IAEA-TECDOC-1291

Study of the impact of food irradiation on preventing losses: Experience in Africa

Proceedings of a final Research Co-ordination Meeting held in Pretoria, South Africa, 20–24 September 1999

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

May 2002

The originating Section of this publication in the IAEA was:

Food and Environmental Protection Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

STUDY OF THE IMPACT OF FOOD IRRADIATION ON PREVENTING LOSSES:
EXPERIENCE IN AFRICA
IAEA, VIENNA, 2002
IAEA-TECDOC-1291
ISSN 1011–4289

Printed by the IAEA in Austria
May 2002

FOREWORD

There have been positive developments on food irradiation in different regions of the world, especially in the United States of America and several Asian and Latin American countries. In some countries in Africa, this technology has been studied in the past few decades with encouraging results. To assist these countries in conducting pilot scale research and development on irradiation of specific commodities of interest to them including market testing and feasibility to establish commercial irradiators for multi-purpose application, a Co-ordinated Research Project (CRP) on Impact of Irradiation to Prevent Food Losses in Africa was carried out between 1995 and 1999.

This CRP demonstrated that food irradiation has a potential to reduce losses of basic staple food crops including yams, dried and smoked fish, potatoes and onions through pilot scale experiments carried out in some African countries. Small scale market testing of such irradiated food such as spices, potatoes and onions showed encouraging results. In some countries (Côte d'Ivoire, Egypt, Ghana, Senegal and South Africa), it is feasible to establish commercial irradiation facilities for treating food. In Morocco, irradiation shows a potential to meet quarantine requirements in international food trade. It should be noted that commercial scale application of irradiation of some food products has been carried out in South Africa since the 1980s.

R. Molins served as the Scientific Secretary of this CRP from the beginning to mid–1999 when he left the IAEA. M. Matin took over the responsibility for this CRP until its completion.

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SUMMARY

1. INTRODUCTION

Research conducted in several countries in Africa demonstrated that irradiation has a potential to be used to reduce high post-harvest losses of products such as roots and tubers, dried meat and fish, ensure microbiological safety of spices and dried vegetable seasonings, and to control insect infestation of fresh and dried fruits for export. In an effort to demonstrate the efficacy of this technology at pilot scale level as well as to evaluate consumer acceptance of some irradiated food products, a co-ordinated research project (CRP) on Impact of Irradiation to Prevent Food Losses in Africa was initiated by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in 1995. Nine participants from Africa and France participated in this project. Three meetings were held under the scope of this CRP in 1995, 1997 and 1999 to plan, review and finalize the work carried out by individual participants.

The final co-ordination meeting was held at University of Pretoria, South Africa, 20–24 September 1999. Statements were made at the Opening of the meeting by J.R.N. Taylor, Department of Food Science, University of Pretoria; F. Chenoweth, FAO Representative to South Africa; and M.A. Matin of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna. These statements supported the work carried out by individual participants as they contributed positively to the food security goal of FAO. The participants were also informed of rapid development in food irradiation, especially in the USA and several Asian countries where the technology has been commercialised on a large scale for treating several types of food products. The meeting was chaired by A. Minaar of the University of Pretoria and assisted by E. Marchioni, France, as Vice-Chairperson.

2. OBJECTIVES OF THE CRP

The objective of this CRP was to assist institutions in the African region in conducting pilot scale studies on food irradiation, test marketing, and economic studies to determine the feasibility of food irradiation and its impact in preventing food losses in Africa.

Major areas of research envisaged under this CRP were:

1. Validation of data on radiation-disinfestation of grains, legumes, fruits, cocao and dried smoked fish.
2. Evaluation of suitable packaging material to prevent reinfestation or recontamination of irradiated foods during storage, transportation and marketing.
3. Validation of sprouting inhibition of yams, potatoes and onions, applied in semi-commercial scale.
4. To conduct test-marketing studies using semi-commercial volumes of irradiated food products and to determine consumer acceptance.
5. To evaluate the cost/benefit of food irradiation in comparison with other food preservation techniques to prevent food losses in African countries and to identify factors limiting the introduction of food irradiation technology in the region.

3. SUMMARY OF THE STUDIES CARRIED OUT UNDER THE CO-ORDINATED RESEARCH PROJECT

Citrus fruits occupy a very important place in the Moroccan agriculture with a yearly production of about 1.5 MT. In 1998, the production of citrus fruits was 1.237 MT. More than one-third of this production is destined for export and constitutes an important crop for the Moroccan economy. However, the Moroccan citrus fruits suffer, as in other countries of the Mediterranean area, from the attack by the Mediterranean fruit fly (*Ceratitis capitata*) that causes considerable losses to the fruit. Thus, it is necessary to develop effective quarantine treatment for export of the fruit. In Morocco, this treatment is done by refrigeration at temperatures between 0 and 2°C for16 days followed by treatment with fungicides during the conditioning. However, this method has many limitations including the cost of the treatment, the difficulty to reach the far away markets and some varieties like clementines and tangerines are fragile at low temperature. The effect of irradiation at doses of 125, 250, 375, and 500 Gy, commonly used for quarantine treatment, on the quality of Maroc-late orange, the most common export variety of Morocco was investigated. In the first study fruits were irradiated without any previous cold conditioning treatment as practiced by the export trade for quarantine purposes. In the second study fruits obtained from the normal chain after conditioning was irradiated. Storage of irradiated fruits was studied at room temperature and 10°C and at 0°C in case of control fruits. The parameters studied included juice yield, total solids, reducunig and total sugars, total acids and volatile acids, dry weight and weight loss. The results showed that irradiation did not affect the technological quality of citrus fruits during four weeks storage. The study is being continued for determining quality parameters and entomological aspects. The result thus far points to the possibility for the successful application of irradiation as an alternative quarantine treatment to the classical methods, which result in browning of the peel. The browning phenomenon could be controlled by waxing and will be the subject of a future study.

Studies undertaken in Zambia using a total of 7 tonnes of onions and 3 tonnes of potatoes of mixed cultivars have shown that irradiation at a dose of 190 Gy inhibited sprouting in these commodities stored under ambient conditions in an open shed in shelves constructed for air circulation. Sprouting, rotting, weight loss, water extractable sugars, vitamin C, inner bud condition of onions and the percentage of good tubers and bulbs as a function of storage time were determined. Results indicated that storage life of potatoes and onions was extended to a maximum of eight months under the test conditions of this study. Consumer acceptance evaluation on the organoleptic qualities using a hedonic scale and through a questionnaire conducted at the National Institute for Scientific and Industrial Research and National Agricultural Exhibitions indicated general acceptance of the irradiated potatoes and onions as well as irradiation as a process. Likewise, marketing tests of labeled irradiated potatoes and onions conducted at an open market in Lusaka where people sell and buy food commodities everyday and in a grocers shop selling fruits and vegetables demonstrated that irradiated products sold very well. Further studies are required to demonstrate the economic feasibility of irradiation so that investors can exploit the technology on a commercial scale.

The effect of irradiation up to a dose of 6 kGy on the quality, shelf life and consumer acceptance of three traditional Nigerian meat and fishery products, namely, "Suya", and "Kilishi" was undertaken. Results showed that 4 kGy was sufficient to reduce the total plate count, yeasts and moulds to acceptable levels and eliminate *Staphylococcus aureus.* Samples of "Kilishi" irradiated at a dose of 4 kGy and stored for 4 months in sealed polyethylene bags (0.04mm thick) at tropical ambient temperatures (21–31°C) were free from moldiness and were rated highly for sensory qualities by a consumer panel consisting of 32 members. Also, a dose of 2 kGy eliminated the problem of insect infestation in smoked-dried fish having 9% moisture content when samples packed in 0.04 mm thick polyethylene bags were stored at tropical ambient conditions for 6 months. The irradiated samples were considered acceptable in sensory attributes by a 32-member consumer panel.

A dose of 150 Gy was found optimal for inhibition of sprouting in yams of the cv "Kopnan" grown in Côte d'Ivoire. In these studies, about one tonne of yam tubers were transported from Abidjan, Côte d'Ivoire to Accra, Ghana, where they were irradiated at the gamma irradiation facility of the Ghana Atomic Energy Commission. After irradiation they were transported back to Abidjan and stored in a specially constructed storage room at the University of Cocody. Market testing of irradiated yams was conducted without indicating that they were irradiated. The irradiated yam was accepted favourably by the consumer. The law n°98–593 on radiation protection and nuclear safety was promulgated on 10 November 1998. In its article 8 it is said that food and industrial products irradiation facilities shall comply with the requirements of the International Code of Practice. The regulations on food irradiation based on this main law are now being considered for promulgation by the competent authority of Côte d'Ivoire. The lack of regulations makes it difficult to legally conduct test marketing of irradiated yams. The economic feasibility of irradiating yams in Ghana and selling them in Côte d'Ivoire has been investigated.

The major causes of spoilage in the post-harvest handling of yam in Ghana were identified as poor harvest, storage and transportation conditions and physiological damage. The effect of gamma irradiation on yam and maize storage and their functionality in the Ghanaian food system were determined. Results indicated that all unirradiated yams sprouted by the 3rd month of storage. Gamma irradiation at a dose of 120–130 Gy effectively inhibited sprouting of yams for 6 months under ambient conditions. There was less rotting in yams stored on the barn compared to those stored on the ground and less rotting in the irradiated yam stored on the barn. Food products from irradiated yams were judged better in quality than those from unirradiated ones.

Semi-commercial studies on radiation preservation of maize were also conducted in Ghana with a view to determine the effect of radiation treatment on the physico-chemical and functional properties as well as the microbiological quality of maize. The study also evaluated the techno-economic feasibility of radiation preservation of maize in Ghana and consumer attitudes towards foods such as 'Ga kenkey' and 'Fanti kenkey' prepared from irradiated maize. In the first study 127 bags of 50 kg maize were used. Maize was repacked in 5-kg consumer packs made from 0.003mm thick polyethylene bags. Ten of the consumer packs were put into woven polypropylene sacks to make up 50 kg bag of maize. Eighty-seven bags of maize were irradiated to a minimum of 2.6 and maximum of 5.6 kGy gamma radiation. Both the irradiated and the unirradiated maize were stored for six months in a commercial warehouse**.** Results indicated that the moisture content (7.2–7.8%), free fatty acid (<0.1%) and peroxide value (35–40 mEq/kg fat) of the maize were stable during storage. The initial mould count of 100–156 cfu/g decreased to 30–43 cfu/g, *Aspergillus oryzae* and *Asp. tamari* were identified. *Sitophilus* sp. was the predominant insect in the control but was replaced by *Rhyzopertha* sp. in the irradiated maize. Seventy-six per cent of the consumer polyethylene packs containing irradiated maize were damaged due to rough handling during transportation to and from the irradiation facility and coupled with poor warehouse hygiene resulted in reinfestation. In a subsequent study in which thicker polyethylene (0.008 mm gauge) was used coupled with careful handling, none of the consumer packs were damaged and the irradiated maize had lower insect population (152 insects/5kg pack) than the control (297 insects/5kg pack) after 4 months storage in a commercial warehouse. These observations underscored the importance of appropriate packaging and good warehouse hygiene in radiation disinfestation of foods. Peak viscosity of irradiated *Dobidi* maize starch was lower (97.5 B.U.) than unirradiated maize starch (365 B.U.). The eating quality of `Fanti kenkey' and `Ga kenkey' prepared from irradiated maize was acceptable and comparable to that prepared from unirradiated maize. Using the peak sale price of maize during the lean season, marginal analysis indicated that irradiation preservation of maize was undominated, however, the marginal rate of return of 17.65% was lower than the recommended 40%. Other scenarios considered suggested that radiation preservation of maize could be implemented and sustained in Ghana. Irradiation of cocoa up to 6 kGy did not adversely affect the quality parameters of products such as cocoa butter processed from them.

The technical feasibility of using ionizing radiation treatment for typical African fruits and vegetables (mangoes, millet, ground nuts, cowpeas) in Senegal was carried out. This work was performed in Strasbourg (France) with a 2.5 MV Van de Graff- electrostatic accelerator of 300 W beam power. The nutritional and hygienic qualities of the foods were studied as a function of the storage time and temperature, and the absorbed doses.

An economic feasibility study was done concerning the setting up of a multipurpose food irradiation facility in Senegal. The results clearly indicated that this plant (500 kCi) should be built in the highest populated region of Senegal (Dakar district) to treat a wide range of foodstuffs destined for local consumption (millet, sorghum, rice, maize, cowpeas, potatoes, onions, mangoes, citrus fruits and dried fishes). This facility can be considered profitable for a private investor and Senegalese food producer (or trader) on the condition that the tonnage of foodstuffs treated is adequate, more than 22 000–77 000 t taking into account the low irradiation doses used for the various foodstuffs. However, no information on food irradiation to the public and no consumer acceptance tests were carried out during this project. Such work should be carried out before any investment because it is of great importance to obtain active participation of the public organizations, the private investors and the food producers in the setting up of a multi-purpose irradiation facility.

Surveys conducted in South Africa of some traditional African foods revealed that a variety of such foods are prepared in the home and enjoyed by a large number of consumers. Currently, hardly any of these foods are available commercially. However, these foods are laborious to prepare, not generally available commercially and have a limited shelf life. The application of irradiation (alone) or in combination with other technologies can help solve these problems. Studies were carried out on the effects of combination processing on the microbiological quality, shelf life and acceptability of a traditional South African ready-to-eat (RTE) meal consisting of spinach (morôgo) and sorghum porridge and the effect of irradiation on selected nutrients in the meal. Although irradiation processing did not appear to affect the macronutrients significantly, vitamin B1 was found to be very sensitive to irradiation in both the spinach and the porridge component. Losses in vitamin C content of the spinach morôgo were due to leaching out of the vitamin during cooking. Irradiation increased the nitrate content of spinach morôgo, whereas irradiation processing significantly reduced the phytic acid in sorghum.

The combined effects of modified atmosphere packaging (MAP) (84.5% N_2 + 15.5% CO_2) and irradiation (target dose of 10 kGy) on the safety and microbiological shelf-life of the RTE-meal were investigated at 5°C and 37°C respectively. A safe RTE meal with a shelf-life of at least 7 d at 5°C using MAP — irradiation combination processing was produced. However, this RTE meal is a low acid food in which *Clostridium botulinum* could grow and produce toxins under favourable conditions. If the cold-chain was broken during distribution and/or retailing, the safety of the meal could be compromised by rapid growth of surviving pathogenic bacteria. From a safety point of view, it was therefore recommended that either higher dose levels or alternative hurdles (e.g. use of nitrites) should be used to render the RTE-meal microbiologically safe and stable.

The effect of irradiation (0, 10, 20 and 30 kGy at 5°C) on the consumer acceptability of the RTE-meal was also investigated. The two components of the meal remained acceptable up to a dose of 10 kGy. The limiting factor for using higher doses was the porridge component, especially in terms of texture (too soft) and taste (off-flavour development). Therefore the use of irradiation at 10 kGy in combination with different levels of sodium nitrite was studied to improve the storability of the RTE-meal. In both the meal components, cooking caused a significant decrease in the final nitrite levels. Irradiation significantly increased the nitrite levels in the spinach component, probably due to the oxidation of nitrate and other nitrogenous compounds by free radicals. However, the final nitrate levels in the RTE-meal (71 ppm in spinach and 52 ppm in porridge) were much lower than allowed legally (200 ppm). In both the meal components, there was a significant decrease in spores with the use of sodium nitrite, probably because nitrites inhibited microbes by interfering with their metabolic systems. However, after 12 days of storage at 10°C, an increase in *C. sporogenes* counts was observed in the porridge component. This might be attributed to the fact that the porridge had less sodium nitrite available during storage than the spinach component. Nitrite in combination with irradiation significantly reduced the *C. sporogenes* counts in both the meal components to less than 1 $\log_{10}$ cfu/g immediately after processing. The use of higher levels of sodium nitrite (but still within legal limits) in combination with irradiation is recommended for the final phases of this project.

In Egypt studies were carried out with the aim to gauge the opinion and attitude of the consumers towards food irradiation and to what extend they accept or refuse food preservation by radiation. The study also had the objective to find out a suitable strategy to attract the consumer to adopt the technique and ensure the successful handling of irradiated foods in markets. One thousand and twenty two completed questionnaires from consumers were collected. The questionnaire was supported with simplified information about the use of atomic energy and radiation for peaceful purposes. The results showed that 62.43% of the total sample size accepted the irradiation technology while the percentage of respondents convinced with the advantage of using irradiated food was 70.45%. About 73.97% of the respondents were willing to accept irradiation technology on a long term basis while 57.53% were willing to consume irradiated food if it was available in the market.

Sensory tests on irradiated smoked fish, chicken, black pepper, coriander, Jew's mallow, broad bean and kidney beans were conducted employing 136 panelists using triangle test (difference test) and duo-trio test. The results showed that the panelists failed to indicate any difference between the irradiated and unirradiated food. About 92.2% of those participated in lunch table of irradiated food (144 persons) claimed that irradiated food was delicious and found no differences between the irradiated and unirradiated samples.

During the market sale of irradiated products, 500 post cards each for black pepper and broad bean were issued to record the consumer response. Out of these 185 cards for black pepper and 160 cards for broad bean with consumer's comments were returned to the National Center for Radiation Research and Technology, Cairo, Egypt. The market test indicated that 95.1% of the respondents found the irradiated (10 kGy) black pepper of excellent or good quality while the percentage was 81.2% for irradiated (2 kGy) broad bean. The study also showed that 62.2% and 68.8% of the persons respectively who returned their cards would buy irradiated black pepper and broad bean again if they were available in the market.

Studies on the economics of food irradiation in Egypt showed that the cost of irradiation for one ton of frozen poultry as US $130.4; smoked fish US $78.2; spices US $260.1 and dried vegetable US $26. Economic evaluation of the study indicated that the average rate of return will be about 16.9% annually and the pay back period will be about 5.9 years.

A study of the techno-economic feasibilty of food irradiation for establishing a commercial facility in Algeria adopted a holistic approach in order to assure a maximum utilization rate of the facility. The assumptions in this study were based on a free standing multipurpose irradiation facility, the throughput of which is expressed in t·kGy/year**,** and the unit cost of the treatment in US $/t·kGy**.** These values may then be applied for the calculation of the treatment cost of any food commodity, according to the irradiation dose needed. The study showed that irradiation treatment of dates is profitable and that the cost of irradiation does not exceed 1.6% of the selling price of the product and post harvest losses may be considerably reduced by the irradiation treatment. A comparative study between irradiation and cold storage showed that irradiation will cost 30% less than cold storage.

Evaluation of consumer acceptance of irradiated potatoes and onions stored for 5 months and irradiated dates stored for 14 months were conducted along with unirradiated products stored under similar conditions. Products were displayed with labels in Algiers during the National Exhibition of Acquirements (29–31 march 1998) and in Bejaia during the Symposium on Nutrition (15–16 April 1998). While unirradiated potatoes and onions were sprouted and dates infested by insects, all irradiated products had a much better appearance. Visitors were orally informed about food irradiation technology, its advantages and limitations and were asked to fill in a questionnaire. The questionnaire was filled and returned by all the 394 people, consisting of 47% male and 50% female, to whom it was given. The response of sample groups of different age groups, namely, under 20, 20–30, 30–40 and above 50 years of age and with different educational background (high, secondary, primary) showed that 68% of the total participants expressed their preference for irradiated products while 32% preferred unirradiated products. Gender wise, 70% women preferred irradiated products as compared to 65% for men and about 85% of the respondents aged between 20–30 years as compared to 55% of those above 40 years. By educational background, 84% of participants having a secondary level of education preferred irradiated products in comparison to 60% for those with a higher level of education. Of the total respondents, 47% had heard about food irradiation earlier, the difference between men and women being marginal, however, people of the age group 30–40 and above 40 and those with a higher education were better informed. The main reason for the preference for irradiated products was mentioned as ‘extended shelf-life’ and ‘quality’. Those who did not like irradiated products, the two major reasons were fear of irradiation and lack of information about the technology. The results indicated the need for an effective public awareness programme for proper dissemination of information on food irradiation.

Based on the presentation of results by different research workers, the meeting decided to compile the status of research, development and technology transfer of food irradiation in different countries (Table 1). A highlight of the meeting was a visit to a commercial irradiation facility, Isoster, Inc. in Croydon, South Africa, which offers a service to the local food and non-food industry. Several irradiated food products are marketed routinely in South Africa in the past few decades.

Table 1. Status of Food Irradiation in Africa

Country	R&D	Pilot, Semi-commercial or Commercial	Legislation	Irradiation Facility	Market Testing and/or Consumer Acceptance	Economic Feasibility	Prospects for Future Applications
Algeria	Irradiation of dates, potatoes, onions, spices	Pilot	None	Pilot scale irradiation facility with 100 kCi max. loading; present strength 7 kCi	Dates Several public awareness programme	Cost-benefits analysis of irradiation disinfestation of dates (30%more effective than cold storage)	Promising
Côte d'Ivoire	Irradiation for sprouting inhibition of Kponan Yams					Economic feasibility have been initiated	
Egypt	Almost all kinds of vegetables, spices, fruits, chicken, fish and meat produce in Egypt **Fruits:** citrus (oranges), pears, apricots, strawberries, bananas, grapes, mangoes etc. **Vegetables:** legumes (broad bean, kidney bean etc.), Jew's mallow, onion, garlic, potatoes, etc. **Spices and herbs:** black pepper, cumin, black cumin coriander etc., Other crops: cotton seeds, sesame seeds sunflower seeds, etc. Fish: Tilapia, herring, eels, seafood, etc. Meat: minced meat, Camel meat, etc	The cobalt-60 source was used for irradiating commercial amounts of spices, herbs and dried garlic and onion especially for export (about 15 tons have been irradiated during 1998).	For certain items namely spices, herbs, dried garlic and onion clearance was issued on 1997/10/22 for a maximum dose of 10 kGy.	- Cobalt source about (400 000 Ci) at present but its capacity is one milion Ci for multi purpose. - Accelerator (1.5 M.V) - Three gamma cells one from Canada, one from India and the third from Russia.	Consumer acceptance has already been done and also market testing for spices (pepper) and dried vegetable (bean).	Economic feasibility has already done for spices, chicken, smoked fish and dried vegetables.	

Country	R&D	Pilot, Semi-commercial or Commercial	Legislation	Irradiation Facility	Market Testing and/or Consumer Acceptance	Economic Feasibility	Prospects for Future Applications
Ghana	Maize, Fruits, Cowpea, Smoked fish, Yam, Sweet potatoes, Spices, Onions, Cocoa has been studied at GAEC under various IAEA Research Contracts.	Semi-commercial. research is now at the Pilot stage where we are collecting data for economic feasibility and also transferring the technology to the end user.	Standard for Irradiated food G.S. 210 was put in place in 1997. It is based on harmonized regulation.	^{60}Co Gamma irradiator Pilot plant which needs upgrading.is a batch type, water storage, with no conveyor . The current activity is about 20 kCi. The shielding capacity is for 500kCi.	Studies are in progress on Yam (4000) tubers, Maize 120 (50 kg) bags, Cocoa (1/2 tonne), and Smoked fish in Accra. Consumer acceptance for yam was also carried out using the farming community at Nkwanta. Irradiated food fair also organized in 1998.	Data collected on maize and Yam are being analyzed.	Economic feasibility to be completed. Studies on irradiation of poultry, red meat and also fresh fish products for quarantine purposes to be pursued.
Morocco	Studies are being conducted at the INRA, Tangier on Citrus, Tomato powder, Potatoes, Dates, Strawberry, and Medicinal plants	Can be semi-commercial if equipped with conveyor system	Harmonized with the African countries — in stage of promulgation by the parliament	Pilot one. No min.100k Ci Actual: 9000Ci Dry storage, no conveyor system	None	Yes in 1993	After replenishment it is proposed to treat products at semi – commercial scale
Nigeria	Has been done for: Sprout inhibition in yams and onions, Decontamination of spices, Disinfestation of smoked dried fish, Decontamination of traditional meat products	Pilot plant studies for: Sprout inhibition in yams and onions, Decontamination of spices, Disinfestation of smoked dried fish, Decontamination of	There is legislation under preparation but not harmonised. Legislation covers: Sprout inhibition in yams & onions, Disinfestation of grains & other products	- Laboratory Co^{60} Gammacell 220 (Canadian) Semi commercial Co^{60} plant with conveyer system >50 kCi under	Limited consumer acceptance studies < 1 ton on sprout inhibition in yams & decontami-nation & disinfestation of traditional meat & smoked dried fish.	None However prospects appear to be great given the high post-harvest losses and the large population (market)	Good for many other traditional Nigerian foods

Country	R&D	Pilot, Semi-commercial or Commercial	Legislation	Irradiation Facility	Market Testing and/or Consumer Acceptance	Economic Feasibility	Prospects for Future Applications
Nigeria	"Suya" & "Kilishi" Quantities less than a ton to demonstrate technical feasibility	traditional meat products "Suya" & "Kilishi"	Decontamination of cocoa, spices & other products Legislation expected to be in place by 2000. Controlling authorities: Federal Ministry of Health, Federal Ministry of Science & Technology, National Agency for Food & Drug Administration & Control, Nigerian Standards Organization	construction at Abuja which should be completed in 2000	No market testing yet.		
Senegal	Fruits and vegetables Optimal dose evaluation and the nutritional consequences (vitamins, proteins etc.) Initial studies were done in Strasbourg (France) on Mangoes, Made, Detar, Ground nuts, Cowpeas, Rice	None	None	None	None	Already done: Profit as a function of the activity of the source and the quantity of food treated (taking into account the period of production and the costs of transport and packaging).	Information to the public, government and investors. Consumer acceptance tests. Construction of a pilot plant.

