prolonged considerably by radiation pasteurization with doses of 300—500 krad. The shelf life of most fish treated in this way was two to three times longer than that of the non-irradiated fish (Slavin *et al.* 1966, Hobbs and Shewan 1967). However, not much is as yet known about the factors influencing the quality of radiation pasteurized fish. According to Slavin *et al.* (1966), not only the radiation dose but also the quality of the raw material has a marked influence on the shelf life and quality of the irradiated product. Other factors affecting the quality are methods of processing, handling, packaging and storing. Radiation pasteurization has a significant economic potential for the fishing industry, and great expectations are accordingly placed on having an irradiator on board the fishing vessel enabling the fish to be irradiated immediately after capture (Meyer-Waarden 1968, Carves *et al.* 1967).

The present study deals with an investigation made on prolonging the shelf life of pike and saithe under refrigeration by radiation pasteurization. The changes in the quality of the fish were followed by determining the quantity of living bacteria and by organoleptic analyses. Pike and saithe are in great demand in Finland. Saithe is imported deep-frozen from Norway in great quantities.

Materials and methods

The pike (*Esox lucius*), weighing 1—1.5 kg, were caught in the Gulf of Finland in the vicinity of Helsinki. After being caught the fish were iced immediately while still alive. On the same day they were packed on shore separately in polyethylene bags, which were tightly sealed. Part of the catch was cleaned before packing by cutting the heads off and by eviscerating the fish. The fish in bags were stored in crushed ice in styrox insulated containers. The gutted and the ungutted fish were subjected to radiation while some of the ungutted fish were stored without radiation for comparison. The radiation of the fish was performed in the cobalt-60 irradiator located in the Department of Radiochemistry, University of Helsinki. The doses used for ungutted fish were 150, 250, 300, 600 and 1200 krad, for gutted fish the doses were 600 and 1200 krad. After this treatment the irradiated as well as the non-irradiated fish were stored in the styrox insulated container under refrigeration at 0° C.

The saithe (*Gadus virens*), mean weight 0.7 kg, were caught off the coast of Central Norway in the vicinity of Kristiansund. The fish were brought alive in the transport ship in tanks filled with sea water to a fish factory, where they were packed separately into polyethylene bags, deepfrozen and directly transported to Helsinki in a temperature of —18° C. After defrosting the fish were packed and stored as described above. The radiation doses used were 150 and 250 krad, part of the fish was again left non-irradiated for comparison.

For bacteriological study samples were taken from fish muscle according to the method described earlier (Linko *et al.* (1961)) In the samples the total counts of viable bacteria were computed from nutrient agar plate and calculated per gram of muscle.

The organoleptic testing was performed by a trained panel of eight persons, who evaluated the flavour and odour, the texture, the colour of the skin and the flesh of the samples cooked in water as well as the appearance of uncooked samples. Fish from the same catch, deepfrozen at the beginning of the experiment and stored at —25° C, were used for comparison. A 9-point scale was used in the evaluation, 9 representing the best possible quality and 1 the organoleptically unacceptable quality.

Results and discussion

When the effect of the different doses of radiation on the quality of the pike after 1, 3 and 7 days in refrigeration storage was evaluated organoleptically, the results presented in Table 1 were obtained. The results show that, after one day had passed from the beginning of the experiment, the organoleptic scores of the non-irradiated fish were distinctly higher than those of the irradiated fish. There was no marked difference between the products irradiated with low doses, though the fish irradiated with doses of 150 and

Table 1. Average taste-panel scores on irradiated whole, ungutted pike packed in polyethylene bags and stored at 0° C.

Storage time (days)	Radiation dose (krad)					
	0	150	250	300	600	1200
1	8.4	7.8	7.7	7.2	7.3	6.4
3	8.5	7.6	7.1	7.1	5.6	5.7
7	7.3	7.5	7.7	7.0	5.4	5.4

250 krad were somewhat better in quality than those irradiated with doses of 300 and 600 krad. Only the fish that had been irradiated with a 1200 krad dose had a typical burnt off-flavour, which is ofter called »the radiation flavour», the skin was yellowish and the flesh brownish. The same defects in appearance was slightly in evidence in the fish irradiated with 600 krad. However, after 3 days of storage under refrigeration, a burnt off-flavour as well as an off-odour were noticed in all the irradiated fish. This was weaker, however, in the fish that had been subject to the lowest radiation doses. Especially in the fish that had been irradiated with 600 and 1200 krad the defect in flavour was rather significant. In the fish that had been subject to lower radiation doses (150 and 250 krad) the off-flavour decreased with increasing storage time at 0° C. Thus, the fish that had been stored 7 days were evaluated as being even better than the non-irradiated fish, whose quality was lowered by the beginning of spoilage (see Fig. 1).

