ECONOMIC FEASIBILITY STUDIES ON RADIATION PRESERVATION OF DRIED AND CURED FISHERY PRODUCTS, ONIONS AND POTATOES

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Abstract

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Dried and cured fishery products, onions and potatoes face enormous storage losses in Bangladesh due to insect infestation and sprouting. Research and development work was carried out to assess the suitability of introducing irradiation processing of these products in the country. Experiments showed that a dose of 0.04–0.68 kGy could inhibit sprouting in onions. Sprouting in potatoes could be inhibited at 0.10 kGy. Dried and cured fishery products could be disinfested of insects at a dose of 0.30 kGy. Infrastructure such as transportation, storage, marketing and existing systems of post-harvest handling were analysed. Post-harvest storage losses of onion and dried fish were more than 50% after 6 months of storage. Potatoes could not be kept at ambient conditions for over 3 months after the harvesting season. Irradiation of onions and dried fish, if they were stored in suitable conditions after proper packaging, could save significant storage losses. Irradiated potatoes could be stored at 14°C instead of 2–4°C as practised normally. On the basis of the data collected on dried and cured fishery products, onions and potatoes, economic feasibility studies were conducted. Assumptions for calculation of cost of the irradiation facility were: (i) strength of the irradiator source: 7.40 PBq of ^{60}Co; (ii) construction period: 2 years; (iii) operating time: 7200 hours per year; (iv) economic life: 20 years; (v) capacity utilization: 80–90%. In addition to dried and cured fish, potatoes and onions, this facility would also treat fresh fish and medical products in order to maximize its use. It would have an investment cost of US $1.9 million. The payback period was found to be less than 4 years. If additional warehouses could be built along with the facility, such a venture would be more profitable. Other additional benefits which could accrue from such technology would be a saving in energy, a reduction in loss of foods due to spoilage, an improvement in food quality, an extension of shelf life, and equity of distribution and marketing. Considering the above mentioned practical aspects it was concluded that irradiation of dried and cured fishery products, onions and potatoes, along with fresh fish and medical products, would be economically feasible in Bangladesh.

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1. INTRODUCTION AND BACKGROUND

Shortage of food is a chronic problem in Bangladesh. There is a trend towards increasing food production in recent years, but the shortfall remains almost constant owing to the increased growth rate of the population. Unless some revolution occurs in food production, which at this stage appears not practicable, there is need to consider other alternatives such as to make available more acreage for production or to make every effort to reduce losses. In a country with a dense population, there is little fallow land left to cultivate. On the other hand very little is being done to reduce spoilage losses that occur during post-harvest processing, storage and marketing.

In Bangladesh processing of food for preservation is in its infancy. The only sizeable processing of any consequence is carried out for export. With the exception of traditional drying of foods by solar energy, methods such as canning, freezing and refrigeration are almost non-existent for products prepared for the home market. Therefore, a new technique, if found suitable for the socio-economic conditions of Bangladesh, is a good practicable solution.

1.1. Irradiation as a method of food preservation

In 1916 Runner [1] disinfested tobacco of cigarette beetles by the application of radiation. In the United States of America, the study of radiation as a process of food preservation was started in 1943. Worldwide enthusiasm was shown in the 1950s and 1960s. Now irradiation as a process for the preservation of food is well established. So far about 30 countries have given approval for processing over 40 food items for human consumption [2]. It has been viewed as a physical process for treating foods [3].

1.2. Importance and justification of the feasibility study

Scientists may be satisfied that radiation processing is a very scientific method that has many advantages over the traditional methods, and may be very useful if integrated into the overall processing technology. In Bangladesh, as in any other country, this may not be acceptable to the grower, the middleman, the operator of a storage facility and the distributor. A method may be very scientific but the immediate reaction from a trader in plain language will be "Can I make money by using this new technology?". This question needs to be answered with facts and figures. Feasibility studies in detail are important for radiation processing because of some inherent and peculiar problems associated with this new technology.

1.3. Objectives

Bangladesh has been engaged in research and development for food preservation by irradiation for almost nineteen years. We studied the feasibility of this processing in the context of our country in 1970 [4]. We have also been assisted by International Atomic Energy Agency experts in 1964 [5] and in 1978 [6] regarding the technoeconomic feasibility of food irradiation. Most of these studies were on the basis of some laboratory results and experiences of other countries. In the mean time, we have completed some semi-commercial studies on irradiated dried fish [7, 8], potatoes [9, 10] and onions [11, 12]. In addition, some significant changes have occurred in the international scene [13]. A new look into the economic feasibility of food irradiation in Bangladesh is indispensable. The latest facts and figures collected from our recent experiments will enable us to convince end users of the efficacy of this technology for the preservation of dried fish, potatoes and onions. An overall look into the immediate application of the technology as a whole is pertinent also to an analysis of the situation as it is now in Bangladesh.