Country	R&D	Pilot, Semi-commercial or Commercial	Legislation	Irradiation Facility	Market Testing and/or Consumer Acceptance	Economic Feasibility	Prospects for Future Applications
South Africa	porridge and spinach relish meal (in collaboration with Biogam and Isoster), Use of irradiation to improve the quality of weaning foods (in collaboration with Biogam) Gamwave and Isoster: R&D within company.	Commercial: 4 Plants Biogam — AEC (Pelindaba), Isoster (Isando), Hepro (Cape Town), Gamwave (Durban)	Act 54 of 1972; Regulation 1600/1983 Not harmonised Code of practice to be introduced	Cosmetic, Pharmaceutical and Cross-linking of materials applications Hepro (Cape Town): Mainly food applications -Gamwave (Durban): Spices Present activities of Co^{60} sources: -Biogam: 140, 000 Ci, Isoster: 1 Mci, Hepro: 250, 000 Ci, Gamwave: 700, 000 Ci	for shelf-stable mushrooms and rice; RTE-sorghum porridge and spinach morôgo meal (blind testing) Commercial companies take part in fairs, outdoor shows, product development exhibitions.	Probabaly done in-house for commercial concerns	
Tunisia	In progress	Pilot	None	Actual 80, 000 Ci Nominal 100, 000 Ci with a conveyer system	None	None	
Zambia	Onions Potatoes Quantities: Onions — 25 packets Potatoes — 25 packets **(each packet contains max. 10kg)**	Onions: 7 tonnes Potatoes: 3 tonnes Irradiation done in Lusaka Potatoes produced mainly in Mazabuka, 61 km from Lusaka in South.	Clearance for the foods (for research and market purposes — consumer) Harmonized regulations as recommended by IAEA adopted as from 1999 (Food & Drug	Co-60 Multi-purpose (Capacity: 100 000 Ci maximum) Present: ≈ 10 000 Ci Batch-type (turn-tables)	Onions Potatoes Tested at open markets and grocer's shops. Consumer acceptance made at place of work (institute) and at	Not done. This is required to be carried out in order to justify investment	Insect disinfestation of cereal especially main grain, Pulses like beans, cow-peas. This will be done for quarantine purposes at

Country	R&D	Pilot, Semi-commercial or Commercial	Legislation	Irradiation Facility	Market Testing and/or Consumer Acceptance	Economic Feasibility	Prospects for Future Applications
Zambia	Dose: 0.19 kGy for both onions and potatoes.	Storage of irradiated items was at the farm.	Regulations of Zambia) The Ministry of Science, Technology and Vocational Training through the National Institute for Scientific and Industrial Research (NISIR) through the radiation Research Unit controls the facility and it is situated at the Institute. They monitor the operation as per code of practice. There are trained operators, dosimetry measurement experts including on labelling. The over all authority lies with the Food & Drug Authority under the Ministry of Health.	It is a dry off-floor type. Shield is biological	show exhibits of agricultural produce. Amounts: Onions: 2.5 tonnes × 2 5.0 tonnes potatoes: Total was 1.0 tonne.		commercial scale

TECHNOLOGICAL QUALITY OF IRRADIATED MOROCCAN CITRUS FRUITS

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Abstract

The effect of irradiation at doses of 125, 250, 375, and 500 Gy, commonly used for quarantine treatment, on the quality of Maroc-late orange, the most common export variety of Morocco was investigated. In the first study fruits were irradiated without any previous cold conditioning treatment as practiced by the export trade for quarantine purposes. In the second study fruits obtained from the normal chain after conditioning was irradiated. Storage of irradiated fruits was studied at room temperature and 10°C and at 0°C in case of control fruits. The parameters studied included juice yield, total solids, reducing and total sugars, total acids and volatile acids, dry weight and weight loss. The results showed that irradiation did not affect the technological quality of citrus fruits during four weeks storage. The result thus far points to the possibility for the successful application of irradiation as an alternative quarantine treatment to the classical methods, which result in browning of the peel. The browning phenomenon could be controlled by waxing and will be the subject of a future study.

1. INTRODUCTION

Citrus fruits occupy a very important place in the Moroccan agriculture with a yearly production of about 1.5 MT. In 1998, the production in citrus fruits was 1.237 MT (SASMA). More than third of this production are destined for export and constitutes a foreign exchange resource and therefore is important for the Moroccan economy. The more exported varieties are the navelier, tangerines, clementines and the Maroc-Late. However the Moroccan citrus fruits suffer, as all countries of the Mediterranean area, from the attack by the Mediterranean fruit fly (*Ceratitis capitata*) that causes considerable losses. In view of this there is the necessity for a quarantine treatment to be able to export them. In Morocco, this treatment is done by refrigeration at temperatures between 0 and 2°C for a period of 16 days coupled with a fungicidal treatment during the temperature conditioning. However, this method has many limitations of which most important are the elevated cost of the operation, the difficulty to reach the faraway markets and the susceptibility of some varieties such as clementines and tangerines to low temperature. In this context, the technique of irradiation seems to be a preferable treatment method in order to reduce the post-harvest losses and to increase the quantity available for marketing and export. The combination of irradiation and storage at moderately cold temperatures has another advantage that would permit to replace the cold treatment at 0–2°C, thus reducing the cost of the treatment. Besides, the United States of America which constitute a potential market for the Moroccan citrus fruits require a quarantine treatment by irradiation at a dose of 225 Gy minimum. Therefore, irradiation will permit the Moroccan citrus fruits to reach this market and consequently to increase the volume of exports. On the other hand, irradiation could substitute the use of pesticides that has harmful effects on the human health and the environment. In addition, the interdiction on the utilization of these products will lead to a ban at medium-term.

In this work, we determined the effect of irradiation on the Moroccan orange quality at doses commonly used for quarantine treatment. Thus, in the first study we irradiated the most exported variety (Maroc-Late) without previous cold treatment. In the second study, we irradiated the same variety obtained from the normal chain of conditioning. The applied doses of irradiation were 125, 250, 375 and 500 Gy and a control sample. Temperatures of storage were the ambient temperature and 10°C for irradiated and 0°C for the control.

2. MATERIALS AND METHODS

2.1. Plant material

In the first study the variety Maroc-Late harvested from the experimental orchards of El Menzah of the INRA, in 1998 were used. These fruits had not undergone any previous treatment for conservation. Oranges received in bulk lots were sorted out to eliminate the damaged fruits and divided into 10 Kg lots for different treatments.

In the second study oranges of the same variety previously conditioned from the station of LUKKUS in Larache were used. Fruit samples were packaged in parallel epipedic wood boxes of 11, 5 Kg of weight and covered by nets. These boxes served also as containers for the irradiation.

2.2. Irradiation treatment

In both the studies, fruits were irradiated to doses of 125, 250, 375 and 500 Gy along with unirradiated control. The choice of these doses was based on an earlier study during the agricultural campaign of 1997, which established the optimal dose ranges for this variety without affecting the fruit quality. The results of these studies using doses of 0, 250, 500, 750 and 1000 Gy showed evidence of a faster decomposition of fruits after three weeks of storage when irradiated to 750 and 1000 Gy, whereas samples irradiated to 250 and 500 Gy could be stored for 45 to 60 days. Therefore, for the present study doses up to 500 Gy were employed. Following irradiation fruits were stored at ambient temperature and 10°C, and the control samples at 0°C.
Before irradiating the experimental samples, dose mapping was carried out to determine the dose distribution in samples. Different devices were used for irradiation of the samples in the two studies.

1st study:
The sample carrier was a container formed respectively of two coaxial cylinders of diameters 40 and 16 cm with 25 cm of height. The products were placed between the two cylinders, and this device was conceived in order to have a good uniformity of doses. The dosimeters were the Red Perspex.
The following table provides data relative to dosimeters:

Dosimeter	Dose (kGy)	Dose Uniformity
DI	14.97	
D2	13.11	
D5	15.15	
D6	16.82	
		D = 1.40

2nd study:

In this case, oranges were irradiated in the package boxes. Two rotating tables have been used and the dosimeters used were the Gamma Chrom films. Following the dose distribution studies, fruit samples were irradiated to different doses in accordance with the dosimetric studies.

2.3. Tests for quality:

- Yield and density of the juice: Five oranges each from samples stored at ambient, 10 and 0^oC were weighed and slurried to determine the volume and the mass of the juice.
- The percentage of soluble solids content (Brix) was determined by refractometry.
- Total acidity was determined by volumetric titration.
- Volatile acidity was determined by volumetric titration after distillation of the volatile part.
- Dry matter of the peel was determined by dehydration under vacuum at 70^oC.
- Reducing and total sugars were determined by the method of Bertrand.
- Fruits were weighed periodically to evaluate the loss in weight during storage.

3. RESULTS AND DISCUSSION

3.1. Yield of the juice

There was no considerable variation in the juice yield between unirradiated fruits and those irradiated to doses of 125, 250, 375, and 500 Gy. The juice yield nearly remained the same in fruits stored at 10 and 0^oC during four weeks of storage, whereas in oranges stored at ambient temperature, some insignificant variations have been noticed for the 4 doses tested.

These results were confirmed by the values for the density of the juice, which showed that in fruits irradiated to different doses and stored at any temperature for one month, the values did not defer from that of the unirradiated control samples.

3.2. Total and volatile acidity:

The results showed no apparent change in the total and volatile acid contents between control and fruits irradiated to different doses during storage for one month at any of the temperatures under study.

3.3. Dry matter and Brix

The soluble solids content in the orange juice and the dry matter of the peel were not affected by irradiation up to 500 Gy or the temperature during storage up to one month. The variation observed in the dry matter content of peel was probably due to natural evaporation and not due to irradiation.

3.4. Reducing and total sugars

The results showed that neither the reducing sugar nor the total sugar levels were changed by doses of irradiation used under any of the temperatures during storage for a period of one month. These results were similar to that observed for the dry matter content of the variously irradiated fruits during storage under different temperature conditions. The absence of variation was probably due to the detection limit of the methods employed.

3.5. Loss in weight

An examination of the data on the trend in loss of weight in oranges as a function of the storage period showed that loss in weight increased with increasing irradiation dose. It was valid for the three weeks of storage for the two storage temperatures studied, namely, ambient temperature and 10^{o}C. However, this variation remained weak and never exceeded 10% of the loss in weight. This variation of the weight could be explained by increased evaporation due to alterations in cell wall constituents of the peel as a consequence of irradiation. Ten days after the irradiation treatment, appearance of brown spot on the peel was observed which may be due to alterations in the composition of the essential oils or in polyphenols.

After thirteen days of irradiation, three oranges stored at ambient temperature was found to be spoiled on account of putrefaction caused by *Penicillium sp*. Indeed citrus fruits underwent some mechanical injuries during the treatment in the LUKUS station and the transport.

4. CONCLUSION

Our study showed that irradiation at dose levels required for quarantine treatment did not affect the technological quality of citrus fruits adversely during four weeks of storage under the test conditions. This study has to be completed during the coming months by third assay and entomological aspects. It can be used with success instead of the classical methods of conditioning to limit the browning of the peel. A future study will examine the use of waxing to control the browning phenomenon.

TECHNO-ECONOMIC FEASIBILITY OF FOOD IRRADIATION IN GHANA[1]

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Abstract

The major causes of spoilage in the post-harvest handling of yam were identified as poor harvest, storage and transportation conditions and physiological damage. The effect of gamma irradiation on yam and maize storage and their functionality in the Ghanaian food system were determined. Results indicated that all unirradiated yams sprouted by the 3rd month of storage. Gamma irradiation at a dose of 120–130 Gy effectively inhibited sprouting of yams for 6 months under ambient conditions. There was less rotting in yams stored on the barn compared to those stored on the ground and less rotting in the irradiated yam stored on the barn. Food products from irradiated yams were judged better in quality than those from unirradiated ones. Semi-commercial studies on radiation preservation of maize were conducted with the view to determining the effect of radiation treatment on the physico-chemical and functional properties as well as the microbiological quality of maize. The study also investigated techno-economic feasibility of radiation preservation of maize in Ghana and consumer attitudes towards foods such as ‘Ga kenkey’ and ‘Fanti kenkey’ prepared from irradiated maize. In the first study 127 bags of 50kg maize were used. Maize was repacked in 5-kg consumer packs made from 0.003mm thick polyethylene bags. Ten of the consumer packs were put into woven polypropylene sacks to make up 50kg bag of maize. Eighty-seven bags of maize were irradiated to a minimum of 2.6 and maximum of 5.6 kGy gamma radiation. Both the irradiated and the unirradiated maize were stored for six months in a commercial warehouse. Results indicated that the moisture content (7.2–7.8%), free fatty acid (<0.1%) and peroxide value (35–40 mEq/kg fat) of the maize were stable during storage. The initial mould count of 100–156 cfu/g decreased to 30–43 cfu/g; *Aspergillus oryzae* and *Asp. tamari* were identified. *Sitophilus sp.* was the predominant insect in the control but was replaced by *Rhyzopertha sp.* in the irradiated maize. Seventy-six per cent of the consumer polyethylene packs containing irradiated maize were damaged due to rough handling during transportation to and from the irradiation facility and coupled with poor warehouse hygiene resulted in reinfestation. In a subsequent study in which thicker polyethylene (0.008 mm gauge) was used coupled with careful handling, none of the consumer packs were damaged and the irradiated maize had lower insect population (152 insects/5kg pack) than the control (297 insects/5kg pack) after 4 months storage in a commercial warehouse. These observations underscored the importance of appropriate packaging and good warehouse hygiene in radiation disinfestation of foods. Peak viscosity of irradiated Dobidi maize starch was lower (97.5 B.U.) than unirradiated maize starch (365 B.U.). The eating quality of ‘Fanti kenkey’ and ‘Ga kenkey’ prepared from irradiated maize was acceptable and comparable to that prepared from unirradiated maize. Using the peak sale price of maize during the lean season, marginal analysis indicated that irradiation preservation of maize was undominated, however, the marginal rate of return of 17.65% was lower than the recommended 40%. Other scenarios considered suggested that radiation preservation of maize could be implemented and sustained in Ghana. Irradiation of cocoa up to 6 kGy did not adversely affect the quality parameters of products such as cocoa butter processed from them.

1. INTRODUCTION

Post-harvest food losses pose serious problems in most countries in Africa. In some cases as much as 35% of cereal and between 20–60% of tubers, root crops and bulbs are lost. Research and development studies carried out earlier in the laboratory under the CRP on “The

[1] Research carried out with the IAEA under Research Contract No. GH. 8448/R3.

provided information on most of the staples and established that food irradiation could play a significant role in reducing food losses and improve food safety. The completion of the Multipurpose Irradiation Facility offered an opportunity for pilot scale studies during which information is expected to accrue to facilitate the practical application of food irradiation.

Yam (*Dioscorea spp*), which is a major source of carbohydrates for most people in West Africa, is saddled with problems of storage, processing and handling. To prevent spoilage, farmers sell their produce cheaply during harvest. This leads to early shortage on the market and high prices and also shortage on the export market. There is also loss in quality through sprouting and rotting for those tubers that are stored. There is therefore a need to extend shelf life and improve the quality of yam.

Data already exists on the effect of radiation on the disinfestation of maize and cocoa beans (1). However, there is a need to test the effective doses at the pilot stage, conduct consumer acceptance studies and test marketing. This study also seeks to determine the economic feasibility of radiation preservation of yam and maize in Ghana. Large scale handlers, wholesalers who are interested in long term preservation and storage will likely benefit from using such a technology.

2. PRESERVATION OF YAMS

2.1 Materials and Methods

2.1.1 Post-harvest handling of yam in markets and farms in Accra and Nkwanta District

A survey was conducted on storage and handling practices of retailers, exporters, farmers as well as consumers in markets, villages and farms in Accra and its suburbs and in Nkwanta district in the Volta Region using a questionnaire. Visits were also made to some markets, warehouses and farms to observe the cultural practices and to conduct interviews.

2.1.2 Preservation of yams by gamma radiation

A storage structure was designed and built on a farm at Nkwanta District for on-farm storage studies to improve on the traditional system of storage and to minimise spoilage. Three hundred tubers of yam were transported to Accra to be irradiated at 125 Gy and taken back to Nkwanta. Two hundred yams were unirradiated and served as control. Both irradiated and unirradiated yams were divided into two halves and one half was stored on the constructed structure and the other half by the traditional method on the ground. Storage lasted 6 months.

2.1.3 Sensory Evaluation

After six months of storage the yams were processed into some local food products such as boiled yam, fried yam and fufu. Sensory evaluation was carried out on them as well as the raw yam using the Hedonic Scale to assess texture, taste, colour and acceptability. A questionnaire was used to evaluate the consumer attitude to irradiated yams. The results were analysed using Analysis of Variance (ANOVA).

2.1.4 Test-marketing of yams

Following the construction of the two yam barns, 4000 tubers of yam were purchased, irradiated and stored in 1997, and 5000 in 1998 and marketed. In order to introduce the technology to farmers, about 1500 tubers were irradiated for a farmer.

2.2 Results and Discussion

2.2.1 Post-harvest handling of yams

The different types of storage structures used traditionally for yam storage have their inherent problems. The yams obtained during the first harvest are stored in ditches covered with soils, which last only for a few weeks because of poor ventilation and water logging. Most get rotten and some spoilt by rodents. Alternately, yams are stacked on the floor to about 3–4 feet in rolls and the enclosures are made from palm frond, yam vines or mud. Sometimes, the stacks are made under trees. The advantage here is free ventilation. The storage on the floor however, leaves the yams to spoilage agents. It was evident from the results of the survey that wholesalers and retailers interviewed do not have any facilities for storage of yams because they feel that yams are perishable and long storage may lead to high losses. Extremes of temperature coupled with high humidity cause high losses.

Rotting

Rotting was found to be the greatest contributor to losses in storage. Rotting is mainly caused by fungi and bacteria, which enter the tubers through wounds. Often, the farmers allow the cut surfaces to dry before storage but the rains and the high humidity encourages mould growth. Other agents aiding rot are termites, black ants and driver ants which nest in the yams causing damages. Rodents and domestic animals cause damage to the yams. Scorpions and snakes also make their homes among the yams and their metabolic activities enhance spoilage apart from themselves posing danger to the farmers.

Physiological damage

These include sprouting, respiration and dehydration. When yam sprouts in storage it utilizes stored food to support the sprout. The resulting increased metabolic activity leads to increase in respiration and loss of water. Yams stored for extended period becomes dehydrated and fibrous. Small yams become hard when boiled.

Transportation and handling

Yams are transported as head loads, on bicycles, tractors, carts etc. Rough handling cause bruises, cuts and breakage which predispose them to rotting. The way the yams are packed onto trucks making use of every available space cause bruises. In most cases, bags of other commodities such as bagged groundnuts, maize are packed on top of the yam and their weight causes damage. Also the tarpaulin used to cover them cause heat build up in the heaps and poor ventilation. Breakdown of vehicle for days during transportation augment spoilage of yams. In some of the few samples taken, the temperature rose between 60 to 70^0C.

Harvesting methods

Improper implements used in harvesting could cause cuts on the yams. The wooden chisels are deemed to be better than the metal ones as they cause damage. Inexperienced diggers can cause damage. Those collecting the yam stems should be careful not to break them.

2.2.2 Preservation of yams by gamma radiation

Results on the effects of irradiation and storage on sprouting and rotting are presented in Tables 1 and 2. It was observed that by the end of the third month of storage, almost all the unirradiated yams had sprouted. The irradiated yams however did not start sprouting until the third month. At the end of the storage period, 5.6% of the irradiated yams stored on the barn and 18% of those stored on the ground showed sprouting as compared to 99% and 97% respectively for the unirradiated yams. The sprouts that appeared on the irradiated yams were found on the bottom part of the yams. This suggests that the dose distribution was not even and the bottom part that was turned away from the radiation source received a less dose than that could prevent the sprouting. The sprouting of the irradiated yams was delayed until the start of the rainy season when there was increased moisture in the atmosphere. There was more sprouting in the yams stored on the ground than those stored on the barn. This might be due to the fact that the wetness of the ground induced more sprouting than the dry atmosphere on the barn. In the two subsequent trials where 4000 and 5000 tubers were irradiated, not a single sprout was observed throughout the storage period because the yams were turned half way during irradiation for uniform dose distribution. Success of using gamma radiation for inhibition of sprouting in stored yams for 5–6 months have been reported by Adesuyi and Mackenzie (2) and Kodia and Kouadia (3).

Table 1. Sprouting of Yams during Storage

Treatment	Initial No.of yams	Number sprouted per month						Total	Sprouted (%)
		1st	2nd	3rd	4th	5th	6th		
Irradiated (crib)	177	-	-	1	3	3	4	11	5.6
Irradiated (ground)	100	-	-	2	4	5	7	18	18.0
Unirradiated (crib)	100	20	48	26	5	-	-	99	99.0
Unirradiated (ground)	100	18	49	30	-	-	-	97	97.0

Table 2. Rotting of Yams during Storage

Treatment	Initial No.of yams	Number rotted per month 1st	2nd	3rd	4th	5th	6th	Total	Rotted (%)
Irradiated (crib)	177	-	-	-	1	1	2	4	2.26
Irradiated (ground)	100	-	2	4	4	5	7	22	22.00
Unirradiated (crib)	100	-	-	1	1	2	4	8	12.00
Unirradiated (ground)	100	-	1	2	2	3	4	12	12.00

There was less rotting in the yams on the barn than those stored on the ground. During 6 months storage 2.26% of irradiated and 10% of unirradiated yams stored in the barn had rotted as compared to 22% and 12% respectively of the yams stored on the ground. It was observed that in all cases, the rotting increased with storage time and there was less rotting in the unirradiated yams stored on the ground than the irradiated ones. This could be due to the fact that the irradiated yams were less able to heal their wounds and thus were more susceptible to fungal attack and therefore rotting.

2.2.3 Sensory evaluation

Results of the sensory evaluation conducted using the Hedonic Scale are presented in Table 3. In all 40 people from Nkwanta, the yam producing area and 30 from Ghana Atomic Energy Commission took part in the tasting. Results were analyzed by Analysis of Variance (ANOVA) at 95% difference level. Table 3 indicates that there was a significant difference between food products made from irradiated and unirradiated yams. Products, namely fresh whole yam, boiled yam, fried yam and fufu from irradiated yams were preferred to those from the unirradiated yams in terms of texture, taste, colour and general acceptability. The taste of the irradiated and unirradiated fried yams was judged not different.

Table 3. Results of Sensory Evaluation on Products Made From Irradiated and Unirradiated Yams (*D. rotundata*, Poir)

Index	Whole yam		Boiled yam		Fried yam		Fufu	
Treatment	Irradiated	Control	Irradiated	Control	Irradiated	Control	Irradiated	Control
Texture	9.0 a	4.3 b	7.6 c	5.2 d	8.0 e	5.3 f	7.5 g	5.4 h
Taste	-	-	8.5 i	6.8 j	7.4 k	7.3 k	7.2 i	5.6m
Colour	8.1 o	5.3 p	8.0 q	6.5 r	7.0 s	5.6 t	8.2 v	6.0 n
Acceptance	8.4 w	4.6 x	7.8 y	5.3 z	8.1 a	6.7b	7.9 d	5.8 e

* Figures marked with different letters are significantly different at P = 0.05.

Note: In cll cases the dishes from irradiated yam were preferred except in the case of fried yam where there was no difference between taste of the two.

2.2.4 Test-marketing of irradiated yams

Yam was sold to three categories of people during 1991 and 1998.

a) Two groups of yam sellers who heard about the sale bought about 500 tubers, which they sold in no time and came back for another 500 tubers.
b) About 70% of the 1998 yam were sold to workers in the Ministries and other public offices. The sale was patronised. 60% came back to buy more.
c) The staff and residents of G.A.E.C bought yam at the same price as on the market. The questionnaire they filled gave the following information: 95% of the respondents said they had bought irradiated yams before, 5% said they had not bought irradiated yams before. During the period yams were marketed, 36.4% indicated that they bought irradiated yams 0–5 times, 39.4% said they bought 6–10 times and 21.1% said they bought 11–15 times.

When asked about how they found the irradiated yams, 24.2% said the yams were very good, 60.6% said they were good, 15.2% said they were average.

When asked whether they would purchase irradiated yams again, 87.9% said 'Yes' and 2.1% said 'No'. 45.5% of the respondents were prepared to pay more for irradiated yams, 45.5% said they would even pay more and 9% did not answer.

The results indicated that the majority of respondents liked irradiated yams and would buy again. The marketing of irradiated yams was very successful.

2.2.5 Economic Aspects

The cost -benefit analysis of irradiated yam is presented below.

Purchase Price
Cost price of yam at farm level in 1997 at Nkwanta located 430 km from Accra = ¢ 500/kg.
Transportation from Nkwanta to Accra = ¢ 100/kg.
Total cost price = ¢ 600/kg.
Cost of irradiation at GAEC: Not determined.

Loss Rate:

Rotting	-	4.42%
Weight loss	-	4%
Bruised tubers during transportation	-	10%
Total Loss:	-	4.42 + 4 +10 = 18.2%

Selling Price: — 1,200 per kg depending on whether the yams were bought in bulk or retailed after 5 months storage.