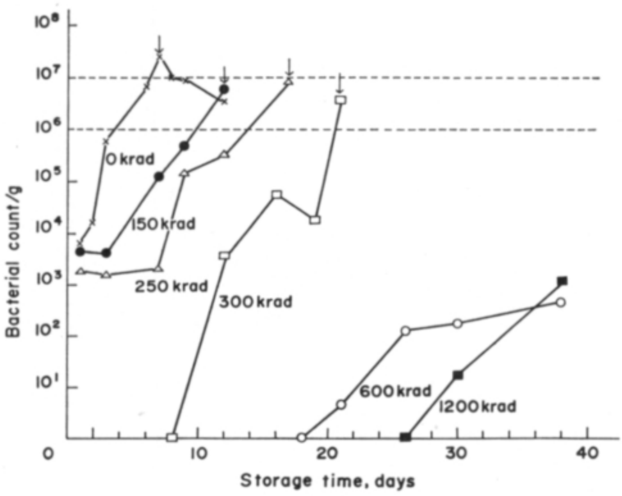

Fig. 1. The growth of bacteria in irradiated and non-irradiated, whole, ungutted pike stored under refrigeration at 0° C.

The results of the organoleptic evaluation for irradiated and non-irradiated saithe after a storage time of 1, 5 and 9 days under refrigeration are shown in Table 2. In view of the results obtained with pike, saithe was treated with radiation doses of only 150 and

Table 2. Average taste-panel scores on irradiated whole, ungutted saithe packed in polyethylene bags and stored at 0° C.

Storage time (days)	Radiation dose (krad)		
	0	150	250
1	8.6	8.1	7.3
5	7.7	7.4	5.2
9	6.9	7.3	4.5

250 krad. As soon as 1 day after the radiation with 250 krad, brown colouring in flesh and a slight burnt off-flavour and off-odour were noticeable in saithe. The defect increased considerably with increasing storage time. At the beginning of the refrigeration storage, the fish radiated with 150 krad differed organoleptically only slightly from the non-irradiated fish and after 9 days of storage the irradiated fish was evaluated as being in fact better in quality.

It is obvious that the influence of radiation pasteurization on the organoleptic features of fish considerably depends on the species of fish. The off-flavour could be noticed in pike irradiated with very low doses of 150 krad, the off-flavour, however, disappeared after about 1 week of storage at 0° C, while saithe irradiated with the same dose did not show any off-flavour whatever. Preliminary experiments with Baltic herring *(Clupea harengus* var. *membranus)* showed radiation damages in flavour, odour as well as in appearance when the fish was radiated with doses no larger than 150 krad. Also Ehlermann and Münzner (1969 b) noted that the defect in flavour disappeared in trout treated with radiation doses of 400 krad after a storage time of about one week under refrigeration, and in trout treated with doses of 200 krad after a storage time of only 3 days. The radiation dose levels reported by Shewan (1966) as to when undesirable off-flavours cannot be noticed vary considerably with the species of fish, being surprisingly high e.g. for cod, 500—1000 krad, for haddock, 600—700 krad, for flounder, 750 krad, and for herring 500 krad. On the other hand, some research workers claim that the undesirable changes in flavour and odour of fish detectable on the third day after radiation do not disappear or even decrease, and can be noticed even in the fish that have been subject to a dose of only 50 krad (Meyer-Waarden 1968). The species of fish were not given in the report, however.

The organoleptic evaluation scores for pike and saithe irradiated with low doses (for pike 150 and 250 krad and for saithe 150 krad) varied during the experiment from 7.1 to 7.8 and from 7.3 to 8.1, respectively, and the fish could be rated as being of good commercial quality.

Along with organoleptic evaluations, also total bacterial counts were determined for the fish. The changes of total bacterial counts in the flesh of irradiated and non-irradiated, whole, ungutted pike during the storage at 0° C are illustrated in Fig. 1. The bacteria levels, 10^6/g, when the fish loses its first class quality and begins to show signs of spoilage and, 10^7/g, when the fish is spoiled, are indicated with dotted lines (see Ehlermann and Münzner 1969 a, b, c). The arrows at the curves show the stage when the fish is organoleptically recognized as spoiled.