The Government of Bangladesh has accepted the international standards of irradiated foods recommended by the Codex Alimentarius Commission in December 1983 [13, 14]. Our research and development work over a long time convinced the Government of the necessity of taking such a step for the purpose of alleviating post-harvest losses of foods.

2. TECHNICAL FEASIBILITY OF RADIATION PRESERVATION OF POTATOES, ONIONS, AND DRIED AND CURED FISHERY PRODUCTS

2.1. Size and characteristics of the market

2.1.1. Potatoes

Potato production is on the increase in Bangladesh [15] owing to increases in acreage under cultivation and also to favourable conditions in the growing areas. Potato production had almost doubled in the period from 1971–1972 to 1982–1983. Table I gives the potato production in Bangladesh over 10 years.

In the 1982–1983 season, the estimated production was over 1.2 million t. Producers faced tremendous problems in the storage and marketing of potatoes. Important potato varieties are Binjje, Desiree, Multa, Alka and Petrones. Most of the high yielding variety (HYV) seeds are imported from the Netherlands. The HYV constitutes over 60% of the total production. Potatoes are grown in a single season and harvested from late November up to the end of March. As the stored stock from the previous season is exhausted at this time, all the stock of the early harvest is marketed and brings a higher price. Potatoes for cold storage are obtained from the late harvest.

TABLE I. ACREAGE AND PRODUCTION OF POTATOES IN BANGLADESH

Years	Area (acres)	Production (t)
1971–1972	188 380	740 910
1972–1973	196 580	746 725
1973–1974	297 825	718 535
1974–1975	231 940	866 465
1975–1976	237 050	888 760
1976–1977	191 200	723 720
1977–1978	222 470	849 410
1978–1979	238 890	894 955
1979–1980	238 410	902 633
1980–1981	252 360	983 130
1981–1982	261 800	1 066 755

TABLE II. PATTERNS OF CONSUMPTION AND SPOILAGE UNDER THE PRESENT CONDITIONS

Description	Total production (%)	1000 (t)
(a) Consumption during the season	40	320
(b) Consumption in early off-season	40	300
(c) Cold storage for later consumption	10	90
Total consumption	*90*	*710*
Spoilage in (a)	15	48
(b)	25	100
(c)	10	10
Total quantity spoiled	*50*	*158*

TABLE III. LOCATIONS OF COLD STORAGE FACILITIES AND QUANTITIES OF POTATOES STORED IN DIFFERENT DISTRICTS IN 1982

Name of districts	No. of cold storage plants in operation in 1982	Capacity (t)	Quantity of potatoes stored in 1982 (t)
Dhaka	52	93 465	85 700
Comilla	17	28 500	31 928
Sylhet	6	7 200	5 778
Chittagong	5	6 200	4 888
Mymensingh	2	2 000	1 852
Noakhali	3	4 500	3 212
Bogra	7	8 480	5 710
Rajshahi	6	8 500	5 306
Rangpur	8	14 600	14 785
Dinajpur	3	6 000	6 231
Khulna	7	11 830	9 235
Jessore	3	6 000	3 820
Kushtia	1	1 000	1 118
Pabna	1	2 500	963
Barisal	1	1 000	746
	122	201 775	181 272

Storage and marketing of potatoes

During the season 40% of the production is consumed (Table II). The rest is stored for off-season consumption and for seed potatoes.

A tremendous increase in cold storage capacity occurred in 1982. The total installed capacity is 201 775 t (Table III) in 122 cold storage units. In 1982 179 436 t, which is nearly 89% of the installed capacity, were stored. The latest position is shown in Table IV. The country has cold storage capacity for almost 20% of the total production. Forty per cent of potatoes are stored by farmers, stockists (hoarders) and wholesalers. This storage incurs huge losses. In cold storages in 1982, a loss of around 10 000 t was recorded owing to power failure, voltage fluctuation, mechanical troubles and collapse of racks. These losses were in addition to

TABLE IV. INSTALLED CAPACITY AND UTILIZATION OF COLD STORAGE FACILITIES IN DIFFERENT DISTRICTS OF BANGLADESH IN 1982 AND 1983 (in tonnes)