Analysis
Co is the Cost Price at time $T_c = O$;
Co = ¢ 600/kg.
Cost Price at T = 5 months (C_t)
$C_t = 600 + 18.2 \times 600 + B$ where B is profit balance
$C_t = 709.2$
When the Selling Price is = ¢ 1000.00 the Profit balance is = ¢ 290.80.
US $ 1 = ¢ 2,580

3. **RADIATION PRESERVATION OF MAIZE**

3.1 Materials and Methods

First study

One hundred and twenty mini bags (50 kg) of maize were purchased from the Ghana Food Distribution Corporation (GFDC). At the GFDC depot in Kumasi, each 50 kg maize was repacked into 10 × 5 kg polyethylene (0.003" gauge) consumer packs and packed into the 50 kg woven polypropylene sacks. The maize was initially transported to the GFDC warehouse at its Head Office in Accra a distance of 250 km and on 29th December 1997 eighty (80) bags were sent to the Gamma Irradiation Facility (GIF) at the Ghana Atomic Energy Commission, Kwabenya. The forty bags of maize left behind at the GFDC warehouse Head Office in Accra served as the control.

At the GIF, 80 bags of maize were treated with a dose distribution of 2.6 kGy minimum and 5.6 kGy maximum gamma radiation. The irradiated maize was transported back to the GFDC warehouse at its Head Office in Accra, a distance of 250 km for storage. The initial quality of maize (unirradiated control) was evaluated in terms of microbiological profile:i.e. total plate count (plate count agar, 36^0C/48h) and fungal count (oxytetracycline glucose yeast extract agar, 28^0C/72h); moisture content; free fatty acids (FFA); peroxide value (POV); pasting characteristics using Brabender viscoamylograph; hidden infestation; and sensory evaluation of prepared products such as 'Fanti kenkey' and 'Ga kenkey'. After six months storage, both the control (unirradiated) and irradiated maize were sampled and analysed for the parameters indicated above. In addition, the number of broken polyethylene consumer packs was determined.

Second Study

In the second study thicker (0.008mm gauge) polyethylene pouches were used for the consumer packs and rough handling of the sacks of maize was minimised.

3.2 Results and Discussion

The moisture content of the maize was fairly low and stable (7.4–7.8%) during storage. GFDC purchases maize and dries it to safe moisture content before storage. When moisture content is low and stable, mould growth is suppressed and the maize may be free from mycotoxins. The free fatty acid content of the maize was also initially low (<0.1%) and remained low during storage. The peroxide value of the maize was also reasonably stable during storage ranging between 35–40 mEq/kg fat. The low and stable moisture content of the maize might have contributed to the stability of the lipids during storage.

3.2.1 Microbiological Quality

Table 4 shows that the initial total plate count of the maize ranged between 130–160 cfu/g whilst mould count was between 100–156 cfu/g. During storage, mould count on the control reduced to values between 30–43 cfu/g. Again, this observation may partly be attributed to the low and stable moisture content of the maize. The initial analysis suggested the presence of *Aspergillus oryzae* and *A. tamari* on the maize. After 6 months storage however, only *A. tamari* was identified.

Table 4. Microbiological Profile of Maize

	Initial analysis	After 6 months storage	
		Control	Irradiated
Total Plate Count	130–160 cfu/g	30–226cfu/g	ND
Mould Count	100–156 cfu/g	30–43 cfu/g	ND
Moulds identified:	*Aspergillus oryzae* *Aspergillus tamar*i	*Aspergillus. tamari*	

ND — not determined

3.2.2 Hidden Infestation

Table 5 shows that *Sitophilus sp*. was the predominant insect (180 insects/5 kg maize) on the maize prior to storage. The rest of the insects were in low numbers and when put together, the total number was less than half of the *Sitophilus* population. In the first study, after 6 months storage, *Sitophilus sp*. was still the dominant insect on the control samples. Other insects identified on the control were *Rhyzopertha sp*.,. *Carpophilus sp*., *Tribolium sp*. *Cryptolestes sp*. and *Cathartus sp.* The irradiated maize had higher *Oryzaephilus sp* population than the control and *Rhyzopertha* was the dominant insect species, exceeding 800 insects/5 kg maize. The doses applied were higher than the dose of 0.8 kGy required for disinfestation. The presence of the high population was therefore the result of reinfestation. These observations were not unexpected in view of the fact that about 76% of the consumer packs (Table 6) containing irradiated maize were damaged. The number of damaged consumer packs in the control sacks was relatively low (10%). An explanation for the high number of damaged consumer packs containing irradiated maize may be found in the handling of the maize. The 50-kg sacks of maize, each containing ten 5-kg consumer packs were initially transported from Kumasi and off-loaded at the GFDC warehouse in Accra. Subsequently, those to be irradiated were re-loaded and transported to tech GAEC (20 km) where they were unloaded, irradiated and transported back to the GFDC warehouse where the control was being stored. All handling of the maize was done manually in the typical rough manner. Unlike the unirradiated maize, the sacks containing irradiated maize were subjected to four additional cycles of loading and unloading. Such excessive handling of the maize might have contributed to the damage of the consumer packs within the 50-kg sacks. Effective packaging is critical when irradiation is used for insect disinfestation. The irradiation treatment has no residual effect; thus irradiated grains can immediately be re-infested once they leave the irradiation chamber and is exposed to insects. The fact that *Rhyzopertha sp*. was the dominant insect in the irradiated maize is noteworthy. Some strains of *Rhyzopertha sp.* can tolerate phosphine, the fumigant used to disinfest grains in the GFDC warehouse where both the control and irradiated maize were stored. Maize in storage is fumigated once every three months. Since the irradiated maize was not fumigated during storage as has been routinely done for the other stored products in the same warehouse and as a large number of the consumer packs were damaged and open, these packages were prone to reinfestation by the phosphine-tolerant strains which developed due to repeated fumigation, hence the high population of insects in the irradiated maize. This observation underscored the importance of effective packaging when irradiation is applied for insect disinfestation.

Table 5. Hidden Infestation

Insect species (counts/5 kg maize)		
Pre-storage		
Sitophilus sp.		180 ± 20 (s.e.)
Others		80 ± 10
AFTER 6 months storage	Control	Irradiated
Sitophilus sp.	315 ± 124	34 ± 14
Oryzaephilus sp.	59 ± 46	58 ± 20
Rhyzopertha sp.	33 ± 23	824 ± 149
Carpophilus sp.	22 ± 8	1 ± 1
Tribolium sp.	14 ± 13	44 ± 9
Cryptolestes sp.	8 ± 4	100 ± 35
Cathartus sp.	6 ± 3	27 ± 19

Table 6. Physical evaluation of the integrity of polyethylene consumer packs

% Broken consumer packs/50 kg sack	
CONTROL	IRRADIATED
10 ± 1	76 ± 2

Second Study

In the second study where thicker polyethylene pouches were used for the consumer packs and rough handling of the sacks of maize was minimised, none of the consumer packs was damaged and the irradiated maize had lower insect population (152 insects per 5 kg pack) than the control (297 insects per 5 kg pack). *Sitophilus sp.* was the major insect pest in the maize before irradiation. After 4 months storage (the study had to be abruptly terminated because the owners needed the warehouse for storage of new maize), *Sitophilus sp.* remained the major insect species in the control as was observed (Table 5) when the maize was stored in the GFDC warehouse. In the irradiated maize however, *Sitophilus sp.* and *Oryzaephilus sp.* (Table 7) were the major insect pests. It is noteworthy that in the first study, *Sitophilus sp.* was replaced by *Rhyzopertha sp.* as the major insect pest in the irradiated maize (Table 5); this observation may in part be linked to the exposure of the maize (damaged packs) to insects from other produce (cowpeas, bambara beans) in the same GFDC warehouse. There is a need to construct research warehouse for pilot scale studies of this nature.

3.2.3 Pasting Characteristics of Maize Starch

Maize sold in the markets in Ghana are mixed varieties but pasting characteristics are generally variety specific. The results of the pasting characteristics of maize are shown in Table 8. From the initial analysis, significant change in the viscosity of 'Dobidi' starch occurred when the temperature reached 80.5^{0}C. The starch viscosity increased from 144 B.U. during 20min hold at 95^{0}C to 575 B.U. when cooled to 50^{0}C. The irradiated and control

Dobidi samples were mistakenly kept in the cold room and became mouldy when they were later stored under ambient conditions. The result showed that starch from mouldy maize exhibited lower gel viscosity. Results of the control and irradiated maize (mixed varieties stored for 6 months) showed lower gel viscosity for starch extracted from irradiated maize; peak viscosity for starch from unirradiated maize was 365 B.U. as compared to 97.5 B.U. for irradiated maize. The reduced starch gel viscosity of irradiated maize may be reflected in the textural quality of food products prepared from it.

Table 7. Hidden Infestation of Irradiated and Non-irradiated Maize During Storage

After 4 months storage	Insect species (counts/5 kg maize)		
	Initial population	Control	Irradiated
Sitophilus sp.	73 ± 18	140 ± 35	45 ± 10
Oryzaephilus sp.	5 ± 2	20 ± 5	39 ± 20
Rhyzopertha sp.	0	1 ± 1	7 ± 3
Tribolium sp.	12 ± 2	56 ± 10	36 ± 11
Cryptolestes sp.	2 ± 1	79 ± 17	23 ± 10
Cathartus sp.	4 ± 1	1 ± 1	1 ± 1
Ephestia sp.	0	0	1 ± 1
Others	0	25 ± 8	0
Total Number	95	297	152

Table 8. Pasting Characteristics of Maize

	Pasting Temp. ^{0}C	Viscosity at 95^{0}C (BU)	Viscosity after 20 min hold at 95^{0}C (BU)	Viscosity at 50^{0}C hold at 50^{0}C (BU)	Viscosity after 20min (BU)	Peak Viscosity (BU)
Dobidi						
Initial analysis	80.5	75	144	575	490	580
Control Stored for 6 mo	95.8	3.5	7.5	47.5	50	50
Irradiated and stored for 6 mo	95.5	3.5	10	52.5	55	60
Mixed variety of maize						
Control stored for 6 mo.	71.5	40	98.5	287.5	36	365
Irradiated and stored for 6 mo.	81	16.5	27.5	92.5	96	97.5

3.2.4 *Sensory quality of 'Kenkey'*

The eating quality of 'kenkey' prepared from irradiated maize was compared with that prepared from unirradiated maize. The results in Table 9 indicated that 15% of the consumers found the eating quality of 'Fanti kenkey' prepared from irradiated maize better than that prepared from unirradiated maize. Majority of the consumers found the eating quality of 'Fanti kenkey' and 'Ga kenkey' prepared from irradiated maize comparable to that prepared from unirradiated maize.

Table 9. Taste Panel Evaluation of the Eating Quality of 'Kenkey' Prepared from Irradiated Maize

	WORSE THAN CONTROL	BETTER THAN CONTROL	NO DIFFERENCE COMPARED TO CONTROL	ACCEPTABLE
Fanti Kenkey	2%	15%	61%	22%
Ga kenkey	2%	37%	41%	20%

4. THE ECONOMIC ASPECT OF IRRADIATION OF MAIZE

4.1 Analytical Procedure

Data required for assessing the economic viability of radiation preservation of maize depends on the method of analysis employed. The present study employed marginal analysis, which considers only recurrent cost, ignoring capital costs. Other appraisal techniques which require data on capital costs and cash flow data include Benefit-Cost analysis, Net Present Value (NPV), Internal Rate of Return (IRR) etc. The capital costs and cash flow (in time series) data on the present project is not available.

4.1.1 *Method of data analysis*

For conclusions to be drawn about the viability of projects, 2 or more projects need to be compared. A control project, using ordinary storage of bagged maize was thus compared with the radiation preservation project.

The different scenarios were considered as different treatment levels for the radiation project. Each treatment is then determined to be dominated or otherwise. A treatment is dominated (inferior) when there exists at least one option that offers a greater net benefit at an equal or lower cost and a treatment is undominated (superior) when no other option exists offering a greater net benefit at an equal or lesser cost.

Marginal analysis was performed for only undominated treatments. To determine how undominated treatments respond to changes in output price and input costs, sensitivity analysis was carried out. A sensitivity analysis is an analytical technique used to find out what happens to the earning capacity of a project when estimated output, price or yield levels differ from the actual. It is thus a test conducted by varying one element or a combination of elements to find out whether the project remains viable.

4.1.2 Data employed

Cost elements

(i) Purchase value for 127 mini bags of maize for both treatments
(ii) Repacking into retail packs for both
(ii) Warehousing and storage for both
(iv) Labour (for transfer of maize to and from irradiation plant)
(v) Transportation (to and from irradiation plant)
(vi) Radiation treatment cost for 3 scenarios*
(vii) Laboratory reagents.

Benefits were measured using the 1998 sale value of products from both irradiated and unirradiated.

4.1.3 Computation procedure

Gross benefit was calculated by finding the product of price and quantity of output. Total variable cost was obtained by finding the product cost of inputs and quantity of output. Net benefit was given by the difference between gross benefit and total variable cost. Benefits and costs were then compared to determine whether treatments are dominated or not. For an undominated treatment, its marginal cost and benefit were calculated by finding the difference between it and the preceding undominated treatment.

The marginal rate of return was then calculated by finding the marginal benefit to cost ratio. The target rate of return is the sum of the actual interest rate on loan and the risk premium. For the purposes of this study, an empirical standard of 40% as recommended in the literature was used.

4.2 Results and Discussion

The following tables present the summary of the results for analysing the economic viability of radiation preservation of maize.

A sensitivity analysis was carried out based on the assumption that the project is viable. The results are shown in Table 12.

Table 10. Net Benefit Calculation for Irradiated and Unirradiated Maize During Storage

	T_0	T_1	T_2	T_3
Gross Benefit	844,208	1,632,784	1,740,784	2,132,784
Total Variable Cost	0	1,361,230	1,587,430	1,922,380
	844,208	271,554	153,354	210,404

Table 11. Marginal analysis of irradiated and unirradiated maize during storage

Treatment	Net Benefit	Total Variable Cost	Dominated Option (D)	Marginal Variable Cost	Marginal Benefit	Marginal Rate of Return (%)
T_3	210,404	1,922,380		334,950	57,050	17.03
T_2	153,354	1,587,430	D	-----	-----	-----
T_1	271,554	1,361,230	D	-----	-----	-----
T_0	844,208	0	-----	-----	-----	-----

T_0 = Control
T_1 = (18 bags @ ¢ 21,000/bag and 56 bags @ ¢ 20,000/bag) and (60,000 tons/throughput/year at ¢4,700/50kg).
T_2 = (18 bags @ ¢ 27,000/bag and 56 bags @ ¢ 20,000/bag) and (20,000 tons/throughput/year at ¢7,300/50kg).
T_3 = (74 bags @ ¢ 27,000/bag) and (10,000 tons/throughput/year at ¢11,500/50kg).
[1] * 10,000 tons/throughput/year at ¢11,500.00/50kg 970,050.00
20,000 tons/throughput/year at ¢ 7,500.00/50kg 635,100.00
60,000 tons/throughput/year at ¢ 4,700.00/50kg 408,900.00

Table 12. Sensitivity Analysis for Radiation Preservation of Maize*

Treatment	Net Benefit (¢)	Total Variable Cost (¢)	Dominated Option (D)	Marginal Variable Cost (¢)	Marginal Benefit (¢)	Marginal Rate of Return (%)
Situation 1: Selling price of maize = ¢35,000/bag						
T_3	830,404	1,922,380	D			
T_0	844,208	0	-	-	-	-
Situation 2: Cost of radiation treatment increased by 100%						
T_3	759,646	2,892,430	D			
T_0	844,208	0	-			
Situation 3: Cost of radiation treatment increased by 50%						
T_3	274,621	2,407,405	D			
T_0	844,208	0	-			
Situation 4: Cost of radiation treatment decreased by 50%						
T_3	695,429	1,437,355		1,437,355	219,425	15.27
T_0	476,004	0	-			

* Without consultancy fees and fuel costs.

It could be concluded that if the sale value of irradiated product is increased to equate that of the national average or if there is a 50 or 100 per cent increase in cost of irradiation, the project will be unworthy of adoption. Project will be viable if and only if costs are reduced by 50 per cent.

The initiative being taken by both the private and the public sector to be part of the evolving process of researching into and commercialising research findings is commendable. The cost subsidisation of borrowed funds for covering establishment and operational expenses such projects will not be worthy of sustaining. If the social benefit to be derived from such a venture proves worthwhile, governments and donor agencies could be encouraged to implement and sustain the project.

5. COCOA

5.1 Materials and Methods

Cocoa butter was extracted using petroleum ether in a Soxhlet extractor. The fat was dried using a rotary evaporator (4). Part of each sample was sent to the Cocoa Processing Laboratory for analysis. The following determinations were made on the cocoa butter; the slip (melting) point, saponification value, unsaponifiable matter, peroxide value and % free fatty acid according to methods specified by Pearson (5). The effect of storage on peroxide values and free fatty acids (FFA) was determined using irradiating freshly dried cocoa.

5.1.1 Analysis on Cocoa Butter

Samples of dried cocoa beans weighing 100g each were exposed to radiation doses of 0 to 6 kGy from a cobalt-60 gamma irradiator. The irradiated and unirradiated samples were all dehulled and ground separately using a laboratory grinder.

5.1.2 Organoleptic Qualities of Products of Cocoa and Test Marketing

One and half tonnes of cocoa were irradiated to 0, 1 and 5 kGy and cocoa butter, cocoa powder and chocolate prepared from it.

Institutions collaborating in this work were The Cocoa Processing Company, The Food Science and Nutrition Department, Legon and The Cocoa Research Institute. Discussions were held on the work. Owing to unavailability of a facility to handle smaller quantities it was decided to have a minimum of ½ tonne per treatment. The work began in October 1999. Processing and test marketing will be done by the Cocoa Processing Company. Organoleptic evaluation will be carried out both by the Cocoa Processing Company and also by the Food Science and Nutrition Department. Quantitative analysis of cocoa butter by chromatography was carried out at the Cocoa Research Institute.

5.2 Results and Discussions

5.2.1 The effect of radiation on Cocoa Butter

The results of analysis made on cocoa butter are presented in Table 13. The results showed that the irradiated samples compared favourably with the specification set by the factory. Slip point value ranged between 34.1 and 34.7°C. The limit is 32.0–35.0°C. The saponification values ranged between 188.02 and 189.67 which compares well with the standard set at factory (188 to 189.0). The slight differences within the values did not correspond to the radiation doses and therefore could not be attributed to the effect of radiation.

The analysis of variance of the cocoa showed that differences within the doses are significant as well as that between the different months of sampling. The table of means (Table 14) showed significant differences within the doses but this did not follow any particular trend. The free fatty acid determined after 9 months was 1.32% even though all determinations made were lower than the acceptable limit of 1.75%. Generally, percentage FFA increased with storage and was not influenced by irradiation.

Table 13. The Effect of Irradiation on Cocoa Butter

Dose (kGy)	Slip Point °C (Melting)	Saponification value meq/kg fat	Unsaponifiable matter
0	34.6	188.71	0.25
1	34.4	188.48	0.25
2	34.6	188.26	0.24
3	34.8	188.15	0.24
4	34.7	188.12	0.23
5	34.5	188.67	0.28
6	34.7	188.60	0.29

Values are means of four replicates.

Table 14. Effects of Irradiation and Storage Period on Percentage free fatty acid in Cocoa Butter

Dose (kGy)	0	1	2	3	4	5	6	sed
Mean FFA (%)	0.66 b	0.60ab	0.94d	0.71c	0.54a	0.71c	0.061d	0.019
Month	0	1	2	9	sed			
Mean FFA (%)	0.42 e	0.61 g	0.55 f	1.32 h	0.69			

Figures marked with same letters are not significantly different (P=0.01).

Peroxide value.

The peroxide values followed the same trend as the percentage FFA. Analysis of variance showed a significant difference between the different months. Comparison of the means showed that the difference between the first two months and that of the other month was highly significant ($p<0.001$) (Table 15). The differences within the dose did not follow any particular trend and was only attributed to the individual samples. The values for the months increased with time but in all the determinations, it was generally observed that as the per cent FFA increased the peroxide value also increased.

Takyi and Amuh (6) analysed cocoa beans after irradiation at dose 0, 0.1, 0.2, 0.5, 2.0 kGy. They found no significant difference in respect of reducing sugars, total fats as determined by iodine value, free fatty acid value, saponification value, refractive index slip point and specific gravity among other determinations. According to Minifie (7), the composition of fatty acids in cocoa butter are as follows: Myristic (14.0) 0.1%; Palmitic (20:0) 0.1%.

Table 15. Effect of Irradiation and Storage Period on Percentage Peroxide value of Cocoa Butter

Dose (kGy)	0	1	2	3	4	5	6	sed
mean p. value	26.83d	22.95f	21.75f	20.94fg	19.23g	26.67d	24.15e	2.35
Month	0	1	2	9	sed			
Mean	16.21b	11.81a	17.69b	47.03c	1.77			

Figures marked with same letters are not significantly different.

Table 16. Comparison of Percentage peak areas of palmitic (16:0), stearic acid (18:0), and oleic (18:1) acids from Butter prepared from Irradiated Cocoa

Dose (Gy)	Percentage free fatty acid		
	Palmitic	Stearic	Oleic
0	27.4	35.0	37.4
1	28.1	31.9	40.1
2	24.4	28.1	42.7
3	20.5	24.9	54.7
4	31.4	32.4	36.3
5	27.8	27.4	44.2
6	27.5	28.3	44.3
7	21.5	30.1	48.4
8	20.0	35.1	44.3
9	26.1	27.9	46.0
10	29.2	30.6	47.1

In the present study the chromatographic separation showed palmitic, stearic and oleic acids in the control (unirradiated) as well as irradiated samples. Oleic acid had the highest peak. These results are in agreement with the earlier reports by several groups of workers. According to Prawato (8) fatty acids of cocoa contain C 14, C 16, C 16: 1, C 18, C 18:1, C 18: 2, C 18:3 and C 20. Of these C16, C18 and C18: 1 was the most predominant. Erickon et al (9) also reported that the composition of fatty acids are palmitate (26%), stearate (34%), oleate (35%), linoleate (3%), (1%) and trace amount of several acids.

6. CONCLUSION

The traditional storage of yam was found to be inadequate and needs improvement. Long term storage facilities outside the farm gate does not exist and needs to be developed. There is an urgent need to construct specialised markets to discourage the sale of yam in the open exposing them to extremes of temperature and spoilage. Applying radiation at a dose of 120–130Gy inhibited sprouting in yam without affecting its physical chemical and eating qualities.The problem of reinfestation of irradiated maize could be overcome by the use of thicker polyethylene packaging material. Test marketing of yam showed that the consumers will buy irradiated food. The irradiation of yam and maize become economical when the products are sold within the peak period and the through put is high. Irradiation of yam becomes economical if yams are marketed within 6 months of storage.

Irradiation of cocoa up to 6 kGy did not adversely affect the quality parameters of products processed from them.

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IRRADIATION FOR SPROUTING INHIBITION OF KPONAN YAMS IN CÔTE D'IVOIRE

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Abstract

Yams of the Kponan variety were transported from Abidjan, Côte d'Ivoire, to Accra, Ghana, irradiated at the facility operated by the Ghana Atomic Energy Commission and brought back to Abidjan,, Côte d'Ivoire. The law n°98–593 on radiation protection and nuclear safety was promulgated on 10 November 1998. In its article 8 it is said that food and industrial products irradiation facilities shall comply with the requirements of the International Code of Practice. The regulations on food irradiation based on this main law are now being considered for promulgation. The lack of regulations makes it difficult to legally conduct test marketing of irradiated yams. The economic feasibility of irradiating yams in Ghana and selling them in Côte d'Ivoire has been investigated.

INTRODUCTION

During the Second FAO/IAEA Research Co-ordination Meeting (RCM) on the Co-ordinated Research project, Tanger, Morocco, 8–12 September 1997, it was agreed upon the following programme for 1997–1998.

1. Main objectives

1.1. To contribute to the promulgation of legislation and regulations on food irradiation;
1.2. To conduct market testing of irradiated Kponan yams;
1.3. To determine the economic feasibility and impact of irradiation to prevent losses of Kponan yams in Cote d'Ivoire

2. Work plan

2.1. Construction of yam storage area;
2.2. Submission of the law on food irradiation to Parliament;
2.3. Submission of the regulations on food irradiation to the national authorities;
2.4. Participation in an international fair on agriculture in Côte d'Ivoire;
2.5. Market testing of irradiated yams;
2.6 Report on economic feasibility and impact of irradiation to prevent losses of Kponan yams

3. Methodology

3.1. To continue co-operation with Ghana Atomic Energy Commission (GAEC);
3.2. To collaborate with South Africa to select appropriate tests and design questionnaires for market testing and determination of consumer acceptance.

4. Work Done

4.1. Construction of storage area

A second room has been added to the irradiator blockaus to serve as storage area for yams.

4.2. Submission of the draft food irradiation law to Parliament

The draft law on food irradiation has been revised at Parliament level, voted and promulgated on 10th November 1998, in a broader law on radiation protection and nuclear safety called: Loi n°98–593 du 10 Novembre 1998 relative à la protection contre les rayonnements ionisants et à la sçureté nucléaire.

4.3. Submission of the regulations on food irradiation to national authorities

After the law, the regulations are now being revised by the national authorities.