After 1 day of storage at 0° C the effect of radiation on the decrease of the number of bacteria can be distinctly noticed in fish treated with a dose of 250 krad, the number of bacteria in fish treated with a dose of 300 krad decreased practically to zero. SLAVIN *et al.* (1966) have also demonstrated the regular decrease in the number of viable bacteria in fish when the radiation dose is increased. Radiation has been found to have a very selective effect on the bacteria population. The bacteria belonging to the *Pseudomonas* species, which cause spoilage of fish, are very sensitive to radiation and die of doses as low as 300 krad (HOBBS and SHEWAN 1967). The type of spoilage, however, did not change in spite of radiation and, according to some research workers, the *Pseudomonas* bacteria gradually start to increase again (SLAVIN *et al.* 1966, RONSIVALLI *et al.* 1967).

Fig. 1 also shows that the total bacterial counts increased distinctly in non-irradiated fish during storage at 0° C starting immediately at the beginning of the experiment, while the growth of bacteria was retarded in all irradiated fish. The duration of this lag phase depends on the amount of radiation, being 3 days with 150 krad, 7 days with 250 krad, 8 days with 300 krad, 18 days with 600 krad and 26 days with 1200 krad. The same lag phase of 16 days was noticed by SEAGRAN *et al.* (1963) in yellow perch fillets irradiated at 600 krad and storaged at 0.6° C, while in fish irradiated at 300 krad the growth of bacteria was progressive but slow.

When the shelf life of fish is considered, the bacteria level 10^6/g is usually set as the limit where the fish can no longer be rated as being of first-class quality (EHLERMANN and MÜNZNER 1969 a, b, c). As seen in Fig. 1, the shelf life of pike that had been treated with doses of 150, 250 and 300 krad was 10, 14 and 21 days, respectively, or compared with non-irradiated fish, whose shelf life was only 4 days, 2.5, 3.5 and 5.2 times longer, respectively. The shelf-life limit for pike irradiated with doses of 600 and 1200 krad was not reached within the experiment time of 38 days.

Organoleptic evaluations showed that non-irradiated pike was distinctly spoiled (indicated by arrows in Fig. 1) after 8 days of storage at 0° C, and the fish irradiated with doses of 150, 250 and 300 krad was found spoiled after 12, 17 and 21 days, respectively. By that time the bacterial counts were near the spoilage limit of 10^7/g. According to some other research workers, the spoilage in fish irradiated with 150—350 krad does not appear until the number of live bacteria rises above 10^8/g (SLAVIN *et al.* 1966). This might indicate that the bacteria remaining after irradiation are not as active biochemically as those normally found in fresh fish, thus greater numbers of surviving bacteria are needed to produce the same effect as is produced by a smaller amount of the more potent spoilage bacteria. The bacteria counts of pike irradiated with very large doses of 600 and 1200 krad did not, during the whole experiment period of 38 days of storage under refrigeration, amount to the initial bacterial counts of fresh fish. However, after that time the flesh of the fish that had been subject to 600 krad irradiation was softer on the side of the abdominal cavity and the viscera were wholly decomposed. The flesh of the fish that had been subject to 1200 krad irradiation was firm all over but their viscera were somewhat softened after 38 days. These phenomena are probably due to the enzymes in the intestines of fish. Enzymes are known to require large amounts of radiation to be rendered inactive. Odour or flavour due to microbiological spoilage could not be niticed in the fish. Gutted pike that had been irradiated with doses of 600 and 1200 krad were also in the experimental series. When they were compared with the corresponding whole, ungutted fish, it was found that the bacterial counts in both were of the same class of magnitude and developed along the same lines during the storage under refrigeration. However, the flesh of the eviscerated fish was firm after 38 days, while the fat of the abdominal cavity had turned rancid and become yellowish. These observations are of importance, because in cases of long storage times enzymatic changes may prove the limiting factors in the preservation of whole fish. These phenomena have not been under consideration earlier as radiation experiments have been performed mostly on fish fillets. Radiation experiments with whole fish have been started only recently when irradiators have been installed on board the fishing vessels for irradiation at sea (CARVES *et al.* 1967).