Districts	Installed capacity	Quantity 1982	Stored 1983	Cold storage under construction
Dhaka	114 965	85 807	80 419	90 110
Comilla	47 000	31 929	30 359	15 000
Sylhet	7 200	5 778	4 826	11 000
Chittagong	6 200	4 388	2 476	—
Noakhali	4 500	3 212	4 545	—
Mymensingh	2 800	1 852	1 689	5 500
Bogra	10 980	5 710	6 556	17 500
Rajshahi	8 500	5 306	4 569	9 500
Rangpur	22 100	14 785	13 047	9 500
Dinajpur	8 500	6 231	5 096	2 500
Khulna	14 830	9 235	6 124	—
Jessore	6 000	3 820	2 867	—
Other districts	4 500	2 827	1 625	1 625
Total	258 075	180 880	164 198	162 225

the normal (about) 5% loss. (Figure 1 shows the marketing channels for potatoes in 1982.)

Potatoes on farms are stored in bulk on racks in well ventilated warehouses. In cold storage, gunny bags with a capacity of about 80 kg are used and placed on racks arranged in honeycomb fashion. The cold storage temperature is around 2°C.

All modes of transportation such as boats, launches, trucks, buses and railways are used. Usually potatoes are handled in bulk on boats; gunny bags are used in all other modes of transport.

Potato price fluctuations

Usually in a normal year, potato prices fluctuate by factors of 2 to 3 between harvesting and the off-season. Table V gives the price fluctuations for 5 years in the Dhaka market (Fig. 2).

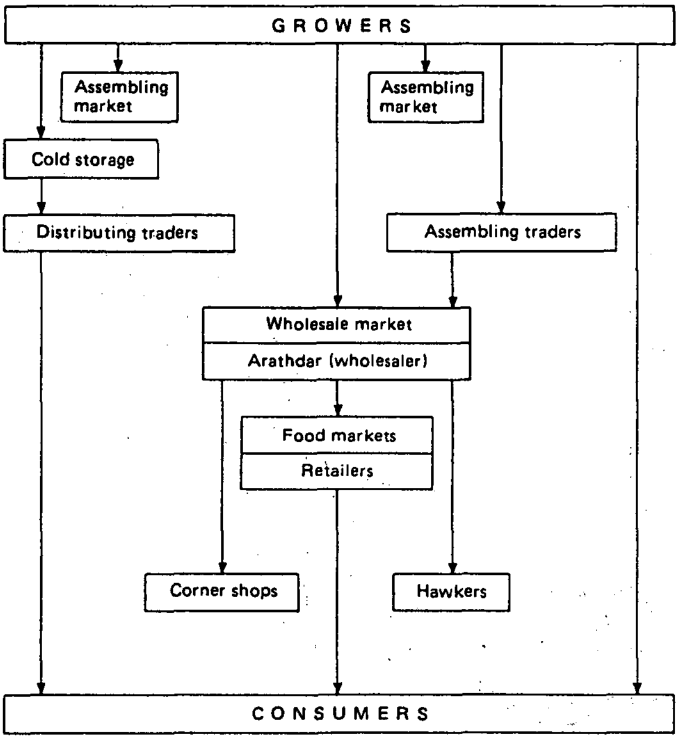

FIG. 1. Marketing channels for potatoes in Bangladesh in 1982.

TABLE V. SEASONAL VARIATION OF THE WHOLESALE PRICE OF POTATOES IN DHAKA MARKET (Tk per maund[a])

Year	Jan.-Jul.	Aug.-Dec.	Annual average
1978	53.93	105.95	79.94
1979	44.84	103.01	73.92
1980	69.15	130.32	99.73
1981	68.17	134.02	101.09
1982	47.85	77.40	62.62

[a] Maund = 37.5 kg.

Note: The taka is the basic monetary unit of Bangladesh. Tk 25 correspond to US $1. In these tables large sums of money are expressed in lakh (1 lakh = 100 000) and crore (1 crore = 10 000 000).