4.4. Irradiation of yams at GAEC

During the period 1997–1998, four thousand (4000) yams weighing 6 tons were bought, treated and sold. Several batches were transported from Abidjan, Côte d'Ivoire, to Accra, Ghana, irradiated at the facility operated by the Ghana Atomic Energy Commission and brought back to Abidjan. The official memorandum of understanding between the two countries is still to be signed by the Ivorian authorities as it has been already signed on Ghana side. Due to this situation, numerous bureaucratic requirements from both countries in the transportation of agricultural products across boundaries are hampering the implementation of the project.

4.5. Collaboration with South Africa

On December 1997, the author established a direct contact with Dr. Amanda MINNAR in South Africa. During this mission, discussions were held as to how to select appropriate tests and how to design questionnaires for market testing and determination of consumer acceptance. Once, food irradiation regulations are adopted by the Ivorian Authorities, market testing will be done officially on large scale.

4.6. Economic feasibility determination

4.6.1. Purchase price determination

Purchase price to peasant in 1997 at Kamala, a village located at 65 km from Bondoukou: 80FCFA/kg

Transport cost from Kamala to Bondoukou: 15FCFA/kg
Transport cost from Bondoukou to Abidjan: 25FCFA/kg
The purchase price is then the sum: 120FCFA/kg

4.6.2. Irradiation cost

Chemical treatment (fungicide and insecticide): 5FCFA/kg
Charge for GAEC facility: 0 FCFA

Transport Abidjan-Accra-Abidjan: 100 FCFA/kg
Incidental expenses (tips, customs, police, etc.): 50FCFA/kg
Then the cost to irradiate the yams in Ghana and bring them back is: 155 FCFA/kg

4.6.3. Cost price of the yams

The cost price of the yams is purchase price + irradiation price: 275 FCFA

Loss rate
Rotting: 10% after 6 months of storage

Weight loss: 20% after 6 months of storage

Bruises during transportation: 10%

Total loss rate: 40%

Storage fee
The storage at University is free of charge.

Selling price determination
After six months we have sold the yams at a price falling in the rage 460FCFA to 500FCFA depending on the market area of the town. It was not possible to bargain higher prices.

Economic feasibility
C (0) is the cost price at time t = 0; C (0) = 275 FCFA/kg

Cost price at time t = 6 months C (t): 275 + 40% × 275 + B,

where B is the profit balance =385+B.

When the selling price is 460FCFA the profit balance B is 75FCFA.

CONCLUSIONS

During the time period 1997–1998, the law allowing food irradiation in Côte d'Ivoire has been promulgated. The regulations on food irradiation are still under revision. Batches of Kponan yams have been irradiated in Ghana and sold in Côte d'Ivoire. This is encouraging.

The economic feasibility study has been initiated and will continue, especially when the regulations on food irradiation are promulgated in Côte d'Ivoire like in Ghana.

ACKNOWLEDGEMENT

The author wishes to thank A. Minnar for the assistance in designing questionnaires and in planning the test marketing.

EFFECT OF IRRADIATION ON QUALITY, SHELF LIFE AND CONSUMER ACCEPTANCE OF TRADITIONAL NIGERIAN MEAT AND FISH PRODUCTS*

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Abstract

The effect of low dose irradiation, up to 6 kGy, on quality, shelf life and consumer acceptance of three traditional Nigerian meat and fish products was investigated. Irradiation inhibited microbial growth in 'suya' and 'kilishi' with substantial reduction in total aerobic counts, yeasts and molds and *Staphylococcus aureus*. Non-irradiated smoked-dried catfish (*Clarias gariepinus*) had a shelf life of less than one week at tropical ambient temperature (21–31°C) due to insect infestation. Irradiated 'kilishi' and smoked dried catfish packed in sealed polyethylene bags (0.04 mm thick) were shelf stable for a period of 4–6 months and remained free from moldiness, infestation and were considered acceptable in sensory quality by a consumer panel of 32 assessors. There was a slight increase in TBA values of irradiated 'kilishi' stored for 4 months relative to non-irradiated controls.

1. INTRODUCTION

'Suya' or 'tsire', 'kilishi' and dried fish are important food products that provide valuable animal protein in the diet of millions of Nigerians. 'Suya'and 'kilishi' are made by roasting the spiced, salted slices/strips of meat (usually beef). 'Kilishi' differs from 'suya' in that the two-stage sun-drying process precedes roasting. Consequently, 'kilishi' has a much lower moisture content (6–14%) than 'suya' (25–35%). Smoking and sun drying are used to preserve a wide variety of Nigerian fresh water species of fish including Clarias, Gymnarchus, Chrysicthys, Citharinus, Alestes, Hydrocynus and Tilapia.

The unhygienic conditions under which meat and fish products are often processed and retailed in Nigeria are of grave concern, from a public health standpoint, as revealed by consumer surveys [1]. In the case of 'suya' and 'kilishi' processing, a variety of spices that are potentially sources of microbial contamination are used. Total viable and coliform counts exceeding acceptable limits for ready-to-eat meat products and the presence of a wide spectrum of pathogenic bacteria have been reported in retail 'suya' [2]. In the case of dried fish, insects, especially blowflies and beetles, are responsible for considerable losses during processing, storage and distribution.

Whilst it is well known that irradiation reduces spoilage and pathogenic microflora in meat and fish products, and destroys insects that damage dried fish, there is some concern regarding lipid stability [3] and consumer acceptance of irradiated foods in Nigeria [4]. The objective of this study was to investigate the effect of irradiation on microflora, shelf life and consumer acceptance of 'suya', 'kilishi' and smoked-dried fish.

* Work performed under IAEA Research Contract No. 8325/R1.

2. MATERIALS AND METHODS

'Suya' and 'kilishi' were purchased on several occasions in 1997 and 1998 from a local processor at the Bodija area of Ibadan, Nigeria. The products were prepared by the traditional method from portions of beef and a variety of spices and other dried ingredients including peanut (*Arachis hypogea*) cake powder, ginger (*Zingiber officinale*), chillies (*Capsicum frutescens*), melegueta pepper (*Aframomum melegueta*), onion (*Allium cepa*), *Piper guineense*, *Thonningia sanguinea*, *Fagara santhoxyloides*, 'Maggi' (trade name of a food condiment containing monosodium glutamate) and salt [1, 5]. Smoked-dried catfish (*Clarias gariepinus*) was purchased from local producers at Aleshinloye market in Ibadan. The product was prepared by gutting *Clarias gariepinus* and bending it into a horse-shoe shape, retained by means of a sharp stick that pierces through the caudal and head regions, before hot smoking by the traditional method with firewood as source of heat and smoke [6].

2.1. Packaging and Irradiation

2.1.1. Pilot studies

Small quantities of 'suya' and 'kilishi' (approximately 20 g) were packed in heat-sealed polyethylene bags (0.04 mm thick). The products were transported by road, inside an ice chest covered with ice in the case of 'suya', from Ibadan to Ile-Ife, over a distance of approximately 90 km for irradiation. Batches of 'suya' and 'kilishi' were irradiated at doses of 1 to 5 kGy (dose rate, 1.5 kGy per h) at ambient temperature (27°–30°C) in a cobalt-60 source Gammacell 220 high dose rate research irradiator at the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria. The irradiated samples together with the non-irradiated controls were transported back to Ibadan by road on the same day. 'Suya' samples were held in an ice chest covered with ice during transportation back to Ibadan.

2.1.2. Scaled-up studies

Individual whole smoked-dried catfish (*Clarias gariepinus*) with an average weight of 170 g each and strips of 'kilishi' were packed in heat-sealed polyethylene bags (0.04 mm thick). The products were transported by road from Ibadan, Nigeria to Accra, Ghana over a distance of approximately 1000km over a period of two days at tropical ambient conditions. The samples were randomly divided into four lots. Three lots were irradiated at estimated doses of 2, 4 and 6 kGy respectively (dose rate 7.3 kGy per h) at ambient temperature in a cylindrical cobalt-60 source gamma irradiator (initial loading capacity, 50 kCi) at the Ghana Atomic Energy Commission, Legon-Accra. The irradiated samples together with the non-irradiated controls were transported back to Nigeria by road and held at ambient conditions, 21°–31°C (mean daily minimum and maximum temperatures).

2.2. Proximate Analysis

Moisture in 'suya', 'kilishi' and smoked-dried catfish (*Clarias gariepinus*) samples was determined by drying to constant weight in an air oven at 103°C. Protein, fat, and ash contents of irradiated and non-irradiated 'suya' were determined by standard procedure [7]. The semi-automated Tecator kjeltec digestion and distillation system was used for the determination of protein by the Kjeldahl procedure, with selenium as catalyst. Protein was estimated as total N × 6.25. Fat was determined by extraction with petroleum ether in a Soxhlet apparatus. Ash was determined by incineration in a muffle furnace at 500°C.

2.3. *Bacterial Counts*

Irradiated and non-irradiated meat products were examined microbiologically by standard procedures [8]. Representative samples were macerated and serially diluted in ¼ strength Ringer's solution. Total aerobic count, yeasts and molds, intestinal pathogens (*Salmonella* and *Shigella*) and *Staphylococcus aureus* were determined on plate count agar (Difco), potato dextrose agar (Difco), desoxycholate citrate agar (Biolife) and mannitol salt agar (Amershan) respectively. Plates were incubated at 35°C for total aerobic count, 37°C for intestinal pathogens and *Staphylococcus aureus*, and 27°C for yeasts and molds.

2.4. *Lipid Oxidation*

The 2-thiobarbituric acid (TBA) test was used to measure the development of oxidative rancidity in irradiated and non-irradiated meat products. Distillates from 'suya' and 'kilishi' samples were heated with TBA reagent in glass-stoppered tubes. Following cooling, the absorbance at 538 nm was measured against a water/TBA reagent blank [9]. TBA numbers were expressed as mg of malonaldehyde/kg sample.

2.5. *Preliminary Sensory Evaluation*

Preliminary sensory evaluation of smoked-dried fish irradiated at 2, 4 or 6 kGy and stored for 3 weeks at tropical ambient temperature was carried out by a semi-trained panel of 9 assessors drawn from students and staff of the Department of Food Technology, University of Ibadan using the multiple comparison difference analysis [10]. The irradiated smoked-dried fish samples were rated twice relative to freshly procured non-irradiated controls for appearance, flavor, texture and overall acceptability on a nine-point scale where 1=extremely inferior to control, 5=same as control and 9=extremely superior to control.

2.6. *Consumer Acceptability*

Consumer acceptance of irradiated 'kilishi' and smoked-dried catfish was evaluated by a randomly selected consumer panel of 32 members consisting of people of diverse background, familiar with the products. Two types of tests were used; the hedonic rating and paired preference tests.

2.6.1. *Hedonic rating test*

The effect of radiation dose on some specified sensory quality attributes was determined by the hedonic rating test. Samples of 'kilishi' irradiated at a dose of 4 or 6 kGy and stored at tropical ambient temperature for 4 months were rated for appearance, texture, flavor and overall acceptability on a 5-point scale where 1= dislike very much, 3= neither like nor dislike, and 5= like very much.

2.6.2. *Paired preference test*

The paired preference test was used to determine which, if any, of the following four treatments was preferred when compared with each other, one on one.

(i) Freshly purchased non-irradiated smoked-dried catfish.
(ii) Smoked-dried catfish irradiated at 2 kGy and stored for 6 months at tropical ambient temperature.
(iii) Smoked-dried catfish irradiated at 4 kGy and stored for 6 months at tropical ambient temperature.
(iv) Smoked-dried catfish irradiated at 6 kGy and stored for 6 months at tropical ambient temperature.

At each testing session, two samples were presented simultaneously to the assessors who were asked to state, which of the two samples was preferred. The assessors were asked to so indicate if both samples were liked equally. Properly coded samples were used and the order of presentation was randomized to eliminate the effect of sample sequence on food preference.

2.7. *Statistical analysis*

Scores of hedonic rating and multiple comparison difference analysis tests were averaged to obtain mean scores, which were subjected to analysis of variance. The results of the paired preference tests were expressed as levels of significance calculated from the table of Roessler et al. [11].

3. RESULTS AND DISCUSSION

'Suya', 'kilishi' and smoked-dried catfish (*Clarias gariepinus*) had mean moisture contents of 25.90%, 12.98% and 9.23% respectively. Irradiation of 'suya', up to 6 kGy, had no significant effect on moisture (25.90%), protein (44.82%), fat (21.50%) and ash (5.21%).

3.1. *Effect of Irradiation on Shelf Life, Insects and Microbiological Quality*

Smoked-dried catfish had a shelf life of less than 1 week at tropical ambient temperature due to infestation with *Dermestes maculatus* and another insect, with features similar to *Korynestes analis*, which could not be completely identified from pictorial charts. Both larvae and adult insects were present in non-irradiated fish. Irradiated smoked-dried fish were free from infestation even after 6 months at 21°–31°C·

Rather high levels of contaminating microorganisms were present in 'suya' with aerobic counts, yeasts and molds exceeding 10^6. This is consistent with previous reports on the microbiological quality of 'suya' [1, 2]. Unsanitary processing environment and poor quality ingredients, especially the spices used for 'suya' preparation, contribute to the high microbial load of 'suya'. Microbial populations were lower in 'kilishi' presumably because of its lower moisture content. Irradiation of 'suya' up to a dose of 5 kGy significantly reduced microbial populations with a progressive decline in total aerobic count, yeasts and moulds with increase in radiation dose. The greatest reduction in microbial populations (2 –3 log cycles) occurred in the dose range of 0 to 2 kGy. Irradiation increased shelf life and inhibited microbial growth in 'kilishi' stored under tropical ambient conditions (Table I). *Staphylococcus aureus* decreased by at least 2 log cycles in 2 kGy irradiated 'kilishi' stored for 4 months at 21°–31°C· There was visible mold growth in non-irradiated 'kilishi' stored at 21°–31°C for 4 months whilst corresponding samples irradiated at 2 to 6 kGy showed no visible signs of moldiness.

Irradiation had no significant effect on TBA number of 'suya' and 'kilishi' immediately after treatment. However, irradiated 'kilishi' had slightly higher TBA values than non-irradiated controls when stored for 4 months at tropical ambient temperature. 'Kilishi' irradiated at 2, 4 and 6 kGy had TBA values of 3.74, 4.84 and 6.08 respectively after 4 months at 21°–31°C while corresponding non-irradiated samples had TBA values of 3.12. It has been reported that with the exception of turkey breast, low dose irradiation up to 10 kGy had no significant effect on lipid oxidation in fresh trimmed meats, possibly because the samples had minimum amount of fat and were analysed within the induction period for free radical chain reactions [3].

Table I. Effect Of Irradiation On Microbial Populations In 'Kilishi'[a]

Radiation dose (kGy)	Aerobic count (cfu/g)	Yeasts and molds (cfu/g)	Intestinal pathogens (cfu/g)	*Staphylococcus aureus (cfu/g)*
0	5.0×10^5	2.3×10^3	<10	1.5×10^3
2	2.0×10^4	<10	<10	<10
4	2.0×10^2	<10	<10	<10
6	<100	<10	< 10	< 10

[a]Samples stored in sealed polyethylene bags for four months at 21°–31°C.

3.2. Effect of Irradiation on Sensory Quality and Consumer Acceptance

Preliminary sensory evaluation by a semi-trained panel of nine assessors revealed that there were no significant differences in the appearance, flavor, texture and overall acceptability of smoked-dried catfish irradiated at 2, 4 or 6 kGy and stored for 3 weeks at tropical ambient temperature. The irradiated samples were comparable to freshly procured non-irradiated controls in sensory quality (Table II). 'Kilishi' irradiated at 4 or 6 kGy and stored at 21°–31°C for 4 months were highly rated (>4.0 on a scale of 1= dislike very much to 5= like very much) for appearance, flavor, texture and overall acceptability by a consumer panel of 32 assessors. Table III gives the results of the paired preference tests by 32 assessors in which smoked-dried catfish irradiated at 2, 4 or 6 kGy and stored for 6 months at tropical ambient temperature were compared with freshly procured non-irradiated controls and with one another. Even though there was a definite preference for fresh, non-irradiated smoked-dried catfish over irradiated samples stored for 6 months at 21°–31°C, panelists still considered the irradiated samples acceptable even after 6 months at tropical ambient temperature. Whilst there were no statistically significant differences between 2, 4 and 6 kGy irradiated samples, there was a slight preference (> 60% positive responses) for smoked-dried catfish irradiated at 4 or 6 kGy compared to those irradiated at 2 kGy after storage for 6 months at 21°–31°C (Table III).

TABLE II. Results of a multiple comparison difference test where irradiated smoked-dried fish stored for 3 weeks under tropical ambient conditions were compared with freshly procured non-irradiated control.[a]

Radiation dose (kGy)	Appearance	Flavor	Texture	Overall acceptability
2	4.5	6.3	6.1	6.1
4	5.5	5.3	5.8	6.3
6	4.7	6.4	5.5	5.7

[a]Rated on a scale where 1=extremely inferior to control, 5=same as control and 9=extremely superior to control.

TABLE III. Results of paired preference tests for irradiated and non-irradiated smoked-dried fish

Pair	Treatment	No. of assessors preferring each sample	Positive responses (%)	Significance
1	Fresh, non-irradiated	31	97	*
	2 kGy, stored for 6 months	1	3	
2	Fresh, non-irradiated	29	91	*
	4 kGy, stored for 6 months	3	9	
3	Fresh, non-irradiated	29	91	*
	6 kGy, stored for 6 months	3	9	
4	2 kGy, stored for 6 months	10	31	NS
	4 kGy, stored for 6 months	22	69	
5	2 kGy, stored for 6 months	12	38	NS
	6 kGy, stored for 6 months	20	62	
6	4 kGy, stored for 6 months	17	53	NS
	6 kGy, stored for 6 months	15	47	

*Significant at the 1% level. NS, no significant difference.

3. CONCLUSION

Low dose irradiation, up to 6 kGy, inhibited microbial growth, infestation and extended the shelf life of traditional Nigerian meat and fish products. Irradiated 'kilishi' and smoked-dried catfish were found acceptable in sensory qualities by a consumer panel after storage for 4 to 6 months at 21°–31°C. By inhibiting microbial growth and increasing shelf life, irradiation offers a practical means of minimizing outbreaks of food borne illnesses associated with 'suya' and similar products and reducing storage and distribution losses of smoked-dried fish, 'kilishi' and, possibly, other traditional Nigerian meat and fish products.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Executive Secretary, Ghana Atomic Energy Commission, Legon-Accra and the Director, Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria for allowing the use of their irradiation facilities for this work. The assistance of Dr. F. K. Ewete of the Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria in identifying insects in smoked-dried fish is gratefully acknowledged.

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FEASIBILITY FOR THE SETTING UP OF A MULTIPURPOSE FOOD IRRADIATION FACILITY IN SENEGAL

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Abstract

The setting up of a cobalt-60 (activity 500 kCi) irradiation facility in the highest populated region of Senegal (Dakar district) to treat a wide range of foodstuffs for local consumption (millet/sorghum, rice, maize, cowpeas, potatoes, onions, mangoes, citrus fruits and dried fishes) is considered as profitable for a private investor or a Senegalese food producer (or trader), provided the tonnage of foodstuffs treated is adequate, more than 22,000 t·kGy, i.e. a total tonnage above 77,000 t, taking into account the irradiation doses used for the various foodstuffs.

1. INTRODUCTION

The safety and versatility of food irradiation, which is increasingly recognized as an effective method for reducing post-harvest food losses and improving the hygienic quality in foodstuffs, have been well-characterized in the literature [1–3]. In spite of the potential benefits, progress of irradiation technology for practical applications has been slower than expected in developed countries. The "wait and see" attitude of the industry towards investment in this technology can be due to the anticipated rejection of this process by the consumer, for psychological reasons and the fact that a number of other food preservation techniques that are often more expensive but less controversial than irradiation are available in these countries.

The situation in the developing countries, especially in Africa, is very different. Traditional methods for food preservation (sun drying, smoke, fire, etc.) are totally inadequate, especially for extended conservation. Control of post-harvest losses due to insect infestation and sprouting can be partially achieved through chemical insecticides and fumigants, but this has the problem of environmental pollution and associated risks. The modern methods of preservation employed in the developed countries (freezing, lyophilization, storage in a controlled atmosphere) cannot be used in Africa for economic reasons, even though the climatic conditions are such that the problems linked to food preservation are more critical than those encountered in countries with temperate climates. As a result, a large proportion of foodstuffs harvested in Africa is lost due to pest infestation, rotting or sprouting. This is unacceptable, since Africa's population growth rate has steadily increased to a current level of 3%.

According to the IAEA [4], the use of ionizing radiation seems promising for reducing the serious post-harvest loss problems of many African countries. However, these countries differ significantly in their population density and distribution, their surface area, communication network, climate and food production, both qualitatively and quantitatively. The economic feasibility for the setting up of an irradiation plant would obviously vary from one country to another. The aim of this study was to determine if such an industrial project could be beneficial to Senegal, a relatively sparsely populated (eight million inhabitants for a surface area of 200,000 km²) country with a high population density in and around the capital Dakar and with a modest food production. This consists mainly of groundnuts (800,000 $t \cdot a^{-1}$ average), cereals (rice, millet, sorghum, maize) (936,000 $t \cdot a^{-1}$ average), fish and shellfish production (355,000 t in 1990), meat production (cattle, sheep, caprids and poultry) and, to a lesser extent, cowpeas, potatoes, onions, cassava and various fruits (e.g. mangoes, citrus and tomatoes).

2. FOODSTUFFS PROPOSED FOR AN IONIZING RADIATION TREATMENT

The list of foodstuffs for which an ionizing treatment could be envisaged in Senegal is shown in Table I. For each foodstuff the following indications are given: production tonnage, purpose of the ionizing treatment and the recommended doses to attain these objectives.

Groundnuts are not included in this list since the ionizing treatment of this leguminous plant does not prevent the production of aflatoxins, nor eliminate these mycotoxins which are mainly produced by the mould *Aspergillus flavus*. According to Bridges et al. [5], the destruction of this mould takes place at a dose of 3 kGy. However, in order to prevent the production of aflatoxins, the ionizing treatment must be performed immediately after the harvest, which is not possible in practice. Once formed, the aflatoxins can resist very high doses of irradiation [6], much higher than the authorized maximum value (10 kGy) for the treatment of the foodstuffs destined for human consumption and in any case incompatible with the conservation of the organoleptic characteristics of the foodstuffs.

TABLE I. Foodstuffs for which an ionizing radiation treatment can be considered in Senegal

Foodstuffs	**Production[(a)] ($t \cdot a^{-1}$)**		**Purpose**	**Dose (kGy)**
Millet/sorghum	651,000		Disinfestation	0.25
Rice	164,000		Disinfestation	0.25
Maize	121,000		Disinfestation	0.25
Cowpeas	20,000		Sprout inhibition	0.10
Potatoes	18,800		Sprout inhibition	0.10
Onions	31,800		Sprout inhibition	0.10
Mangoes	60,700		Inhibition of ripening	0.75
Citrus fruits	26,500		Inhibition of ripening	0.50
Dried fishes	36,500		Disinfestation	0.50

[(a)] Average value over 5 a (1988–1993). Standard deviation in brackets (Source: Senegalese Agriculture and Fishery Departments).

No fresh foodstuff of animal origin is listed in Table I. As far as meat is concerned, it is usually consumed immediately after slaughter of the animal. In fact very often, the cattle, sheep, caprids and poultry are bought live by the Senegalese. The eating habits of the Senegalese are such that meat treated by irradiation cannot be envisaged at present, nor can fresh shellfish and fish which are consumed soon after having been caught.

The consumption of fresh fish is, however, limited to the coastal regions. Further inland, where this foodstuff is usually eaten dried and smoked and because it is susceptible to a high contamination by insects, a disinfestation treatment by irradiation could be useful. Owing to the fact that some interesting works have been published concerning the irradiation of this particular foodstuff [7], it has been considered judicious to include it in the present study.

A significant part of the fish and shellfish production (about 30%) is actually exported in the frozen state to the developed countries, mainly European. Therefore it could be envisaged to carry out an ionizing treatment (instead of freezing) on a part of this production. However, because of the current reticence of several European countries to accept food irradiation, it seemed more reasonable in this feasibility study not to take into account fresh fish, shellfish, and in general all foodstuffs destined for export.

Two foodstuffs of plant origin, of which the production in Senegal is not insignificant, the cassava (60,000 $t \cdot a^{-1}$) and the tomato (17,000 $t \cdot a^{-1}$) have not been included. In the case of the cassava, an ionizing treatment could be envisaged in the fresh state in order to retard the senescence and in the dry state to carry out disinfestation. The reason for this rejection is mainly the absence of any technical study on this foodstuff. As far as the tomato is concerned, the interest of an ionizing treatment for increasing its shelf life is not obvious. In fact, the tomato is cultivated in Senegal mainly to produce pulp concentrate. The industrial plants are situated near the production sites, but in a region of relatively low population, *a priori,* far from the eventual construction site of the irradiation facility. Such a treatment would therefore not be of interest either economically (high transport costs) or qualitatively (risk of deterioration during transport).

Finally, the foodstuffs shown in Table I are mainly foodstuffs of plant origin (only one, dried fish, is of animal origin), produced and consumed exclusively in Senegal, on which the effects of an ionizing radiation treatment are well known and certainly beneficial.

3. CHOICE OF IRRADIATION TECHNIQUE — LOCATION AND SIZING OF IRRADIATION FACILITY

The choice between the two industrially used irradiation techniques [accelerated electrons and gamma rays (cobalt-60)] depends mainly on the nature of the foodstuffs to be treated and the physical characteristics of the technique used (dose rate, penetration depth). In the present study where varied foodstuffs of different forms and densities will be irradiated (usually at low doses), gamma irradiation with cobalt-60 should be preferred to irradiation by accelerated electrons. Additionally, a cobalt-60 treatment unit is more energy economic, more robust, less demanding in terms of qualified maintenance personnel and less dependant on the quality of the electrical supply, compared to an electron beam accelerator.