For saithe the total bacterial counts were 7×10^3/g before radiation and 10^2/g after radiation with 150 krad. When stored under refrigeration at 0° C, non-irradiated saithe was spoiled in 25 days (the limit being 10^7/g) and saithe irradiated at 150 krad was spoiled in 43 days. The shelf life of saithe, using the level of 10^6/g, was prolonged from 23 days to 40 days. This is in the same class of magnitude as has been obtained when other white fish, viz. cod and haddock, were irradiated and stored under refrigeration (CARVES *et al.* 1967). In addition to the doses of radiation there are, however, many other factors, especially the temperature and the packaging, that must not be overlooked when the average total shelf lives of irradiated fish are compared.

Summary

The prolonging of refrigeration shelf life (at 0° C) of pike and saithe was studied by radiation pasteurizing the fish with cobalt-60 gamma rays. The fish were packed whole in polyethylene bags. The radiation doses varied for pike between 150—1200 krad and for saithe between 150—250 krad. Organoleptic evaluations showed burnt off-flavour and off-odour in irradiated pike, which in fish that had been subject to small doses of 150 and 250 krad disappeared only after about one week of storing under refrigeration. For saithe no off-flavour was noticed when it was irradiated with a dose below 250 krad. After radiation at only 150 krad for saithe and 300 krad for pike the total bacterial counts in the muscle were reduced by nearly 100 per cent. With radiation doses of 150, 250 and 300 krad, the shelf life of pike under refrigeration increased 2.5, 3.5 and 5.2 times, respectively, compared with non-irradiated fish. The shelf-life times listed in the same order were 10, 14 and 21 days, but for non-irradiated fish only 4 days. For saithe the shelf life increased from 23 days (of non-irradiated fish) to 40 days when irradiated with a dose of only 150 krad.

When whole fish were irradiated with large doses of 600 and 1200 krad, spoilage caused by bacteria was prevented for a long time while enzymatic spoilage caused by intestines was detected after 38 days as the contents of the intestines became decomposed and the flesh at the side of the abdominal cavity turned soft.

A c k n o w l e d g e m e n t: The radiation of the fish was carried out in the cobalt-60 irradiator located in the Department of Radiochemistry, University of Helsinki, for which the author wishes to express his gratitude to the Head of the Department, Professor J. K. Miettinen Ph. D.

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SELOSTUS

ELINTARVIKKEIDEN SÄTEILYSÄILÖNTÄ

I. Tuoreen kalan säilyvyyden lisääminen säteilypastöroinnilla

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Tutkittiin hauen ja seitin kylmäsäilyvyyden lisäämistä (0° C:ssa) säteilypastöroimalla koboltti-60 gammasäteillä. Kokonaiset kalat pakattiin polyeteenipusseihin. Säteilyannoksien suuruudet vaihtelivat hauella 150—1200 krad ja seitillä 150—250 krad. Organoleptisissä analyyseissa havaittiin säiteilytetyissä hauissa palaneen sivumaku ja -haju, mikä pienillä säteilyannoksilla (150 ja 250 krad) käsitellyistä kaloista

hävisi noin viikon kylmävarastoinnin jälkeen. Seitillä ei säteilyn aiheuttamaa sivumakua voitu todeta 150 krad:n annoksilla käsitellyissä kaloissa, mutta 250 krad:n annoksilla käsitellyissä kaloissa oli sivumaku selvä ja pysyvä. Säteilytettäessä haukea 300 krad:n annoksilla ja seitiä 150 krad:n annoksilla kokonaisbakteerien pitoisuudet pienenivät kalojen lihassa miltei 100 %:sesti. Hauen kylmäsäilyvyys lisääntyi 150, 250 ja 300 krad:n säteilyannoksilla samassa järjestyksessä lueteltuna 2.5, 3.5 ja 5.2 kertaisesti säteilyttämättömään kalaan verrattuna. Säilyvyysajat olivat niinikään samassa järjestyksessä lueteltuina 10, 14 ja 21 vrk, säteilyttämättömän kalan säilyvyysajan ollessa vain 4 vrk. Seitillä kylmäsäilyvyys lisääntyi 23 vrk:sta (säteilyttämätön kala) 40 vrk:een 150 krad:n annoksilla säteilytettäessä.

Kokonaisia kaloja suurilla 600 ja 1200 krad:n annoksilla säteilytettäessä kalojen bakteriologinen pilaantuminen voitiin estää kokeen kestoaikana (38 vrk), mutta sitävastoin todettiin suoliston entsyymien aiheuttamaa pilaantumista suolensisällyksen liuetessa ja kalan lihan pehmetessä vatsaontelon puolelta.