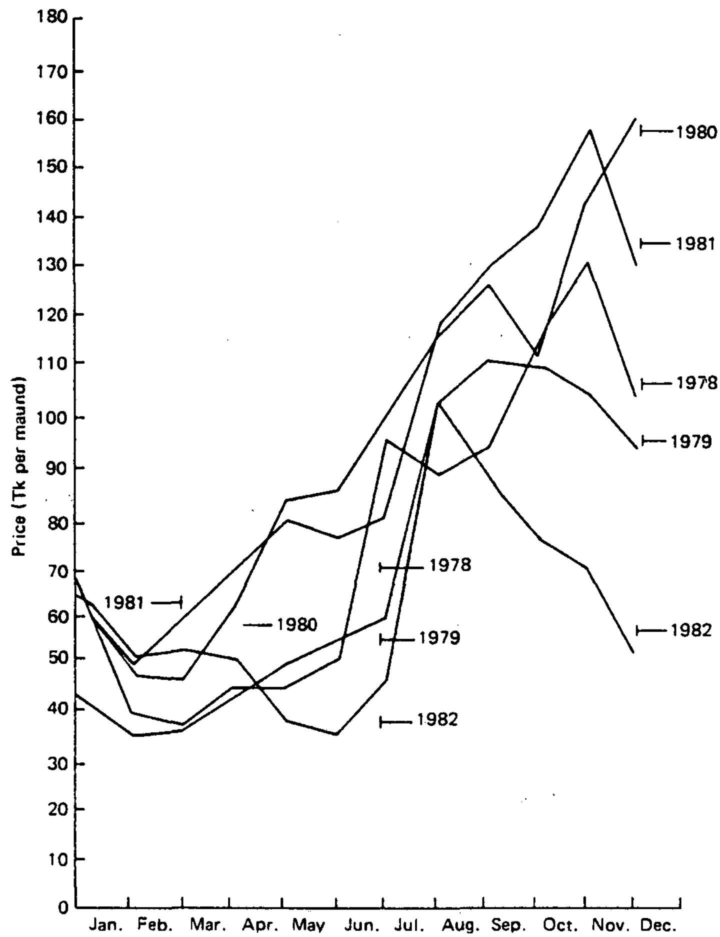

FIG. 2. Trends in wholesale prices for Holland-white potatoes in Dhaka market from 1978 to 1982. (Maund: 37.5 kg.)

There has been a continuous upward trend in the price of potatoes with the exception of the year 1982 when the potato growers had great difficulty [16]. Even at the end of the season (i.e. December) about 34 000 t of potatoes remained in cold storage compared with about 10 000 t in a normal year. In 1983 the overall price situation was normal. Figure 2 and Table V show the monthly price fluctuations in these years.

Tables VI and VII show the price farmers received in 1983 in Munshiganj which is the most important potato growing area of the country near Dhaka. The grower's share of the retail price in the Dhaka market in the season is only 57% and in the off-season 40%. After paying for fertilizers, seeds and other costs, the grower's share is less than 20% of the retail price.

TABLE VI. MARKETING COSTS OF POTATOES (Holland-white) ON 27 MARCH 1983

Sundry costs	Source of supply: Dhaka (Munshiganj) Terminal: Dhaka market Price per maund[a] (Tk)	Share as % of retail price (Tk)
Net price received by the farmer (ex field) from the bepari	34.00	56.67
Expenses incurred by the bepari		
Carrying cost ex field to loading point	2.00	3.33
Transport cost from loading point to Shambazar[b] by boat	2.00	3.75
'Cooli' charge at Shambazar	0.50	0.83
Inland Water Transport Authority	0.10	0.17
'Tashuri'[c]	0.25	0.42
Arathdari commission	3.00	5.00
Profit of the bepari	1.90	3.16
Price paid by the retailer	*43.75*	*73.33*
Expenses incurred by the retailer		
Weighting charge (Kayali[c])	2.00	3.33
'Cooli' charge[c]	1.25	2.08
Carrying cost up to Newmarket[d]	2.50	4.17
Weight loss	0.75	1.25
Profit retailer	9.50	15.84
Price paid by consumer	*59.75*	*100.00*

[a] 1 maund = 37.5 kg.
[b] A wholesale market in Dhaka city.
[c] Cooli, Kayali and Tashuri charges are handling charges for potatoes.
[d] A retail market in Dhaka city.

Losses of potatoes in storage

(a) *Moisture loss*: Weight is lost owing to moisture loss. Although potatoes stored in cold storage are at a low temperature (2°C), and in humid conditions, an average loss of 1% per month occurs over a 6½ month storage period.
(b) *Rot*: The incidence of rot is high with room temperature storage during the hot and humid days; immediate storage is needed after curing during the harvest season.

TABLE VII. PRICE MUNSHIGANJ FARMERS RECEIVED FOR 40 kg OF POTATOES IN SEP. 1984 AND PRICE PAID BY DHAKA CONSUMERS

Channels of marketing		(Tk)
Price payable to farmer		60.00
Transport cost:		
(a) Farmer's home to cold storage		3.00
(b) Cold storage to Shambazar (A wholesale market in Dhaka)		2.00
(c) Shambazar to retail market		2.00
		67.00
Storage and bagging cost		3.00
Rent for cold storage:		40.00
(a) Arathdar[a]	Tk 4.00	
(b) Weighing	Tk 1.00	5.00
Rotting and weight loss		15.00
Ghat charge (toll)		1.00
Trader's profit		6.00
Retailer's profit		12.00
Price paid by consumer		149.000

Note: The grower's share of the retail price is 40%.