The installation of such a unit can only be envisaged in a very highly populated area, capable of consuming the total amount of foodstuffs treated, in order to reduce the additional transport cost incurred by the ionizing radiation treatment to a minimum. In fact, on this assumption it is quite admissible to consider that these foodstuffs would in any case have been transported from their region of production to this region of high consumption. This unit should therefore be set up near to the capital, Dakar, which, together with its urban districts, totals nearly two million inhabitants. In order to support this choice, it is equally important to note that more than half the quantity of foodstuffs retained in this project would then be produced at less than 150 km from the chosen site.

The choice of irradiation source activity obviously depends on the annual quantity of foodstuffs available to be irradiated. The hourly throughput HT (in $t{\cdot}kGy{\cdot}h^{-1}$) can be expressed in relation to the activity of the irradiation source by the equation:

$$HT = 0.0533 \times f \times A \quad (1)$$

Where, A is the source activity (in kCi) and f the cobalt utilization efficiency. According to Kunstadt and Steeves [8], f, which depends on the apparent density of the foodstuffs irradiated, varies between 0.25 and 0.40 for a pallet carrier (system retained for the project, see below). Assuming that the mean value of f is 0.30 for foodstuffs listed in Table I and that the number of treatment hours is 625 per month (about 20 hours per day), the monthly throughput MT (expressed in $t{\cdot}kGy{\cdot}month^{-1}$) will be given by the formula:

$$MT = 1000 \times n \quad (2)$$

Where, n represents the number of kCi, in hundreds, of the irradiation source. Assuming that the annual treatment period is 11 months (the 12th month being necessary for maintenance of the irradiation unit), the annual throughput AT (expressed in $t{\cdot}kGy{\cdot}a^{-1}$) will therefore be:

$$AT = 11{,}000 \times n \quad (3)$$

In the case of an irradiation unit intended to treat mainly varied foodstuffs of plant origin, the production of which is seasonal and the treatment needs to be carried out just after the harvest (a storage time less than 1 month has been used in this study), the choice of the activity of the irradiation source (and therefore n) must also take into account the diversity in the production periods of the foodstuffs treated. Knowing the production tonnage and the irradiation doses used (Table I) for each foodstuff, periods of production and ionizing treatments (Table II) clearly show that high tonnages of foodstuffs (cereals, cowpeas and dried fishes) should be treated between October and December. Considering that the monthly production of these foodstuffs is around 322,000 t (312,000 t of cereals, 7,000 t of cowpeas and 3,000 t of dried fishes) and that the irradiation dose chosen are 0.25 kGy for cereals, 0.10 kGy for cowpeas and 0.50 kGy for dried fishes, the maximum percentage of the production that is possible to treat monthly is given by the ratio n/ 80 (it has been assumed that the monthly production of a foodstuff remains constant during all the months of its production). It is therefore 1.25% for an activity of 100 kCi, 3.75% for an activity of 300 kCi, and 6.25% for an activity of 500 kCi. During the nine remaining months of the year, the production tonnage of the other foodstuffs suitable to be treated is much lower (about 170,000 t). It would therefore be difficult, except with a source of 100 kCi, to achieve a very satisfactory utilization of the unit throughout the year. As an example, Fig. 1 shows the monthly utilization rates of this unit obtained with irradiation sources of 100, 300 and 500 kCi, with the assumption that 10% of the total production of each foodstuff (or failing that, the maximum percentage) is irradiated [taking into account the monthly throughput of the irradiation plant, the maximum percentage is less than 10% for cereals, cowpeas and dried fishes (from October to December), whatever the activity of the source maybe, and for mangoes, dried fishes (from June to September), potatoes and onions (from June to August) when the activity of the irradiation source is 100 kCi]. The annual utilization rates (calculated for 11 months) are then 85% (100 kCi), 51% (300kCi) and 41% (500 kCi). In the light of these results, the choice of an activity greater than 500 kCi would seem to be unrealistic.

TABLE II. Production periods (dark spaces) and irradiation periods (hatched spaces) of the foodstuffs studied

Foodstuffs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Millet/Sorghum									dark	dark, hatched	dark, hatched	hatched
Rice									dark	dark, hatched	dark, hatched	hatched
Maize									dark	dark, hatched	dark, hatched	hatched
Cowpeas									dark	dark, hatched	dark, hatched	hatched
Potatoes		dark	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	hatched				
Onions		dark	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	hatched				
Mangoes					dark	dark, hatched	dark, hatched	dark, hatched	hatched			
Citrus fruits	dark, hatched	dark, hatched	hatched									dark
Dried fishes	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched	dark, hatched

4. ESTIMATION OF THE MEAN COST OF THE IONIZING RADIATION TREATMENT TO ENABLE AN INVESTOR TO RUN A COST-EFFECTIVE IRRADIATION UNIT

The knowledge of initial total investment (capital costs), operating costs and loan costs and the fixing of a return on investment make possible the estimation of the mean cost of the ionizing radiation treatment necessary for a cost-effective irradiation facility. Items of capital and operating costs taken into account in this study have been related in detail by Urbain [9].

Table III shows the initial total investment necessary to set up a cobalt-60 irradiation facility of which the activity sources would be 100, 300 or 500 kCi. The values represented in the table concerning the costs of cobalt-60, of the irradiation chamber, conveyor and auxiliary equipment, have been drawn from the work of Kunstadt and Steeves [8]. The concrete thickness of the irradiation chamber is calculated in such a way that it would not need any modification in case of an increase in the activity of the source from 100 to 500 kCi. The conveyor chosen is a pallet system, which is the system best adapted to the diversity of the foodstuffs to be irradiated, with manual loading, preferred to automation in a country where labour is inexpensive. Neither refrigeration nor freezing is provided for foodstuffs during irradiation and storage. The cost estimation of the construction takes into account the current prices in Senegal.

The operating costs and the loan costs for an irradiation facility, in relation to the activity of the irradiation source, are given in Table IV. The operating costs include the salaries (for a manager, a quality control and radiation safety officer, a secretary, three operators and 12 handlers) and supplementary costs (travelling and training courses, research and development),

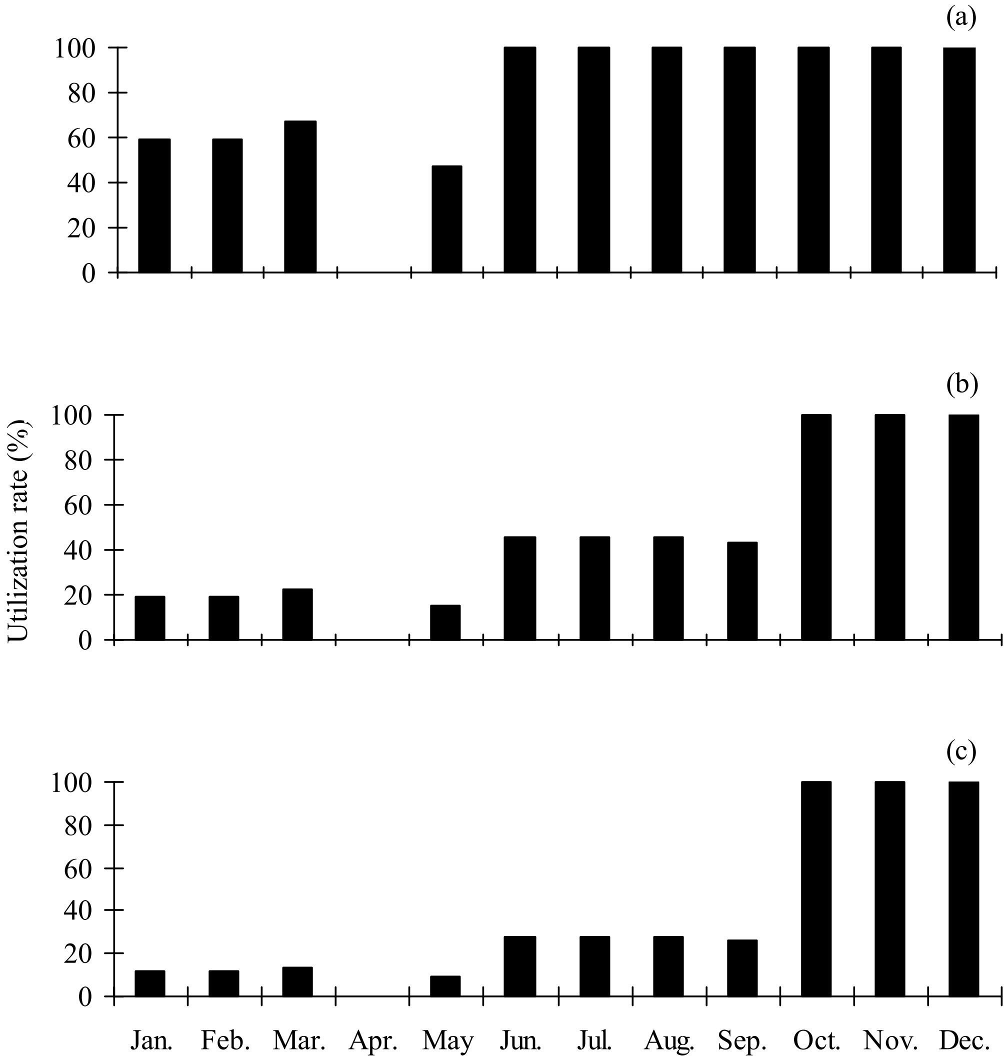

FIG. 1. Monthly utilization rates of the irradiation plant on the hypothesis that 10% of the total production of each foodstuff, or, failing that the maximum percentage, is irradiated. Activity of the irradiation source: (a) 100 kCi; (b) 300 kCi; (c) 500 kCi. The month of April is reserved for maintenance of the irradiation plant. Potatoes, onions and dried fishes produced in March will be treated in May.

cost of cobalt-60 replenishment (12.5% of the initial cost of the source), maintenance and miscellaneous costs (electricity, water, fuel, taxes, etc.) estimated, respectively, at 2 and 4% of the total initial investment) and the depreciation costs which have been calculated based on a 10 a amortization of conveyor and auxiliary equipments, 15 a amortization of cobalt-60 and 25 a amortization of buildings [8, 10]. The loan costs have been calculated with the supposition that the total investment has been borrowed at an interest rate of 13% (average figures supplied by the Senegalese Statistics Department), with a repayment period of 15 a. The annuities A_n are then represented by the equation:

$$A_n = K \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \tag{4}$$

where K is the initial total investment, i the interest rate of the loan and n the repayment period (expressed in a).

TABLE III. Total initial investment (in thousands of US $) necessary to set up a cobalt-60 irradiation facility in Senegal in relation to the activity of the irradiation source.

	Activity (kCi)		
	100	300	500
^{60}Co	180	540	900
Irradiation chamber	500	500	500
Conveyor and auxiliary equipments	1,600	1,600	1,600
Office, warehouse, land	500	500	500
Total initial investment	2,780	3,140	3,500

The required annual profit (Table IV) has been calculated on the hypothesis that the investment is private (a choice which conforms with the present evolution of the economic policy in Senegal) and that the investor would wish to recover his investment in 5 a (return on investment of 20%).

The mean cost of the ionizing radiation treatment C_m that the investor needs to charge a Senegalese trader (or a producer if he sells directly) to treat a given foodstuff, will depend, of course, on the operating costs, the loan costs and the required profit, but also on the utilization rate of the irradiation plant, therefore on the total quantity of foodstuffs treated annually. It is represented (expressed in US $\$\cdot t^{-1}\cdot kGy^{-1}$) by the equation:

TABLE IV. Annual operating and loan costs for the irradiation facility and required annual profit for a return on investment of 20% (expressed in thousands of US $) in relation to the activity of the irradiation source

	Activity (kCi)		
	100	300	500
Salaries and supplementary costs	400	400	400
^{60}Co replenishment	20	65	110
Maintenance	55	65	70
Miscellaneous (water, electricity, taxes, insurance, etc.)	110	125	140
Depreciation	210	235	260
Operating costs	795	890	980
Loan cost	430	485	540
Required profit	560	625	700

$$C_m = \frac{OC + LC + RP}{X_t} \tag{5}$$

where OC are the annual operating costs, LC the annual loan costs, RP the annual required profit (in US \$) and X_t the total quantity of foodstuffs treated annually (in t·kGy).

Fig. 2 represents the determination of the mean cost of the ionizing radiation treatment in relation to the total quantity of foodstuffs treated annually and the activity of the irradiation source. It can be noted that the mean cost value is always higher than 150 US $\$\cdot t^{-1}\cdot kGy^{-1}$ with an irradiation source of 100 kCi, even when the maximum throughtput of irradiation facility (11,000 t·kGy) is acheived, which precludes the choice of such a source. A mean cost value less than 100 US $\$\cdot t^{-1}\cdot kGy^{-1}$ implies the treatment of more than 20,000 t·kGy of foodstuffs, necessitating recourse to an irradiation source of at least 300 kCi activity. Such a quantity of irradiated foodstuffs is far from being negligible. In order to achieve this figure with an irradiation source of 300 kCi, it is necessary to irradiate 3.75% of the total cereal and cowpea production (the highest percentage possible) and approximately 15% of the total production of the other foodstuffs. With an irradiation source of 500 kCi, it is necessary to irradiate 6.25% of the total cereal and cowpea production (the highest percentable possible) and 10% of the total production of the other foodstuffs. It therefore seems unrealistic to further lower the mean cost of the ionizing radiation treatment by increasing the percentage of foodstuffs treated, and unlikely, with the foodstuffs chosen in this project, to achieve the maximum throughput offered by the different sources [33,000 $t\cdot kGy\cdot a^{-1}$ (300 kCi) or 55,000 $t\cdot kGy\cdot a^{-1}$ (500 kCi)].

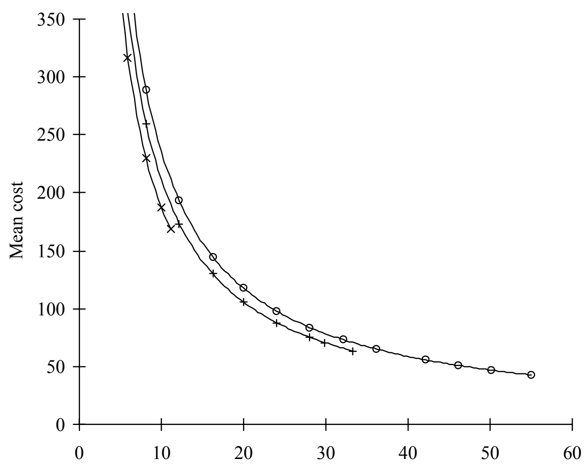

FIG. 2. Annual quantity of foodstuffs irradiated (in $t\cdot kGy\cdot 10^{-3}$) FIG. 2. Variation of the mean cost of the ionizing radiation treatment (in US $\$\cdot t^{-1}\cdot kGy^{-1}$) in relation to the annual quantity of foodstuffs treated (in $t\cdot kGy\cdot 10^{-3}$). Activity: 100 kCi (x-x); 300 kCi (+ ——+); 500 kCi (o-o).

5. ADDITIONAL COST AND BENEFIT FOR A SENEGALESE TRADER (OR PRODUCER) USING IRRADIATION

The additional cost (AC) for the Senegalese trader having recourse to irradiation for a given foodstuff (expressed in US $\$\cdot t^{-1}$) is represented by the relation:

$$AC = C_i + AC_p + AC_t \tag{6}$$

in which C_i is the cost of ionizing radiation treatment, AC_p the additional cost resulting from the packaging and AC_t the additional cost resulting from the transport.

The cost of the ionizing treatment C_i (in US $\$\cdot t^{-1}$) is easy to calculate knowing the mean cost of ionizing treatment C_m (in US $\$\cdot t^{-1}\cdot kGy^{-1}$) and the irradiation dose chosen D (in kGy):

$$C_i = C_m \times D \tag{7}$$

An additional cost due to packaging is only to be considered for cereals, cowpeas and dried fishes. In the case of these foodstuffs, the aim of the treatment is a disinfestation and therefore it is imperative that no recontamination by pests is possible once the treatment has been carried out. Thus it is necessary to replace the packaging usually employed (jute sacks for cereals and cowpeas) by a packaging resistant to penetration by pests. Polyethylene sacks of a thickness greater than 100 µm, much less expensive than the multi-layer plastic sacks, satisfy this requirement [11, 12], but the additional cost due to such a change in packaging can nevertheless be estimated at 9 US $\$\cdot t^{-1}$. On the other hand the objectives of the ionizing treatment for the other foodstuffs (sprouting inhibition for onions and potatoes, delayed senescence for mangoes and citrus fruits) do not justify a change in packaging.

As far as transport is concerned, considering that the irradiated foodstuffs would in any case (treated or non-treated) have been transported to the vicinity of the irradiation plant and consumed by the inhabitants in this area (see above), only a small addition, caused by this location, compared to the shortest route, should be taken into account in order to determine the additional cost related to the transport. This addition can be estimated at approximately 40 km. The mean cost of transport being in the order of 0.05 US $\$\cdot t^{-1}\cdot km^{-1}$ according to the Food Security Commission in Senegal, the additional cost related to transport will therefore be fairly modest, about 2 US $\$\cdot t^{-1}$.

It is therefore possible to calculate approximately for each category of foodstuff, the additional cost linked to the ionizing radiation treatment in relation to the total quantity of foodstuffs treated. The results obtained in the case where the source activities are 300 and 500 kCi are represented in Figs. 3 and 4. The additional cost, of course, becomes much greater when the total quantity of foodstuffs treated decreases and when the irradiation dose used increases, but it can also be considerably increased by the necessity to place the irradiated foodstuffs in special packaging after treatment. In the study carried out, when the total quantity of foodstuffs treated becomes greater than 22,000 t·kGy with a source activity of 500 kCi, the additional cost incurred by the packaging used to protect the cowpeas from weevil infestation becomes greater than the cost of the ionizing radiation treatment alone.

The profit that a Senegalese trader can obtain from an ionizing radiation treatment is more difficult to estimate than the additional cost incurred by this treatment. The ionizing radiation treatment certainly enables this trader to avoid the loss of a part of the food production. The profit resulting from the avoided loss P can be expressed simply (in US $\$\cdot t^{-1}$) by the relation:

$$P = SP \times PL \tag{8}$$

where SP is the selling price to the consumer (or to the retailer) of the foodstuff in question (in US $\$\cdot t^{-1}$) and PL represents the percentage of the post-harvest loss for this foodstuff in the absence of an ionizing radiation treatment, avoided after treatment.

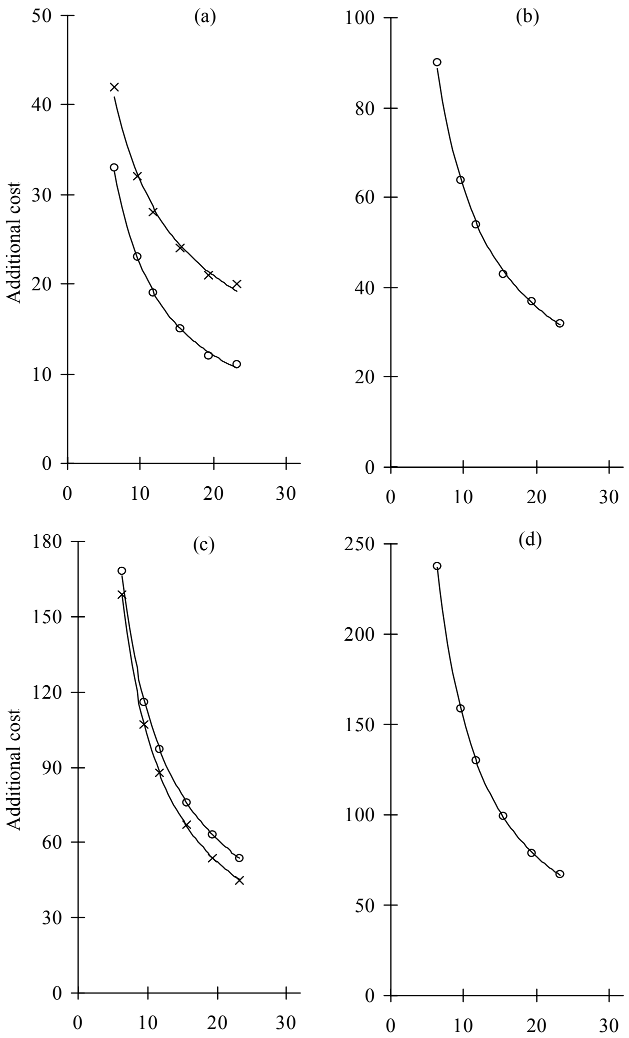

FIG. 3. Variation of the additional cost (AC) linked to the ionizing radiation treatment (in US $\$\cdot t^{-1}$) in relation to the total quantity X_t of foodstuffs irradiated (in $t\cdot kGy\cdot 10^{-3}$) for (a) potatoes and onions (o-o) and cowpeas (x-x) irradiated at 0.1 kGy; (b) cereals irradiated at 0.25 kGy; (c) dried fishes (o-o) and citrus fruits (x-x) irradiated at 0.5 kGy; (d) mangoes irradiated at 0.75 kGy. Activity of the irradiation source: 300 kCi.

The percentage of post-harvest losses are difficult to evaluate: according to the Senegalese Statistics Department, it varies between 10 and 20% for cereals and between 20 and 30% for other foodstuffs studied. According to Chinsman [13], the lowest values to consider would be 10% for cereals and leguminous plants, 20% for onions and potatoes and 30% for fruits. In the publications cited by this author, the values for post-harvest losses are nevertheless often greater than these minimum values. Finally, in this study the percentages of post-harvest losses avoided by irradiation have been estimated at 15% for fruits and dried fishes, and 10% for other foodstuffs.

The average selling prices to the consumer in Dakar (according to the data provided by the Senegalese Statistics Department and the Food Security Commission) are actually 730 US $\$\cdot t^{-1}$ for potatoes, 680 US $\$\cdot t^{-1}$ for onions, 380 US $\$\cdot t^{-1}$ for cowpeas, 420 US $\$\cdot t^{-1}$ for rice, 300 US $\$\cdot t^{-1}$ for millet/sorghum, 320 US $\$\cdot t^{-1}$ for maize, 430 US $\$\cdot t^{-1}$ for dried fishes and 600 US $\$\cdot t^{-1}$ for citrus fruits and mangoes. If only the avoided post-harvest losses are considered, the profit made by the trader using an ionizing radiation treatment is then

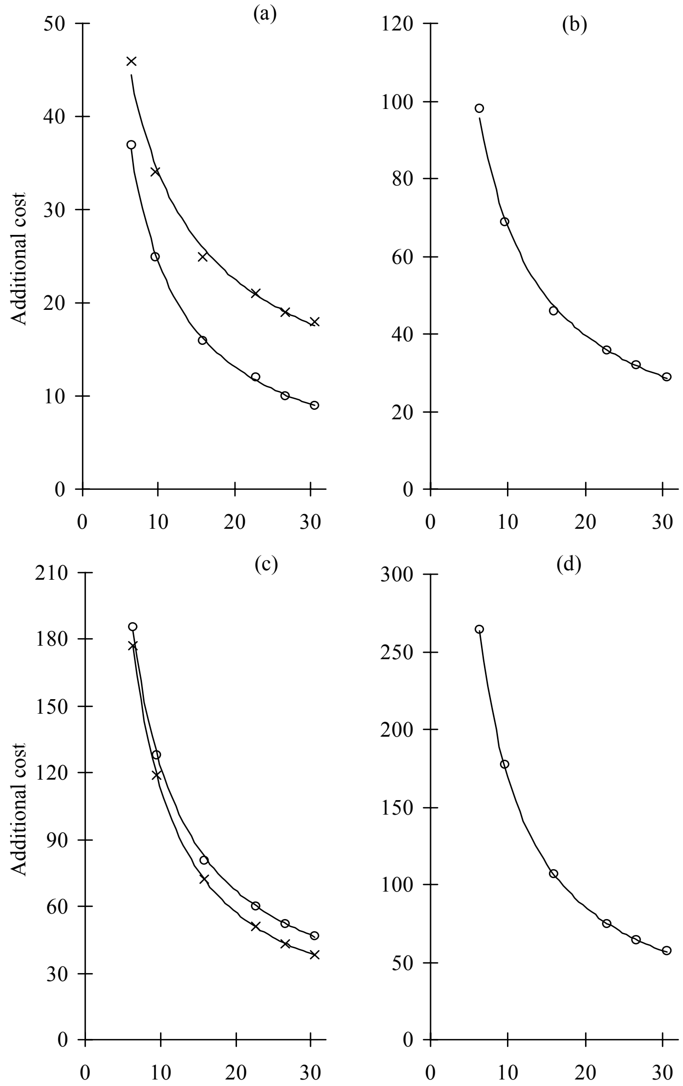

FIG.4. Variation of the additional cost (AC) linked to the ionizing radiation treatment (in US $\$\cdot t^{-1}$) in relation to the total quantity X_t of foodstuffs irradiated (in $t\cdot kGy\cdot 10^{-3}$) for (a) potatoes and onions (o-o) and cowpeas (x-x) irradiated at 0.1 kGy; (b) cereals irradiated at 0.25 kGy; (c) dried fishes (o-o) and citrus fruits (x-x) irradiated at 0.5 kGy; (d) mangoes irradiated at 0.75 kGy. Activity of the irradiation source: 500 kCi.

approximately, with reference to equation (8), 73 US $\$\cdot t^{-1}$ for the potatoes, 68 US $\$\cdot t^{-1}$ for the onions, 38 US $\$\cdot t^{-1}$ for the cowpeas, 42 US $\$\cdot t^{-1}$ for the rice, 30 US $\$\cdot t^{-1}$ for the millet/sorghum, 32 US $\$\cdot t^{-1}$ for the maize, 64 US $\$\cdot t^{-1}$ for the dried fishes and 90 US $\$\cdot t^{-1}$ for the citrus fruits and the mangoes.

In the case where the source activity is 300 kCi, the comparison of these figures with those of the additional cost incurred by the ionizing radiation treatment (Fig. 4) clearly shows that the ionizing radiation treatment is globally cost-effective, provided that the total quantity of foodstuffs treated attains at least 20,000 t·kGy (which corresponds to the treatment of 3.25% of the total cereal and cowpea production and 15% of the total production of the other foodstuffs). When the source activity is 500 kCi, the total quantity of foodstuffs treated should attain at least 23,000 t·kGy (which corresponds to the treatment of 6.25% of the total cereal and cowpea production and 10% of the total production of other foodstuffs).

However the benefits of the ionizing radiation treatment for the trader are not limited simply to a reduction in post-harvest losses. While increasing the market life of a foodstuff, this treatment not only prevents, to some extent, an excessive production of this foodstuff during a very short period (and therefore prevents a sudden drop in the selling price), but also extends its duration on the market and therefore allows the trader to sell it at a good price, since if untreated this would have disappeared from the market. These kind of benefits are more difficult to estimate, but they should certainly improve the overall viability of the proposed project.

6. CONCLUSION

The results obtained during this study have shown that the setting up of a cobalt-60 (activity 500 kCi) irradiation facility in the region of Dakar, Senegal, to treat a wide range of foodstuffs destined for local consumption can be considered as cost-effective for a private investor, on the condition that the tonnage of foodstuffs treated is adequate (about 23,000 t·kGy, i.e. a total tonnage of about 77,000 t, taking into account the irradiation doses used for the various foodstuffs).

The profitability of the irradiation unit could be improved by further increasing the percentage of each foodstuff treated, but the profit may only be small. In fact, it should be noted that, with a source of 500 kCi, no more than 6.25% of the cereal and cowpea production can be irradiated and that, under these conditions, in order to treat more than 23,000 t·kGy of foodstuffs, more than 10% of the total production of other foodstuffs must be treated.

It could also be improved by lowering the irradiation doses used for certain foodstuffs: in fact, it has been shown [12] that the elimination of the weevil *Callosobruchus maculatus* in cowpeas was possible with a dose of 50 Gy. A similar lowering of the irradiation dose could probably be envisaged for cereal treatment. For these foodstuffs, this would result in a lowering in the cost of the ionizing radiation treatment and in a possible increase of the percentage of the production treated.

However, it is more certain that a profitability improvement would be obtained by adding other foodstuffs to the list of those proposed for the project in order to increase the utilization rates of the irradiation plant. Among foodstuffs of plant origin, the choice is without doubt limited to certain fruits and vegetables produced at the beginning of the year. The problem of seasonality has less effect on the foodstuffs of animal origin, none of those destined for local consumption, except the dried fish, would be suitable for irradiation. On the other hand, the ionizing radiation treatment of fresh fish and shellfish destined for export at doses of a few kGy (destruction of pathogenic bacteria and reduction in the total microbial flora), economically acceptable for foodstuffs for which the market value is much higher than that of foodstuffs destined for local consumption, could be seriously envisaged for the future, on condition that certain European countries and their consumers decide to accept this preservation technique for foodstuffs. The use of pasteurization treatment would certainly imply an increase in treatment capacity of the irradiation unit and therefore the use of a greater activity of the irradiation source.

A contribution to this project from the Senegalese state could be considered, for example in the form of a grant of the irradiation unit to a private administrator and this would also help to improve its profitability. In fact, the benefit of such a project to the Senegalese state is obvious. This would give rise to a 0,6–1,5% increase in the plant tonnage produced by the Senegalese agriculture (except for groundnuts), to more satisfaction for the Senegalese consumer because of better quality foodstuffs and longer market availability, to a resulting price stabilization for these foodstuffs, to a slight reduction in certain imports, as for example for rice (around 1000 $t \cdot a^{-1}$, which is about 0.2% of the total quantity of this cereal actually imported), to the exportation of certain foodstuffs to bordering countries (onions, potatoes) or to European countries (fish and shellfish), to the stimulation of profitable culture of excellent quality, such as cowpea grains, the production of which has dropped dramatically in Senegal (from 64,000 t in 1986 to 16,000 t in 1992), mainly because of contamination by a weevil, and finally to the development of a food processing industry, which is still at an embryonic stage .

If the setting up of a cobalt-60 irradiation facility in Senegal seems promising for economical and industrial reasons, it could only be considered after preliminary research and development studies, in order to check if irradiation is really suitable for the preservation of varieties of plant foods (especially fruits) cultivated in this country. In other respects, information campaigns should be conducted amongst the Senegalese producers and manufacturers to explain all the advantages that this conservation technique would represent for them. Last but not least, test-marketing and acceptance studies should be carried out in order to answer the fundamental question: is the Senegalese consumer ready to buy and consume irradiated foodstuffs ? The future of this technique in Senegal depends entirely on this answer, which must be clearly positive before undertaking of any industrial project. To carry out these various preliminary tasks, the installation of a pilot plant is therefore first required in Senegal. The purchase price of such a facility (approximately 700,000 US $ for a 30 kCi activity source) and its processing costs [training courses, travelling, testing, research and development, maintenance, miscellaneous costs (e.g. electricity, water), etc...] are far from being negligible and the Senegalese state would not be able to support such expenses without the help of international organizations concerned by the problem of foodstuff preservation in developing countries (IAEA, FAO) and the financial contribution of private investors and potential users of the future industrial facility.

The last important but inexpensive requirement for the Senegalese state is that implementation of food irradiation in Senegal must also be preceded by the enactment of appropriate legislation (non-existent up to now), which should be harmonized with legislations of other countries to facilitate future trade in irradiated foodstuffs.

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USE OF IRRADIATION IN THE PRESERVATION OF TRADITIONAL SOUTH AFRICAN FOODS

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Abstract

A variety of traditional African foods are prepared in the home and enjoyed by a large number of consumers. Currently, hardly any of these foods are available commercially. However, these foods are laborious to prepare, not generally available commercially and have a limited shelf life. The application of irradiation (alone) or in combination with other technologies can help solve these problems. The effect of irradiation (0, 10, 20 and 30 kGy at 5 °C) on the consumer acceptability of a traditional South African ready-to-eat (RTE) meal consisting of spinach (morôgo) and sorghum porridge was investigated. The two components of the meal remained acceptable up to a dose of 10 kGy. The limiting factor for using higher doses was the porridge component, especially in terms of texture (too soft) and taste (off-flavour development). Therefore the use irradiation at 10 kGy in combination with different levels of sodium nitrite was proposed to improve the storability of the RTE-meal. Research is in progress investigating the effects of combining mild heat, sodium nitrite and irradiation on the microbiological quality, shelf-life and acceptability of a RTE- meal consisting of spinach (morÔgo) and sorghum porridge. Washing in chlorinated water reduced inoculated *Clostridium sporogenes* spores in spinach by about 2 log_{10} cfu/g probably because hypochlorites are bacteriostatic. Blanching of spinach after the chlorine treatment did not effect the *C. sporogenes* counts. However, *C. sporogenes* counts increased by about 1 log_{10} cfu/g during cooking, probably due to the activation of the spores by heat. On the other hand, cooking reduced *C. sporogenes* counts in the porridge significantly (by about 2 log_{10} cfu/g). Gelatinised starch granules probably protected the spores against heat activation. In both meal components, cooking caused a significant decrease in the final nitrite levels. This may be due to the fact that nitrite can form complexes with other components during heating. Nitrites also probably leached out during the cooking process (for spinach) or evaporated during cooking (for spinach and porridge). Irradiation significantly increased the nitrite levels in the spinach component, probably due to the oxidation of nitrate and other nitrogenous compounds by free radicals. However, the final nitrate levels in the RTE-meal (71 ppm in spinach and 52 ppm in porridge) were much lower than required legally (200 ppm). In both meal components, there was a significant decrease in spores with the use of sodium nitrite, probably because nitrites inhibited microbes by interfering with their metabolic systems. However, after 12 days of storage at 10 °C, an increase in *C. sporogenes* counts were observed in the porridge component. This might be attributed to the fact that the porridge had less sodium nitrite available during storage than the spinach component. Nitrite in combination with irradiation significantly reduced the *C. sporogenes* counts in both the meal components to less than 1 log_{10} cfu/g immediately after processing. Therefore, the use of higher levels of sodium nitrite (but still within legal limits) in combination with irradiation is recommended for the final phases of this project.

1. INTRODUCTION

Traditional foods such as porridges (ting, phuthu, maqebekoane), gruels (mageu, lesheleshele, motoho wa mabele), relishes (morôgo, achar, linaoa) and meals (likgobe tsa linaoa le poone) form part of our South African culture. They are the staple food of the majority of our people and they are produced from locally grown foodstuffs. However, these foods are laborious to prepare, not generally available commercially and have a limited shelf life. The application of irradiation (alone) or in combination with other technologies can help solve these problems.

The effects of modified atmosphere packaging (MAP) (84.5% N_2 + 15.5% CO_2)-irradiation (target dose of 10 kGy) combination treatments on the safety and microbiological shelf-life of a traditional South African ready-to-eat (RTE) meal consisting of spinach (morÔgo) and sorghum porridge were investigated at 5°C and 37°C respectively (Minnaar, Taylor, Obilana and Duodu, 1998) Irradiation reduced *Clostridium sporogenes* counts (4 $\log_{10}$) and total plate counts (TPC) (3 $\log_{10}$) in the RTE meal significantly. MAP had no effect on the proliferation of *C. sporogenes* during the storage period at 37°C but reduced their proliferation beyond 5 d of storage at 5°C. MAP had a significant effect on TPC at both 5°C and 37°C. The shelf-life of the RTE meal at 5°C was 3 d for the control, 5 d for the MAP alone treatment, at least 7 d for both the irradiation alone as well as the combination treatment. At 37°C, the shelf-life of the RTE meal was less than 1 d for both the control and the MAP alone treatments, 3 d for the irradiation alone treatment and at least 7 d for the combination treatment.

A safe sorghum porridge and spinach RTE meal with a shelf-life of at least 7 d at 5°C using MAP — irradiation combination processing was produced. However, this RTE meal is a low acid food in which *Clostridium botulinum* could grow and produce toxins under favourable conditions. If the cold-chain were broken during distribution and/or retailing, the safety of the meal could be compromised by rapid growth of surviving pathogenic bacteria. From a safety point of view, it was therefore recommended that irradiation should not be combined with MAP conditions (favouring the absence of oxygen in a full barrier packaging material). It was further recommended that either higher dose levels or alternative hurdles (e.g. use of nitrites) should be used to render the RTE-meal microbiologically safe and stable**.**

2. DESCRIPTION OF RESEARCH CARRIED OUT

2.1 Objectives

Primary objectives:

To develop a system to apply suitable modern food technologies to the manufacture of a RTE-spinach morôgo and thick sorghum meal, and to scientifically assess the quality of this meal. To improve the storability and reduce the preparation time of the RTE-meal.

Secondary objectives:

1. To investigate the effect of irradiation (0, 10, 20 and 30 kGy at 5°C) on the sensory acceptability of the RTE meal.

Depending on the highest dose level at which the meal is still found to be acceptable, one of the following options will be followed:
Option 1 (meal is still acceptable at 30 kGy):
Use of irradiation in combination with mild heating (cooking) to produce a safe food product

- Inoculate raw spinach and sorghum meal with *Clostridium sporogenes* spores.
- Investigate the effects of processing (i.e. washing in chlorinated water – 250 ppm; blanching, cooking and irradiation) on the survival of inoculated spores.

Option 2 (meal still acceptable up to 20 kGy):

Use of irradiation in combination with mild heating (cooking) as well as sodium nitrite to produce a safe food product

- The effect of varying sodium nitrite levels on the inhibition of spores of *Clostridium sporogenes* in the RTE-meal will be studied.

- Inoculate raw spinach and sorghum meal with *Clostridium sporogenes* spores.
- Investigate the effects of processing (i.e. washing in chlorinated water – 250 ppm; blanching, cooking, addition of optimum level of sodium nitrite and irradiation) on the survival of inoculated spores.

2. To select the most effective treatments (alone or in combination) and to determine the microbiological quality and shelf life of the RTE-spinach morôgo and sorghum porridge meal.

2.1 To determine consumer acceptability and preference of the most promising treatments for producing an RTE-spinach morôgo and sorghum porridge.

2.2 Preparation of the RTE-meal

A simplified flow diagram of the preparation and processing of the RTE-meal is given in Figure 1.

2.3 Consumer sensory acceptability of irradiated RTE meal

2.3.1 Objective:

To conduct consumer acceptability tests to establish the sensory cut-off point for the irradiation dose in spinach (morôgo) and sorghum porridge ready-to-eat meal.

2.3.2 Methods:

Consumer acceptability tests were performed for four irradiated spinach meal samples (0, 10, 20 and 30 kGy) in order to establish the most promising irradiation treatment for producing a RTE meal. 50 panellists did sensory evaluation. A 9-point hedonic scale (where 1= Dislike extremely; 5 = Neither liked nor disliked and 9 = Liked extremely) was used and the following characteristics were evaluated: Appearance (spinach); appearance (porridge); texture (spinach); texture (porridge); taste (spinach) and taste (porridge); overall acceptability of the meal.

2.3.3 Results and Discussion:

Table 1 shows the effect of different irradiation doses on the consumer acceptability of the meal. The two components of the meal remained acceptable up to a dose of 10 kGy. The limiting factor for using higher doses was the porridge component. The tasting scores for the porridge irradiated at 20 and 30 kGy were unacceptably low, and the texture of the sample irradiated at 30 kGy was also found to be too soft. Depolymerisation of starch molecules caused the softening effect of porridge at high irradiation dose levels, whereas free radical formation probably resulted in off-flavours in the meal irradiated at the higher dose levels. Based on these results, it was decided that only up to 10 kGy would be suitable for producing an acceptable RTE-meal. Therefore, it was recommended that option 2 would be followed, i.e. where irradiation would be combined with other hurdles (i.e. sodium nitrite).

Young, soft leaves of spinach

↓

Leaves chopped

↓

Rinsed in chlorinated water
(250ppm)

↓

Blanched in two changes of hot water to remove nitrates and oxalates
(77 ^{o}C for 6 min)

↓

Cooking of spinach morôgo
(cooked chopped spinach added to simmered canned tomato and onion mix — salt and pepper used as flavourants; preparation time: ca 30 min)

↓

Cooking of sorghum meal (sorghum meal mixed with cold water to form a paste; paste poured into boiling water; stirring to prevent formation of lumps; cooking of watery paste; preparation time: ca 40–60 min)

↓

Packed in polystaene trays and permeable polyethylene bags Sealed
Kept refrigerated overnight (5^{o}C)

↓

Transported to irradiation facility (using insulated boxes)

↓

Irradiated in a ^{60}Co source at refrigerated temperatures

↓

Stored at refrigerated temperatures (5^{o}C)

Fig. 1. Flow diagram of preparation and processing of the RTE — spinach morôgo and thick sorghum porridge meal.

2.4. Effect of different levels of sodium nitrite and irradiation (at 10 kGy) on the survival of inoculated C. sporogenes spores in the RTE-meal

2.4.1 Objectives:

- To study the effect of pre-processing steps (i.e. washing, blanching and cooking for spinach and cooking for porridge) on the survival of inoculated *C. sporogenes* spores.
- To determine the effect of cooking (alone) and irradiation (alone) on added sodium nitrite.

- To determine the effect of sodium nitrite (at different concentrations) alone, and in combination with irradiation at 10 kGy on the survival of *C. sporogenes* spores in the RTE-meal stored at 10 °C for 12 days.

Table 1. Effect of irradiation on consumer sensory acceptability of the RTE-meal[1]

Irradiation Dose (kGy)	Appearance		Texture		Taste		Overall acceptability of meal
	Porridge	Spinach	Porridge	Spinach	Porridge	Spinach	
0	7.26 c (1.93)[2]	7.20 b (1.62)	7.16 c (1.99)	7.12 b (1.59)	6.76 c (2.38)	7.28 b (1.70)	7.20 c (1.35)
10	6.36 b (1.95)	6.74 b (1.72)	6.16 b (2.16)	7.12 b (1.19)	5.70 b (2.44)	7.08 b (1.78)	6.43 b (1.80)
20	5.50 a (2.17)	6.58 b (1.68)	5.64 b (2.24)	6.80 ab (1.50)	4.68 a (2.21)	6.56 ab (1.94)	5.96 ab (1.70)
30	5.30 a (2.10)	6.30 a (1.83)	4.64 a (2.63)	6.30 a (2.21)	3.82 a (2.11)	6.10 a 2.13)	5.41 a (1.91)

1. Mean values with different letters in columns differed significantly from each other ($p<0.05$).
2. Standard deviation in parenthesis.

2.4.2 Methods:

Inoculated pack studies were conducted as follows:
A stable *C. sporogenes* spore suspension was prepared according to the methods of Anellis, Berkowitz, Kemper & Rowley, (1972) and Anellis, Shattuck, Rowley, Ross, Whaley & Dowell (1975). *C. sporogenes* DSM 1446 and two locally isolated C. sporogenes strains, i.e. Cl 5 and Cl 10, were used for the suspension.

For each processing treatment, aliquots of the spore suspension (10^7/ml) were inoculated into the washing or cooking water of the sorghum porridge and spinach morôgo components of the meal, respectively. RTE-meal packs were sealed and irradiated at 10 kGy at refrigerated temperatures.

2.4.2.1 Effect of pre-processing steps

Preliminary experiments were conducted to determine the effect of washing in chlorinated water (250 ppm of $NaOCl_2$), blanching (in two changes of water at 77 °C for 6 min.) and cooking (mild heat treatment) in spinach morôgo on the survival of inoculated *C. sporogenes* spores (10^7 spores/g). Similar experiments were carried out with porridgere garding the effect of cooking. The effect of cooking and irradiation, respectively, on sodium nitrite was also done using AOAC Method 39.1.21 (AOAC, 1995).

2.4.2.2 *Effect of different levels of sodium nitrite*

The cooked meal components were treated with sodium nitrite alone (0, 50, 100, 150 and 200 ppm) to determine its effect on the survival of inoculated *C. sporogenes* spores (10^7 spores/g).

2.4.2.3 *Effect of sodium nitrite in combination with irradiation*

A combination of irradiation (10 kGy) and sodium nitrite (0, 50, 100, 150 and 200 ppm) was used to determine the optimal treatment combination that would give the most significant reduction of the inoculated spores in the RTE-meal over a period of 12 days at 10°C.

2.4.3 Results and Discussion

The effects of pre-processing on the survival of inoculated spores are given in Table 2.

Washing in chlorinated water reduced inoculated *Clostridium sporogenes* spores in spinach by about 2 $\log_{10}$ cfu/g probably because hypochlorites are bacteriostatic. Blanching of spinach after the chlorine treatment did not effect the *C. sporogenes* counts. However, *C. sporogenes* counts increased by about 1 $\log_{10}$ cfu/g during cooking, probably due to the activation of the spores by heat. On the other hand, cooking reduced *C. sporogenes* counts in the porridge significantly (by about 2 $\log_{10}$ cfu/g). Gelatinised starch granules probably protected the spores against heat activation.

Table 2. Effect of pre-processing on *Clostridium sporogenes* counts (log10 cfu/g)

Pre-processing step	Spinach (log10 cfu/g)	Porridge (log10 cfu/g)
Inoculation of sample	5.00 c	5.00 b
Washing	3.41 b (0.28)	N/A
Blanching	3.09 b (0.24)	N/A
Cooking	4.03 a (0.40)	3.02 a (0.22)

Mean values with different letters in columns differed significantly from each other ($p < 0.05$)
Standard deviation in parenthesis N/A

The effect of cooking alone and in combination with irradiation on added sodium nitrite is provided in Table 3. In both meal components, cooking caused a significant decrease in the final nitrite levels. This may be due to the fact that nitrite can form complexes with other components during heating. Nitrites also probably leached out during the cooking process (for spinach) or evaporated during cooking (for spinach and porridge). Irradiation significantly increased the nitrite levels in the spinach component, probably due to the oxidation of nitrate and other nitrogenous compounds by free radicals (Duodu, Minnaar and Taylor, 1999). However, the final nitrite levels in the RTE-meal (71 ppm in spinach and 52 ppm in porridge) were much lower than required legally (200 ppm). The effect of different levels of sodium nitrite over a storage period of 12 days at 10 °C on *C. sporogenes* counts in the spinach and porridge meal components of an RTE-meal is is illustrated in Tables 4 and 5.

Table 3. Effect of cooking alone and in combination with irradiation on added sodium nitrite in the meal components of an RTE-meal

Before cooking (ppm sodium nitrite)	Sodium nitrite concentration in spinach component[1] (ppm)		Before cooking (ppm sodium nitrite)	Sodium nitrite concentration in the porridge component[1] (ppm)	
	After cooking	After cooking and irradiation[3]		After cooking	After cooking and irradiation
50 a	7.56 b (1.14)[2]	40.14 c (4.07)	50 a	19.20 b (1.66)	19.60 b (1.02)
100 a	9.67 b (1.93)	59.06 c (22.96)	100 a	35.38 b (6.60)	29.89 b (5.09)
150 a	13.48 b (1.68)	67.30 c (25.68)	150 a	38.47 b (5.31)	39.37 b (9.60)
200 a	15.65 (b) (1.68)	71.22 c (27.74)	200 a	49.32 b (8.15)	52.00 b (10.23)

1. Mean values with different letters in rows differed significantly from each other ($p < 0.05$).
2. Standard deviation in parenthesis; 3 Actual irradiation doses for different replicates: 1 (13.8 kGy); 2–10.4 kGy; 3–10 kGy).

Table 4. Effect of sodium nitrite on *Clostridium sporogenes* counts ($\log_{10}$ cfu/g) in the spinach component of RTE-meal stored over a period of 12 days at 10°C

Time of storage (days)	Sodium nitrite levels (ppm)[3]					Time effect[1]
	0	50	100	150	200	
0	4.03	4.10	4.03	3.72	2.86	3.75 a (0.50)
6	5.06	3.79	3.30	3.21	3.22	3.72 a (0.77)
12	4.56	3.46	3.54	3.34	2.80	3.54 a (0.77)
Treatment effect[2]	4.55 d (0.57)	3.78 bc (0.34)	3.62 bc (0.38)	3.42 b (0.55)	2.96 a (0.38)	

1. Mean values with different letters in columns differed significantly from each other ($p < 0.05$).
2. Mean values with different letters in rows differed significantly from each other ($p < 0.05$).
3..Standard deviation in parenthesis.

Table 5. Effects of sodium nitrite alone on *Clostridium sporogenes* counts ($\log_{10}$ cfu/g) in the porridge component of RTE-meal stored over a period of 12 days at 10°C

Time of storage (days)	Sodium nitrite levels (ppm)[3]					Time effect[1]
	0	50	100	150	200	
0	2.96	2.65	2.50	2.43	3.13	2.73 a (0.40)
6	4.74	2.86	2.94	2.47	2.46	3.10 a (0.93)
12	5.65	5.00	3.59	3.12	3.01	4.07 b (1.17)
Treatment effect[2]	4.45 d (1.26)	3.51 c (1.14)	3.01 bc (0.56)	2.67 a (0.46)	2.87 ab (0.53)	

1. Mean values with different letters in columns differed significantly from each other ($p < 0.05$).
2. Mean values with different letters in rows differed significantly from each other ($p < 0.05$).
3. Standard deviation in parenthesis.

In both meal components, there was a significant decrease in spores with the use of sodium nitrite, probably because nitrites inhibited microbes by interfering with their metabolic systems (Jay, 1996). Not surprisingly, higher levels of added sodium nitrite resulted in lower *C. sporogenes* counts. However, after 12 days of storage at 10 °C, an increase in *C. sporogenes* counts were observed in the porridge component. This might be contributed to the fact that the porridge had less sodium nitrite available during storage than than the spinach component. Nitrite in combination with irradiation significantly reduced the *C. sporogenes* counts in both the meal components to less than 1 log_{10} cfu/g immediately after processing. The gamma D_{10}-values of *C. sporogenes* in the RTE-meal was found to be between 2.58 and 2.60 (Obilana, 1998). Therefore a target dose of 10 kGy would result in a 4 log_{10} cycle reduction in C. sporogenes counts

2.5 Conclusion

The use of higher levels of sodium nitrite (but still within legal limits) in combination with irradiation (10 kGy) is recommended for the final phases of this project.

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COMMERCIAL FEASIBILITY AND EVALUATION OF CONSUMER ACCEPTANCE FOR CERTAIN IRRADIATED FOOD PRODUCTS IN EGYPT

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Abstract

Studies were carried out to assess consumer attitude towards food irradiation through questionnaires, sensory tests and market sale of irradiated products. The results showed that out of 1020 persons responded to the questionnaire, 62.43% accepted the irradiation technology while 70.45% were convinced with the advantages of irradiated food. About 73.97% of the respondents were willing to accept irradiation technology on a long term basis while 57.53% were willing to consume irradiated food if it was available in the market. Sensory tests on irradiated smoked fish, chicken, black pepper, coriander, Jew's mallow, broad bean and kidney beans using triangle test (difference test) and duo-trio test showed that the panelists consisting of 136 persons failed to indicate any difference between the irradiated and unirradiated food. About 92.2% of 144 persons participating in a lunch table of irradiated food opined that irradiated food was delicious and found no difference between the irradiated and unirradiated samples. Consumer comments recorded during the market sale of irradiated black pepper and broad beans indicated that 95.1% of the respondents found the irradiated (10kGy) black pepper of excellent or good quality while the percentage was 81.2% for irradiated (2 kGy) broad bean. The study also showed that 62.2% and 68.8% of the persons respectively would buy irradiated black pepper and broad bean again if they were available in the market. Studies on the economics of food irradiation showed that the cost of irradiation for one ton of frozen poultry as US $130.4; smoked fish US $78.2; spices US $260.1 and dried vegetable US $26. Economic evaluation of the study indicated that the average annual rate of return will be about 16.9% and the pay back period will be about 5.9 years.

1. Introduction

Food production in Egypt, as in most developing countries, suffers from an annual loss of about 25% due to hot climate and the unavailability of adequate refrigeration capacity. The government's policy is to reduce these losses to the minimum level. As we know, conventional methods of food preservation have, however, obvious limitations in view of the loss of flavor and freshness associated with canning, the expensive equipment needed for refrigeration and freezing, and the steadily rising public opinion against food additives. For these reasons the use of ionizing radiation offers new solutions to these problems.

During the last 30 years, extensive research activities on the radiation preservation of food have been conducted in Egypt with respect to the adaptability of the method to the local environment, the optimal radiation doses required for specific changes in organoleptic, physical, chemical and microbiological properties of irradiated food, and the technology of the process. Major research activities conducted along this line have been oriented to solving problems of local and regional importance e.g. inhibition of sprouting in potatoes, onions and garlic; extension of shelf-life of certain vegetables and fruits including strawberries, oranges, pears and mangoes; preservation of meat and its products, chicken and its products, fish and sea-food and their products; elimination of parasites and pathogens from processed meat, chicken, animal feeds and spices and disinfestation of stored grains and grain products. Studies have been conducted to determine the lowest effective radiation level required for short term storage, assessment of changes in organoleptic, physical, chemical and microbiological levels of irradiated food and their nutritive status.

Egypt has been participating and closely following the efforts made by the International Organizations to formulate an overall policy for international acceptance for irradiated food. Egypt's participation in a Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food held in Geneva 1981 has been seriously undertaken along that line. A report on the actual local need for legislation based on both international recommendations and the extensive acquired local experience has been submitted to Ministries of Health, Agriculture and Industry. In 1997/10/22 Egyptian government issued clearance for irradiating certain items of food namely: spices, herbs and dried onion and garlic to a maximum dose of 10 kGy. Approval of some other items of food such as poultry, fish and dried vegetables will be issued in the near future.

2. Program of work

1. Irradiation of smoked fish, dried vegetables, spices and poultry at doses previously determined as optimal.
2. Market tests of the above mentioned products in parallel with unirradiated ones to determine consumer response.
3. Economic evaluation of the feasibility of the process for each tested product.

3. Studies carried out under the project

1. Collection of data on agricultural production and percentage of losses as well as factors causing the losses.
2. Marketing studies including the consumer acceptance of irradiated food in general.
3. National seminar to inform public about food irradiation and its benefits.
4. Analysis of data obtained from the survey of consumer's acceptance of irradiated food.
5. Irradiation of smoked dried fish, poultry, certain spices and certain dried vegetables at the optimal dose.
6. Sensory testing of the above mentioned products in parallel with unirradiated ones to determine consumer response.
7. Analysis of data obtained from the sensory testing of the above mentioned products.
8. Market test for black pepper (representative spice) and broad bean (representative dried vegetable).
9. Economic evaluation of the feasibility of the process for irradiated smoked fish, chicken carcasses, dried vegetable and black pepper.
10. Profitability ratio of the irradiation process for the above food products.

4. Experimental method

4.1. Consumer acceptance of irradiated food

The objective was to know the opinion and attitude of the consumers as well as to what extent they accept or refuse food preservation by radiation. Also, to arrive at a method that can attract the consumers to adopt the technique and ensure the success of handling irradiated foods in Egyptian markets.

4.1.1 Research samples

Cairo governorate was selected to carry out the study for its large population (about 12 million person, represent 20% of the population). Random samples were taken to represent educated class from all parts of Cairo. These samples were chosen for their ability to distinguish between the useful and harmful methods, especially in the field of food handling. Also, they have an effect on the behavior of non-educated.

4.1.2. Characteristics of sample

The characterestics of the sample population used for testing the consumer attitude to food irradiation is given in Table 1. One thousand and twenty two questionnaires were distributed to the sample population which were divided into two categories:

4.1.2.1 The workers at Atomic Energy Authority:

The total number was 212, i.e. 20.74% of the total sample size. They were selected as they are working in the same field and are knowledgeable about food irradiation and also to find out how they would accept irradiated food.

4.1.2.2 Non-workers at Atomic Energy Authority:

The total number was 810, i.e. 79.26% of the total number of the sample. The characterestics of the sample population used for this study is given in Table 1. The questionnaire was supported with simplified information about the use of atomic energy and radiation for peaceful purposes. We chose a question-answer model that gives the consumers a correct idea about the peaceful uses of radiation treatment for agricultural products. This question-answer model was based on the information extracted from the ICGFI brochure "Facts about Food Irradiation".

Table 1. Characteristics of the sample population used for testing consumer attitude to food irradiation

Age	Atomic Energy Authority Personnel				General Population			
	Number	%	Males	Females	Number	%	Males	Females
Less than 20 years					18	1.76	10	8
20-Less than 30 years	40	3.91	25	15	166	16.24	102	64
30-less than 40 years	80	7.83	48	32	228	22.31	137	91
40-less than 50 years	80	7.83	45	35	290	28.38	168	122
50 years or more	12	1.17	7	5	108	10.57	63	45
Total	**212**	**20.74**	**12.5**	**87**	**812**	**79.26**	**480**	**330**

4.2. Sensory Tests:

The foodstuffs studied were commercial products such as poultry meat (chicken), smoked fish (herrings), spices (black pepper, cumin and coriander) dehydrated vegetables and legumes (broad bean, kidney bean and Jew's mallow).

Ckicken meat was irradiated in the frozen state at a dose of 5 kGy, smoked fish received 3 kGy, spices were irradiated at 10 kGy while dehydrated vegetables and legumes received 2 kGy.

All samples were packed in polyethylene bags (0.25-mm thickness) and sealed by heat. Each bag contained about 1 kg. The irradiation process was carried out at the National Center for Radiation Research and Technology (NCRRT), Nasr city, Cairo, Egypt at a dose rate of 2 kGy/h. The sensory evaluation of the irradiated samples was performed one week after irradiation. Irradiated and unirradiated products were judged for various sensory parameters using sensory evaluation sheets by 136 persons to determine the organoleptic quality and acceptability of radiation processed foods.

Two test procedures were used for this purpose, namely, Triangle test and Duo-Trio test, in addition to the lunch table of irradiated food.

4.2.1. Triangle test:

In the triangle method the panelist received three coded samples and they were told that two of the samples were the same and one was different. The panelists were asked to identify the odd sample. This method is based on the probability that if there is no detectable difference, the odd sample will be selected by chance one third of the time (Larmond, 1982).

4.2.2. Duo-Trio test:

To determine if there is a differences between the irradiated and unirradiated food samples Duo-Trio test was used. In the Duo-Trio test, three samples were presented to the panelist. One was labeled R (Reference) and the other two were coded. One coded sample was identical with R and the other was different. The panelists were asked to identify the odd sample.

The Duo-Trio test can be used in place of the paired comparison test if no characteristic is specified. In the simple paired comparisons test, the panelist is asked which sample has more or some specified characteristic, whereas in the Duo-Trio the panelist bases his judgment on any difference he can detect.

Questionnaire for Due-Trio Test

Name ---------- Date-------------Product-------------------

On your tray you have a marked control sample ® and two coded samples. One sample is identical with R and the other is different. Which of the coded samples is different from R?

Samples Check odd samples

A ------------
B -------------

Comment

4.2.3. Lunch table of irradiated food

Lunch table of irradiated food was prepared as Egyptian cooking with the following menu to compare the taste between the irradiated and unirradiated food. Every food presented to the guests in this lunch table was irradiated except the bread and drinks.

1. Fried poultry meat irradiated at 5 kGy and spiced with black pepper treated with 10 kGy.
2. Deboned smoked fish (herrings) irradiated at 3 kGy.
3. Kidney bean salad irradiated at 2 kGy.
4. Stewed broad bean (*Vicia faba*) irradiated at 2 kGy.

4.3. Market test:

Currently, the Egyptian food law permits irradiation of certain items of food. On 22 October 1997, the Egyptian Organization for Standardization and Quality Control issued its permission for irradiation of spices, herbs, dried onion and garlic at maximum dose of 10 kGy. The Ministry of Health considers irradiated spices and dried foods safe and wholesome.

Under the above mentioned condition, trial sale was ran from December 1997 to the end of January 1998 to test the opinion of the consumer for the irradiated food acceptance. During that time we offered 50 kg black pepper irradiated at 10 kGy and 250 kg broad bean irradiated at 2 kGy. The irradiated black pepper were packed in 100 g and broad bean were packed in 500 g in plastic bags with label in Arabic language (free from fumigants and treated by ionizing rays).

Irradiated products were put for sale alongside with unirradiated ones in 6 food stores (supermarket). Irradiated black pepper were 10% more expensive than untreated ones while, irradiated broad bean were 5% more than unirradiated ones. In all stores signs were displayed around products shelves (75 × 120 cm) to explain the merits offered by the irradiation process. As mentioned earlier, simplified information in Arabic language was made available to customers about the use of atomic energy and radiation for peaceful purpose based on the brochure “Facts About Food Irradiation” published by ICGFI.

A questionnaire (see below) was handed out to the consumers who bought irradiated black pepper and broad bean for assessing their opinion after the consumers had used the product.

Questionnaire for Market Test

Would you please mark your opinion and post this card to: National Center for Radiation Research and Technology, P.O.Box 29 Nasr city, Cairo-Egypt.
Thank you

I think these black pepper/broad bean are of excellent quality.
I think these black pepper/broad bean are of good quality.
I think these black pepper/broad bean are of poor quality.
I will buy this black pepper/broad bean again.
I will not buy this black pepper/broad bean again.
I do not know.

Comment: ------------------------

4.4. Economic Feasibility:

In Egypt, the direction now is to give permission for commercial application of ionizing radiation to preserve and extend the shelf-life of certain foods. The government issued clearance in 1997/10/22 for irradiating spices, herbs and dried onion and garlic at a maximum dose of 10 kGy. Approval of some other items of food such as poultry, fish and dried vegetables will be issued in the near future.

As with other commercial operations, the objective of commercial food irradiation is to obtain a particular beneficial effect and to market such foods to obtain a profit. In seeking this objective, business management evaluates benefits and risks and determines the course of action to be taken in order to generate profits. This evaluation usually requires an economic analysis. Therefore, this study is conducted to determine the commercial feasibility for certain irradiated food products namely: poultry, smoked fish, spices and dried vegetables.

The study was based on the choice of gamma irradiation facility with the following characteristics:

Characteristics of the irradiator
Irradiator type: pallet irradiator
Source activity: 400000 Ci
Maximum capacity: 76000 m^3
(m^3/kGy/400 kCi/52 week) 45600 tons
Average of the product density (k/m^3) 600.

The cost was calculated on the bases of the following:
1. Project life time: 15 years from the actual operation
2. Application of the unit: 90% of the maximum capacity
3. Cobalt degradation: 12.5% yearly.

5. Results and discussion

5.1. Consumer Acceptance of Irradiated Food

From the results obtained it was clear that 62.43% of the total sample size accepted the irradiation technology whereas 37.57% refused it. Persons convinced with the advantage of using irradiated food reached 70.45% and non-convinced reached 29.55%. As to the continued use of this technology, 73.97% agreed while 26.03% objected. The persons who said that they will buy irradiated food for consumption if it is available in the markets were 57.73% while the objection percentage was 42.27.

Comments:
Question No.11 Reasons for not being convinced that radiation technology is a safe way for food treatment.

1. Genetic researches on human and animal are not enough in this field.
2. Psychological reasons.
3. No trust in the radiation equipment’s maintenance.
4. May prove to be harmful in the future.
5. Chernobyl reactor accident and the side effects that happened.
6. The idea and means of irradiation are not clear.

7. Accurate instruments are not available to calculate dose.
8. Suspect that it may be a means to destroy the health of the developing countries.
9. Effect of irradiated food on children and pregnant women are unknown.
10. Fear from application of this experiment outside the research laboratories on commercial scale and that great mistakes may happen due to the wrong application of this technology.

Question No.12 Reasons for not being convinced that irradiation technology as a method for reducing losses of food.

1. Irradiation is an uneconomical means to preserve the food.
2. Fear from cancer diseases after eating these foods.
3. There are no studies to show its chemical effect on food comparing with the other preserving methods.
4. Thirty-year studies on irradiated food are insufficient period to prove its results on the coming up generations.
5. Presence of an international agency to control the food irradiation processes is necessary.
6. The trend of the world and developing countries is to use natural and fresh foods.
7. There are no laws to control this technology, beside mistrust in using radiation in food treatment.

Question No.13 Reasons for being unconvinced with the advantage of using irradiated food.

1. Some believe that irradiated foods may carry charged particles harmful to health.
2. Others believe that this technology is suitable for surgical tools sterilization only.
3. Some suggested to use this technique for treatment of food for export only.
4. Fear from commercial fraud.
5. Increasing cancer diseases in developed countries that use this technology.
6. Unknown side effects in the long run.
7. There are no merits of this technology more than the other means of preserving.
8. This technology is still in the experimental stage and complete truth is unknown.
9. Harms are more than benefits.

Question No.23 Methods that can explain the facts concerning safe use of food irradiation technology.

1. Using the stickers in the streets.
2. Exhibition of samples of irradiated foods and explaining the merits in terms of shape, taste and odor.
3. Using the newspaper treatises.
4. Advertisements about food safety.
5. Exhibit irradiated food samples in exhibitions and social clubs.
6. Broadcasting programs about food irradiation through media from World Health Organization and other International Agencies.
7. Show the experiments from other countries.
8. The scientists have to eat irradiated food before the public in T.V.

5.2. Sensory tests

5.2.1. Triangle test (Difference test)

Analysis:

The panelists failed to indicate any difference between duplicate and odd samples of smoked fish. The number of correct answers was 42 out of 136 panelists (30.88%). According to

Larmond (1982), for rapid analysis of triangle (appendix A), there was no detectable difference between irradiated and unirradiated smoked fish samples. Almost the same results were obtained for chicken meat, black pepper, cumin, coriander, Jew's mallow, broad beans and kidney beans. The percentages of correct answers were 36.92, 26.92, 29.23, 27.27, 31.25, 22.79 and 27.94 respectively.

5.2.2. Due-Trio test (Determination the differences)

Analysis:

Result of statistical analysis showed that the numbers of the correct judgment were not significant even at 5% level of all the products under investigation.The conclusion is that irradiation treatment does not cause any significant differences for the tested food.

5.2.3. Lunch table of irradiated food

About 92.2% of those participated in lunch table (144 person) claimed that irradiated food was delicious and there was no difference between the irradiated and unirradiated samples. 6.5% of the participants who ate irradiated food did not give any comment, while the rest (1.3%) did not agree to have irradiated food due to psychological reason.

5.3. Market test

During the sale of black pepper and broad bean 500 postcards each for black pepper and broad bean were handed over to the buyers for their opinion. Out of these, 185 cards for black pepper and 160 cards for broad bean were returned to NCRRT, i.e. 37% and 32% of the consumers sent their opinions for black pepper and broad bean respectively to our institute.

The results of their opinion are presented in Tables 2 and 3. The data in Table 2 indicated that 62.2% of the consumers would buy irradiated black pepper while 14.6% would not buy it and 23.2% were undecided. Among those consumers who said no or were undecided indicated that they were not sure whether the process is safe. This maybe due to lack of information about the irradiation process. The data in Table 2 also show that after consumption of the black pepper, 64.9% of the consumers indicated that the irradiated black pepper were of excellent quality, 30.2% said that they were of good quality while the rest of consumers (4.9%) were not satisfied with the quality of the irradiated pepper.

The consumer's attitude towards broad beans irradiated at 2 kGy was positive. Results of this study indicated that 68.8% of the respondents (160 consumers) would buy it again, while 25.6% of the consumers indicated that they will not buy it again, whereas 5.6% were undecided (Table 3). It should be mentioned here that in general consumer response to labeled irradiated black pepper and broad bean has been positive. Irradiated products sold well in 6 stores and the percentage of consumers interested in purchasing irradiated black pepper and broad bean were 62.2% and 68.8% respectively. Health risks, including cancer, were the most prevalent reason for unwillingness to buy irradiated black pepper (14.6%) and irradiated broad bean (25.6%) in addition to lack of information about the process.

Table 2. Response of consumers for irradiated black pepper

Opinion	Response number	Percentage
Excellent quality	120	64.9
Good quality	56	30.3
Poor quality	9	4.9
I will buy again	115	62.2
I will not buy again	27	14.6
I do not know	43	23.2
Total	185	100

Table 3. Response of consumers for irradiated broad bean

Opinion	Response number	Percentage
Excellent quality	82	51.2
Good quality	48	30.0
Poor quality	30	18.8
I will buy again	110	68.8
I will not buy again	41	25.6
I do not know	9	5.6
Total	160	100

Economic feasibility:

In view of the beneficial effects of radiation processing, Egypt has approved the process for commercial application and has accorded clearances on 22/10/1997 to irradiate four items of food namely: spices, herbs, dried onion and garlic. It was therefore desirable to study the economic feasibility of food irradiation in order to enable the business community to evaluate the profitability of food irradiation process. The use of irradiation in the field of food preservation has many benefits comparing with the other methods of preservation. The most important benefits of this new technique can be summarized as follows:

1. Control of insects that cause damage to the grains, beans and dried fish during storage.
2. Elimination of pathogenic microorganisms such as *Salmonella*, *Enterococcus faecalis* and *Staphylococcus aureus* in contaminated foods that cause many diseases which sometimes result in death, in addition to mycotoxins producing fungi causing liver cancer.
3. Reduction in microbial load of foods to extent its shelf-life.
4. Sterilization of foods for patients undergoing organ transplantation, or with AIDs, and, for astronauts.
5. Prevent sprouting in bulb and tuber crops such as onion, garlic, yam and potatoes to reduce storage losses and permit their marketing allover the year.
6. Additional benefits of irradiation in food preservation include elimination of some diseases of vegetables and fruits, reduction of cooking time for grains and increased juice recovery from some fruits.

While establishing a food irradiation facility and in the economic analysis of food irradiation process there are some important factors affecting the profitability of the process that should be taken into consideration. According to Urbain (1993) these factors include:

1. Types of food.
2. Aim of irradiation process.
3. Quantity of food.
4. Price of food.
5. Thickness of food.
6. Packaging technique of food.
7. Dose required.
8. Irradiation plant (location, type of source, irradiation system, others).
9. Temperature during irradiation process (cooling, freezing).
10. Temperature of storage before and after irradiation.
11. Efficiency of using the irradiation plant (number of operation hours per day, number of days of operation).
12. Combination treatments with irradiation for preserving foods.
13. Transportation of food products to and from the irradiation plant.
14. In addition, other factors required for commercial project such as governmental laws, capital required, operation costs and expected profits and others.

The aim of the present study was to arrive at the costs of irradiation plant construction and irradiation process of some foods in Egypt namely: poultry, smoked fish, black pepper (representing spices and herbs), beans (representing beans, grains and dried vegetables). This will enable the businessmen to know the irradiation cost of food that could be used to estimate the profits.

5.4.1.General information about irradiation plant

A. Irradiator type = pallet irradiator
B. Radiation source activity = 400000 Ci
C. Maximum capacity (m^3/kGy/400 kci/52 week) = 76000 m^3
= 45600 ton
D. Average of product density (k/m^3) = 600
E. Plant utilization (%) = 90
F. Cobalt decay (%) = 12.5.

5.4.2.General information about the irradiated products

This information includes the aim of irradiation, dose required and quantity of each product that could be irradiated on the basis of 90% of maximum plant capacity.

A. Poultry:

Large part of poultry consumed in Egypt is slaughtered, frozen and sold to consumers in the frozen state. During the slaughter operation, poultry can be contaminated by several pathogens that cause microbial poisoning. Contamination due to *Salmonella* in frozen poultry is estimated to be about 46% of the production and reaches 62% in the summer season. Additionally contamination by other pathogens such as *Staphylococcus aureus, Enterococcus faecalis*, *E. coli* and others can also occur. The aim of irradiating poultry is to eliminate these pathogens in the frozen product by using a dose of 5 kGy. Quantity of poultry that could be irradiated in the plant under investigation is about 9000 tons/year if the plant is used for poultry only.

B.Smoked fish:

The basic problem facing the exploitation of the fish resources in Egypt is the remoteness of these sources from the main markets of consumption such as High Dam lake and Red sea. So, a great part of the fish caught in these regions reaches the markets in unsuitable state for consumption. In case of smoked fish like herrings and snakes, some fungi grow on it and cause spoilage in addition to mycotoxins producing fungi. The aim of irradiating these products is to reduce microbial load and prevent the fungal growth on the smoked fish. Quantity of smoked fish that could be irradiated in the plant is about 15000 ton/year.

C. Spices:

Spices are exposed to microbial contamination during collecting, storage and handling in the markets. Consequently, it becomes a source of contamination in food. The Egyptian government approved irradiation of spices at a dose level of 10 kGy as it is sufficient to eradicate most of the microbial contamination. Quantity of spices that could be irradiated at this plant is estimated to be about 4500 ton/year.

D. Dried vegetables and beans:

Beans and dried vegetables are exposed to attack by many types of insects during storage which lead to spoilage of about 30%. A dose of 1 kGy is sufficient to destroy all types of insects, in addition to reducing the microbial load of these products. Quantities that could be irradiated is estimated as about 45000 ton/year if the plant is used for beans and dried vegetables only.

5.4.3. Total investment costs for any project is defined as the expenditure required for construction of the building and associated infrastructure. Table 4 explains the costs for construction of the irradiation facility.

5.4.4. Pre-operation expenses:

This includes license, studies, experiments, wages during the construction period etc. The details of these expenses are given in Table 5.

5.4.5. Depreciation:

Table 6 gives the depreciation costs estimated on the basis of depreciation of buildings and irradiator building for a 25-year period. Depreciation of irradiator was calculated on the basis of 12.5% annually, equipment and transportation for 10 years and furniture for 5 years.

5.4.6. Annual operation costs:

Includes wages, salaries, cobalt replenishment, depreciation, maintenance, operation, advertisement, and insurance.

Table 7 explains the value of these costs on the basis of administration and wages are at the same level of recent wages for similar activities.

Table 4. Total investment cost

Item	Costs $ 10^3$
1. Land	300
2. Buildings	600
3. Irradiator with complete Conveyor system	1600
4. Cobalt-60	800
5. Equipment	100
6. Furniture	50
7. Transportation means	50
8. Expenditure before operation	100
9. Expenditure of primary Operation (*)	60
10. Emergency (**)	183
Total	3843

* Estimated on the basis of 10% of annual operation costs.
** Estimated on the basis of 5% of items 1-9.

Table 5. Pre-operation expenses

Item	Value $ 10^3$
1. Licenses	5
2. Studies and experiments	15
3. Wages and salaries during construction period	50
4. Other expenses (cash in hand)	30
Total	100

Table 6.Annual depreciation

Item	Value $ 10^3$	Expected Age	Depreciation value $ 10^3$
1.Buildings	600	25	24
2.Conveyer system +Irradiator	1600	25	64
3.Cobalt-60	800	12.5%	100
4.Equipments	100	10	10
5. Furniture	50	5	10
6.Trans.means	50	10	5
Total	3200		213

Table 7. Annual operation costs

Item	Costs $ 103
1.Adminstration 2.Wages 3.Cobalt replenishment 4.Depreciation 5.Operation (*) 6.Maintainance (**) 7.Advertisment 8.Insurance and emergency (***)	30 120 100 213 45 60 5 24
Total	597

* Includes costs of water, electricity, spare parts and others.
** Estimated on the basis 2.5% of buildings costs, irradiator, equipment, furniture and transportation means.
*** Estimated on the basis 1% of irradiator costs and irradiator source (Cobalt-60).

5.4.7. Total irradiation costs:

It is well known that there is a direct relationship between the throughput of the project and its profitability. Increasing the throughput decreases the irradiation cost of the product until the irradiation plant reach its maximum. On this basis irradiation costs of the product = total costs ÷ quantity of product irradiated.

From the previous study and on the basis of using 90% of the maximum, the quantities that could be irradiated will reach 45600 ton/1 kGy/52 week with a source activity of 400 kCi. The annual loan interest in Egypt is about 15%.

Annual irradiation costs:

= profit on capital + annual operation expenses
= (15% × 3843000) + 597000
= 576450 + 597000
= $ 1173450

Operation hour costs = $\dfrac{1173450}{52 \times 7 \times 24}$ = $ 134.3

Costs of one ton of frozen poultry irradiated with 5 kGy = $ 130.4
Costs of one ton of smoked fish irradiated with 3 kGy = $ 78.2
Costs of one ton of spices irradiated with 10 kGy = $ 260.1
Costs of one ton of beans and dried vegetables irradiated with 1 kGy = $ 26.0

5.5. Profitability ratio

Several analytical criteria have been applied to arrive at the expected performance of the project. Generally, two criteria are usually used.

A. Average Rate of Return
B. Pay back period

5.5.1. *Average Rate of Return*

This criterion pointed out the average benefit of the project expressed as a plain% of the average of the total investment cost as follows:

$$= \frac{\text{Average of annual net profit} \times 100}{\text{Average investment cost}}$$

$$\text{Average of annual net profit} = \frac{\text{Net profit during the project life}}{\text{project life}}$$

$$\text{Average of investment cost} = \frac{\text{Initial investment + Terminal value}}{2}$$

5.5.2. *Pay back period*

It implies the number of years required to recover the initial investment cost.

$$\text{Pay back period} = \frac{\text{Average of investment cost}}{\text{Average of net profit}} = \text{years}$$

Table 8 indicates the residual value of the fixed assets in the year 15 (the expected end of the project) while Table 9 shows the maximum quantities and total prices of each product. Analysis of the data related to total operational cost of irradiation and the expected revenues for poultry, smoked fish, dried vegetables and spices were performed assuming the disposal of final product and the gradual utilization of the full capacity as 60% in the first year, 70% in the second year, 80% in the third year, 90% in the fourth year and 100% in the fifth year (i.e. 90% of the maximum capacity of the irradiator). As tax holiday for such projects in Egypt is 5 years, the estimations were carried out on that base. Tax ratio reaches 35% of the total net profit after the fifth year. The analysis revealed that the average rate of return for the above products range between 16.8 and 16.9% while the pay back period is about 5.9 years.

Table 8. Residual value of fixed assets in years 15*

Asset	Initial value $ 10^3	Terminal value $ 10^3
Land	300	300
Irradiator	1600	---
Cobalt	800	---
Machinery and equipment		
Building	100	25
Trans means	600	100
Furniture	50	25
Office equipment	50	
Pre-operation expenses	100	
Primary working capital	100	
Contingency		
	60	
	183	
Total	3843	450

* The expected end of the project.

Table 9. Quantities and irradiation cost for each product

Item	Unit	Irradiation cost per unit $	Maximum quantity in ton	Total price $
Poultry	Ton	130.4	9000	1173600
Smoked fish	Ton	78.2	15000	1173000
Spices	Ton	260.1	4500	1170450
Dried vegetables	Ton	26	45000	1.170000

5.6. Seminar:

A National seminar on Food Irradiation was held in Cairo, Egypt from 24–25 March 1996. The program included the following lectures:

1. Peaceful uses of radiation.
2. Present status of food irradiation in Egypt and elements of draft legislation.
3. Wholesomeness of irradiated food and worldwide status of food irradiation.
4. Replacement of chemical fumigants by irradiation.
5. Irradiation in prevention of food losses.
6. Food irradiation in the context of food safety.
7. Operation and control of commercial food irradiation facilities.
8. Trends in commercial application of food irradiation.
9. Market testing and consumer acceptance of irradiated food.
10. National public acceptance of irradiated food.
11. Cost benefit of food irradiation.

Summary

Extensive research have been conducted in Egypt during the last thirty years on the radiation preservation of food with respect to the adoptability of this technology to the local environment, the optimal radiation doses required for specific changes in organoleptic, physical, chemical and microbiological properties of irradiated food, the technology of the process and the identification of irradiated food.

The aim of the present study was to know the opinion and attitude of the consumers as well as to what extend they accept or refuse food preservation by radiation. The study also had the objective to find out a method that can attract the consumers to adopt the technique and ensure the successful handling of irradiated foods in markets.

One thousand and twenty two completed questionnaires from consumers were collected. The questionnaire was supported with simplified information about the use of atomic energy and radiation for peaceful purposes. The results showed that 62.43% of the total sample size accepted the irradiation technology while the percentage of respondents convinced with the advantage of using irradiated food was 70.45%. About 73.97% of the respondents were willing to accept irradiation technology on a long term basis while 57.53% were willing to consume irradiated food if it was available in the market.

From the results of the sensory tests, the panelists failed to indicate any difference between the irradiated and unirradiated food. About 92.2% of those participated in lunch table of irradiated food (144 persons) claimed that irradiated food was delicious and found no differences between the irradiated and unirradiated samples.

During the market sale, 500 post cards each for black pepper and broad bean were issued to record the consumers response. Out of these 185 cards for black pepper and 160 cards for broad bean with consumers comments were returned to NCRRT. The market test indicated that 95.1% of the respondents found the irradiated (10kGy) black pepper of excellent or good quality while the percentage was 81.2% for irradiated (2 kGy) broad bean. The study also showed that 62.2% and 68.8% of the persons respectively who returned their cards would buy irradiated black pepper and broad bean again if they were available in the market.

The present study showed that the cost of irradiation for one ton of frozen poultry as US $130.4; smoked fish US $78.2; spices $ 260.1 and dried vegetable $ 26. Economic evaluation of the study indicated that the average rate of return will be about 16.9% annually and the pay back period will be about 5.9 years.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude and thanks to the authorities of Joint FAO/IAEA/ Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency for funding this project. The results of the project gave confidence and influenced the Egyptian government authorities to issue clearance in 1997/10/22 for irradiating certain items of food namely: spices, herbs and dried onion and garlic. Special appreciations are due to Dr.Paisan Loaharanu, Dr.Ricardo Molins and Ms.Teresa Benson and their staff.

The authors are greatly indebted to thank Prof.Dr.Hesham F.Aly Chairman of the Egyptain Atomic Energy Authority and soul of Prof.Dr. Amin El-Behy, late Chairman of National Center for Radiation Research and Technology (NCRRT) for the facilities and valuable guidance throughout the work.

Our sincere thanks to Prof.Dr.Abd Elhameed Zahran Chairman of NCRRT, Prof.Dr. Aly Hammad, Head of Microbiology Department and to all the staff members of the Microbiology Department (NCRRT) for cooperative helps in accomplishing this work.

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COST/BENEFIT STUDY ON DATE DISINFESTATION BY GAMMA IRRADIATION IN ALGERIA

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Abstract

To establish the irradiation technology, one must have a holistic approach to the technology of food irradiation in order to assure a maximum utilization rate of the facility. The assumptions in this study are based on a free standing multipurpose irradiation facility, the throughput of which is expressed in t·kGy/year, and the unit cost of the treatment in US $/t·kGy. These values may then be applied for the calculation of the treatment cost of any food commodity, according to the irradiation dose needed. The study showed that irradiation treatment of dates is profitable and that the cost of irradiation does not exceed 1.6% of the selling price of the product. Post harvest losses may be considerably reduced thanks to irradiation treatment. A comparative study between irradiation and cold storage showed that irradiation will cost 30% less than cold storage. This study is completed by an evaluation of consumer acceptance of irradiated food products.

1. INTRODUCTION

Of the 93 million palm trees recorded world wide, 8 million are located in Algeria. The national production of dates represents about 15% of the world production. Palm trees are well adapted to the warm and dry climatic conditions of the Sahara region. They are spread out over the country in such a way, that the higher concentration is located in the southeast region. This concentration decreases towards the western and southern regions. Dates of the best quality are mainly produced in the eastern regions, such as Zibans, Oued Righ and Oued Souf. In the other regions mainly common dates are produced. The varietal composition of the Algerian phoeniciculture is as follows:

- Palm trees Deglet Nour, which produce a semi-soft dates of a high quality that are destined for trade as a fruit.
- Palm trees Ghars, which produce soft dates. This variety is much appreciated by the Sahara's population. For their preservation, fruits are pressed in jute or leather bags.
- Palm trees of common dates. This category includes more than 100 varieties.

The annual production of dates varies between 190 000 to 250 000 tons (Table 1). Deglet-Nour, which is the most appreciated variety, represents about 40% of the total production.

Table 1: Date production in Algeria (t/a)

Year	1987	1988	1989	1990	1991	1992	1993
Production	224,400	196,062	210,137	205,907	209,093	265,515	261612

Two companies of the public sector and many private companies are involved in the distribution and marketing of dates in Algeria. The market of dates is spread out as follows:

- Public sector: 15%
- Private sector: 75%
- Local consumption: 10%.

Public companies buy from the producers exclusively dates of a high quality that are destined for the local market out of the production areas and for the external market i.e. export. These two markets are exigent on both the quality of dates and the quality of the packaging. The national companies have established 75 collecting points in the production areas with a view to facilitate the producers for the marketing of their products. Theses companies have also many plants for the selection, the packaging and the storage of dates. Both, the private and the public sectors export dates. But there are few data related to the quantities of dates exported annually. The National Company of Dates exports about 6 000 to 10 000 tons/years. Its objective is to reach 30 000 t/a by the year 2000. It is difficult to evaluate the quantities exported by the private sector, more particularly those exported to the neighboring countries, such as Mali and Niger.

In general, the phoeniciculture is confronted to insect infestation by lepidopters, such as *Cadra*, *Plodia* and *Ectomyelois*. *Ectomyelois ceratoniae* is the insect, which causes more damages in not properly stored dates. Infestation generally starts on the palm tree during the ripening stage of the fruit.

2. QUANTITIES OF DATES TO BE TREATED

On the basis of the data collected, the quantities of dates that may necessitate disinfestation treatment may be evaluated as follows:

Only dates of the variety Deglet-Nour should be irradiated due to their high commercial value. This variety represents about 40% of the total production i.e. 80 000 t/a. Let us assume that 10% (i.e. 8 000 t) of this production is consumed locally at the production area, and the losses due to handling and sorting out to be of 5% (i.e. 4 000 t). So the quantities which necessitate irradiation treatment will be 68 000 t.

3. TREATMENT PERIOD

The harvesting period starts in October and ends in December. Irradiation must be applied before the hatching of insect eggs, i.e. less than two weeks after harvest. So the treatment will be efficient during the harvest period and may be followed during two weeks thereafter. It means that irradiation will be carried on during 3.5 months.

4. SITE SELECTION

The site selection has a bearing on the operating costs. So the irradiator must be built in close proximity to the production area. Since the dates of a high commercial value are mainly produced in the eastern region of the country, so the facility should be built in that region. The cities such as Annaba and Skikda are more adequate for such a facility since they are well served by port, railways and by an important network of roads.

5. IRRADIATOR CHARACTERISTICS

Source activity

In case where 68000 tons will be irradiated in the same facility, the needed activity will be:
$A = 18{,}7 \times X \times D/f$

where: A — source activity (Ci)
X — Irradiator throughput (kg/h): 68 000 t/(105jours × 24h) = 27 000 kg/h.
f — irradiator efficiency (40%)
D — treatment dose (0,7 kGy)

A = 18,7 × 27 000 × 0,7/0,4 = 0.88 MCi

Such activity is too high, so it will be difficult to assure a good utilization rate of the facility all over the year, since dates are seasonal products. This will lead to situations where the source will not be in use for long periods. In this cases, in addition to the absence of incomes, the cobalt decay will cost about 4 000 US $ a week. Moreover for the treatment of 68 000 t in three months, the loading/unloading rhythm will be too high, i.e. 900 kg/min. So, there is no sense to establish the irradiation technology only for date disinfestation. One must have a holistic approach to the technology of food irradiation in view to assure a maximum utilization rate of the facility. That means that irradiation treatment must be extended to other food commodities of seasonal or non-seasonal character. For this reason, the assumptions in this study are based on a free standing multipurpose irradiation facility, the throughput of which is expressed in t·kGy/year, and the unit cost of the treatment in US $/t·kGy. These values may then be applied for the calculation of the cost of the treatment of any food commodity, according to the irradiation dose needed.

This study is based on the choice of a multipurpose gamma irradiation facility, which is designed for a maximum activity of 3 MCi. Irradiator will be loaded initially with a cobalt source of 350 kCi. The selected source-overlapping configuration presents the advantage of reducing to a minimum the product handling operations. The basic data of this study are given in Table 2.

Table 2. Basic data

Price of cobalt-60	1,7 US $/Ci
Cobalt Efficiency	40% for dates and spices
	20% for medical products
Number hours/year	6 800 hours/year
Depreciation	12 years linear
Source activity	350 kCi
Cobalt replenishment	12,3% per year
Financial loan	100% of the investment
Financial fees	10%; 10 years
Irradiation dose for dates	0,7 kGy
Irradiation dose for spices	8,0 kGy
Irradiation dose for medical products	25 kGy

6. CAPITAL COSTS

The initial investment, which includes costs of buildings, equipment, forklifts and cobalt represents the capital costs (Table 3). Equipment costs include their transportation, taxes and installation. Buildings costs includes the irradiation chamber, warehouse, product loading/unloading areas, machinery room, offices, dosimetry laboratory, control panel, site development, engineering and taxes.

Table 3. Capital costs

Items	Cost (US $)
1. Equipment	
1.1. Irradiator	1 400 000
1.2. Cobalt source	595 000
1.3. Forklifts	100 000
1.4. Customs taxes	379 000
Sub-total equipment	**2 474 000**
2. Buildings	
2.1. Irradiation cell	260 000
2.2. Warehouse	240 000
2.3. Lab., offices, ...	72 000
2.4. Enclosing wall	143 000
2.5. Site development	150 000
2.6. Engineering	86 000
Total investment	**3 425 000**

7. ANNUAL OPERATING COSTS

Operating costs are variable costs that are paid when the facility is being used. They include cobalt replenishment at 13% per annum, salaries, casual labor costs, overhead costs (25% salaries), utilities (1% investment), maintenance (2% investment), taxes (2% investment), and depreciation (buildings 25 years, equipment 10 years, cobalt 15 years). Salaries are calculated on the basis of 16 employees. In this calculation operating costs include the reimbursement of loan, which is estimated to be 100% of the initial investment. The interest rate is 10% for a period of 10 years. In Table 4 the operating costs for the first year are given. Table 5 shows the operating costs for the first 10 years.

Table 4. Operating costs

Item		Cost (US $)
1. Depreciation		
Buildings		38 000
Equipment		188 000
Cobalt		40 000
Sub-Total Depreciation		266 000
2. Salaries:		
Plant Manager	01	8 600
Administ. & fin.	02	12 000
Rad. Protect. Officer	01	7 000
Operators	04	19 200
Product handlers	08	28 800
Overhead costs	25%	18 900
Total salaries		94 500
3. Maintenance		68 500
4. Utilities		35 000
5. Taxes		68 500
6. Interest on loan		342 500
Total operating cost		875 000

Table 5: Annual operating costs for the first 10 years

Year	1	2	3	4	5	6	7	8	9	10
Op. Cost 10^3 US $	875	913	880	846	812	777	743	715	675	640

8. **Determination of the throughput of the facility in t·kGy**

Hourly throughput:
$A \times f/18\,700 = 350\,000 \times 0.4/18\,700 = 7.5$ t·kGy/h
A — Source activity in curies
f — Cobalt efficiency ratio (40%)

Annual throughput:
On the basis of 20 h/day during 11 months, the number of hours/year will be 6 800
$X = 7.5 \times 6\,800 = 51\,000$ t·kGy/year

But this theoretical throughput may be reached only at the moment when the activity of 350 kCi is installed. The throughput was calculated on the basis of the actual activity of the source at the end of the first year, is 13% less, that is 45 000 t.kGy/year.
Let us assume that the average throughput is:
$X_{av} = 47\,000$ t·kGy/year.

9. Cost of the irradiation treatment:
The cost of the treatment may be calculated according to the formula
$C_t = OC/X_{av}$
OC — operating cost,
Let us give to OC the higher value, which is the operating cost of the second year

$C_t = 913\,000/47\,000 = 19.42$ US $/t·kGy
The cost to be charged to the producer will be:
$C_{sel} = C_t + B$
B — is the profit 30% of C_t
$C_{sel} = 19.42 + (19.42 \times 0.30) = 25.25$ US $/t·kGy

10. Cost/Benefit Analysis
On the basis of the selling price the cost/benefit analysis is given in Table 6.

Table 6: Cost/benefit analysis (in 10^3 US $)

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Oper. Cost	875	913	880	846	812	777	743	715	675	640
Income	1187	1187	1187	1187	1187	1187	1187	1187	1187	1187
Balance	312	274	307	341	375	410	444	472	512	543

This analysis shows that the initial investment may be recovered in 9 years. In case where the owner of the facility wishes to recover his initial investment in 5 years, which is the case of private investor, the minimum cost to be charged will be:

$C_{sel.min} = (OC + RB)/X$
RB is the required benefit to recover the investment in 5 years. It represents 20% of the initial investment.: RB = 3 425 000 × 0.20 = 685 000 US $/year.
$C_{sel.min}$ = (913 000 + 685 000)/47 000 = 34 US $/t
Let us apply this cost to the treatment of dates.
The cost to be charged for the treatment of dates will be:
$C_{dates} = C_{sel.min} \times D$
Where: D — Irradiation dose in kGy,
C_{dates} = 34 × 0.7 = 23.8 US $/t

The average selling price of dates at the production area is actually 1.5 US $/kg, that is 1 500 US $/t.

The treatment by irradiation charged to the producer (23.8 $/t) represents only 1.6% of the selling price of dates. The quantity of dates that may be treated, taking into account that irradiation will be applied only during 3.5 months due to the seasonality of this product, will be as follows:
Annual throughput 47 000 t·kGy/year
Hourly throughput 7.5 t·kGy/hour
Daily throughput 7.5 × 20 = 150 t·kGy/day
3.5 months represents 105 days

$X_{3.5\ months}$ = 150 × 105 = 15 750 t·kGy
quantity of dates that may be treated
$X_{dates} = X_{3.5\ months} \times 1/D$
X_{dates} = 15 750 × 1/0.7 = 22 500 t

The benefit that would be realized by the dates producer, owing to the reduction of losses will be:
$B = P_{sel} \times QL$
B — Benefit
P_{sel} — Average selling price
QL — Quantity of losses that is avoided thanks to irradiation treatment (15%)

B = 1 500 × 22 500 × 15 /100 = 5 063 000 US $

Comparative economic analysis between irradiation and cold storage

The study on the cost of irradiation, showed that date disinfestation at a dose of 0.7 kGy is estimated to be 23.8 US $/t. The price of the cold storage applied in 1999 by the most important national company involved in cold storage of food products is: 7.7 US$/$m^3$/month. The packaging density of dates is: 0.6 t/m^3
So the cost of the cold storage of dates is: 12.8 US $/t/month
This cost includes:
the cost of refrigeration
the cost of storage (area occupied)

The former represents about 50% of the price applied. Let's assume that dates will be stored during 10 months:
The cold storage will cost: 12.8 × 10 = 128 US $/t.
The storage of irradiated dates will cost (without cold): 128 × 50% = 64 US $/t
We have to add to this value the cost of irradiation: 64 + 23.8 = 87.8 US $/t
So the benefit due to irradiation will be: 128–87.8 = 40.2 US $/t
This means that irradiation will cost 30% less than cold storage.
That represents: 40.2 US $ × 22 500 = 904 500 US $

Evaluation of consumer acceptance/preference of irradiated food products:

The test on evaluation of consumer acceptance/preference of irradiated food products was conducted in Algiers during the National Exhibition of Acquirements (29–31 March 1998), and in Bejaia during the Symposium on Nutrition (15–16 April 1998).

The test were conducted as follows: potatoes and onions, irradiated and stored for 5 months after irradiation, were displayed and labeled as being irradiated at the same stall with unirradiated samples. Irradiated and unirradiated dates stored for 14 months were also displayed at the same stall and labeled as being irradiated. There was a big difference in appearance of the irradiated and unirradiated products. Unirrdiated onions and potatoes had sprouted and unirradiated dates were infested by insects. Irradiated products had a much better appearance.

People visiting the product display area were appraised verbally about the treatment by the test conductors. Test conductors were scientists of the Irradiation Technology Laboratory of the Nuclear Techniques Development Center. After explanation, participants were invited to complete the questionnaires designed in view to evaluate their preferences. The test is based only on the appearance of the products. Most of the participants asked questions about the process and the product. They asked if the process is safe, if it would induce radioactivity in the product, if the consumption of irradiated foods could cause cancer. Other participants were interested in the investment, they asked questions, such as how the process works, what is the investment of such a facility ...

During these five days, 394 people filled the questionnaires handed by the test conductors. None of the people, who stopped at the stall to participate, declined to complete the questionnaire. The biographic profile of the subjects is given in Table 7.

Table 7: Biographic profile of the subjects

Variable		%
	under 20	25
Age (a)	20–30	51
n # 394	30–40	15
	above 40	09
	High	65
Education	Secondary	31
	Primary	04
Gender	Male	47
	Female	53

Preferences obtained:

Sixty-eight percent (68%) of the total number of participants expressed their preference for irradiated products, while 32% for unirradiated ones (Table 8).

Table 8: Participants who preferred irradiated products

Variable		Total Number of participants[1]	Number of participants that preferred irradiated products[2]	% Relative[3]	% Absolute[4]	% Actual[5]
Total number		394	267	100	68	68
Gender	M	186	121	45	31	65
	F	208	146	55	37	70
Age	Under 20	99	84	32	21	85
	20–30	201	128	48	33	64
	30–40	60	33	12	8	55
	Above 40	34	22	8	6	65
Education	High	256	153	57	39	60
	Secondary	122	102	38	26	84
	Primary	16	12	5	3	75

1. Number of participants
2. Number of participants that preferred irradiated products
3. Percentage calculated vs. 267
4. Percentage calculated vs. 394
5. Percentage calculated vs. the number corresponding for each category (column 3).

By gender, 70% of women expressed their preference for irradiated food products, while this was 65% for men. By age, the most favorable category for irradiated food products was the range from 20 to 30 years old, with 85%. The less favorable one was the category above 40 years old (55%). By instruction level, 84% of participants that have a secondary level of instruction preferred irradiated products. The more reticent category (60%) seems to be that with a higher level of education.

From the total population tested 47% had heard before about food irradiation, 46% and 48% respectively for men and women (Table 9). By age, people of the categories of above 40 years and of 30–40 years seem to be more informed about the process, since the rates by these category were respectively 77% and 72%. By instruction level, participants of high education level represent the highest rate, with 56%, while those of a primary level represent only 19%.

Answers to the questions were subjective, because participants completed the questionnaire after explanation given by the test conductors. Fifty-two participants said that they understand the term “irradiated” (Table 10). The highest rates by category were:
52% for women
82% for category of above 40 years
64% for category of high level of education.

The predominant criterion of choice for irradiated food products was “ Extended shelf life” with a rate of 70%. The criterion “best quality” of irradiated products came in the second position with a rate of 48%. In spite of expressing their choice for irradiated products 5% revealed their fear of irradiation, while 10% considered that there is a lack of information about the process (Table 11).

Table 9: Participants who heard about food irradiation

Variable		Total Number of participants[1]	Number of participants that preferred irradiated products[2]	% Relative[3]	% Absolute[4]	% Actual[5]
Total number		394	185	100	47	47
Gender	M	186	85	46	22	46
	F	208	100	54	25	48
	Under 20	99	29	16	7	29
Age	20–30	201	87	47	22	43
	High	256	142	77	36	56
Education	Secondary	122	40	22	10	33
	Primary	16	3	2	1	19

1. Number of participants
2. Number of participants that heard about food irradiation
3. Percentage calculated vs. 185
4. Percentage calculated vs. 394
5. Percentage calculated vs. the number corresponding for each category (column 3).

Table 10: Participants who understand what is irradiation

Variable		Total Number of participants[1]	Number of participants that preferred irradiated products[2]	% Relative[3]	% Absolute[4]	% Actual[5]
Total number		394	206	100	52	52
	M	186	91	44	23	49
Gender	F	208	115	56	29	52
	Under 20	99	29	14	7	29
Age	20–30	201	110	53	28	55
	30–40	60	39	19	10	65
	Above 40	34	28	14	7	82
	High	256	164	80	42	64
Education	Secondary	122	40	19	10	33
	Primary	16	2	1	0.5	13

1. Number of participants
2. Number of participants that understand what is irradiation
3. Percentage calculated vs. 206
4. Percentage calculated vs. 394
5. Percentage calculated vs. the number corresponding for each category (column 3).

Table 11: Criterion of choice

	IRRADIATED PRODUCTS			UNIRRADIATED PRODUCTS		
Criterion	Number	Relative %	Absolute %	Number	Relative %	Absolute %
Best quality	128	48	32	22	17	6
More safe	92	34	23	39	31	10
Extended shelf life	186	70	47	10	8	3
Fear of irradiation	13	5	3	61	48	15
Lack of information	26	10	7	54	43	14

For the people who preferred unirradiated products the main reasons of their choice seem to be the fear of irradiation (48%) and the lack of information (43%). Thirty-one per cent of them considered that unirradiated products are more safe.

In conclusion, from the total of 394 people that participated in this test, 267 expressed their preference for irradiated food products, this represents 68%. The main reason of their choice is that , on one hand the irradiation extends the shelf-life of products, and on other hand irradiated products are of a best quality. For people that didn’t like irradiated products, there are two major reasons: fear of irradiation and lack of information about the technology. Fear of irradiation is closely linked to the lack of information, so a good public awareness programme will fill this gap.

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02-00527