[a] Person who rents space for storage and on occasions also acts as wholesaler.

Nevertheless, rotting continues, but at a slower rate. Very little rotting occurs in cold storage. In the marketing of potatoes up to the retailers' level, the loss due to rotting is about 20–25%.

(c) *Sprouting:* Without refrigeration the dormant period of the potato lasts from 50 to 60 days. Potatoes which have been in cold storage start sprouting 4–5 days after removal from storage for marketing. This shelf life limitation hampers the distribution of stored potatoes to the inland part of the country, especially in places distant from cold storage locations. Therefore, during the off-season only a small supply of potatoes is available in rural markets.

(d) *Potato tuber worms*: Potatoes are attacked by tuber worms. Infestation starts in the field, and, unless kept in cold storage, spoilage continues. The Deshi (local) variety of potatoes in northern districts stores well even at room temperature. Although

TABLE VIII. ONION PRODUCTION

Years	Quantity (t)
1973–1974	146 564
1974–1975	143 476
1975–1976	147 606
1976–1977	136 162
1977–1978	146 398
1978–1979	139 424
1980–1981	93 586
1981–1982	129 528

the exact amount of loss is not known, it is estimated that 20–30% of tubers are spoiled owing to tuber worms.

(e) *Sweetening*: Owing to breakdown of starch, sugar accumulates during 4–5 months storage at low temperatures and makes the potato sweet. In addition to the high cost of storage, this sweetening also makes the potato unattractive for off-season consumers. Sugar accumulation also lowers the quality for processing such as chipping and crisping. In Table II, the patterns of consumption and spoilage of potatoes are given. Even using the existing cold storage facilities the total national loss of potatoes in ideal situations is around 17%.

2.1.2. Onions

Onion production is more or less static in the country. Table VIII shows the production over 10 years. The crop is produced in a single season and is harvested from December to the end of April. The early crop is marketed directly for consumption because the quantity left over from the previous season is too little to meet the demand.

The early variety is known as 'Murikata'. The late variety known as 'Hali' (seed), which constitutes the major supply, is stored to meet the demand until the next harvest.

Storage, transportation, packaging and grading

Onions are stored by stockists, wholesalers and big farmers for a maximum period of 8–9 months. Onions generally are stored in bulk on raised platforms made of split bamboo poles to avoid the effect of dampness. Some growers store onions close to the ceiling of their dwellings. Traders store onions on raised platforms in the case of a katcha (not cemented) floor or on a pucca (cemented) floor in bulk without any dunnage platform. Some growers also store onions in gunny bags.

All modes of transportation are used. Head load (i.e. carrying on the head) is most common among growers. Boats, carts and ponies are also used by growers and beparis[1]. But beparis mainly use launches, trucks, buses and railways. Transport used by retailers are head load, rickshaw, push cart and baby taxi (three wheeled taxi).

Onions may be transported in bulk in boats. In all other forms of transport, i.e. carts, ponies, launches, trucks, buses, railways, rickshaws, baby taxis and head loads, the onions are packed in gunny bags. One gunny bag is used for approximately 80 kg of onions, bags are reused 10–15 times.

There are no official government standards for onions. Normally damaged bulbs are sorted out by growers. At the premises of the arathdar[2], onions are graded according to size, origin and variety. Improved varieties of onions are those which are bigger in size and less pungent. These bring higher prices than others which are smaller in size and more pungent. Onions grown from bulbs bring a lower price than those grown from seeds or seedlings.

Marketing channels of onions

Itinerant merchants locally known as faria/paikar (bulk buyers) or beparis are the first important links in the chain of intermediaries (Fig. 3). They collect onions from farms or rural markets and transport them to the assembling markets or city wholesale markets and sell them to the wholesalers who are known locally as arathdars or stockists. Normally they operate independently.

Village merchants who have fixed business premises in the village markets undertake both short and long term storage. Some growers also secure products from other growers in addition to their own for storage and marketing.

Wholesalers, stockists and arathdars are engaged in the distribution of onions. The wholesalers usually buy from the bepari, the paikar and the faria for short term and long term storage. Stockists differ from wholesalers in that they buy during the harvesting season when the onion prices are low with the expectation of selling at high prices during the off-season.

[1] Itinerant merchants — first important link in the chain of intermediaries.

[2] Person who rents space for storage and on occasions also acts as wholesaler.

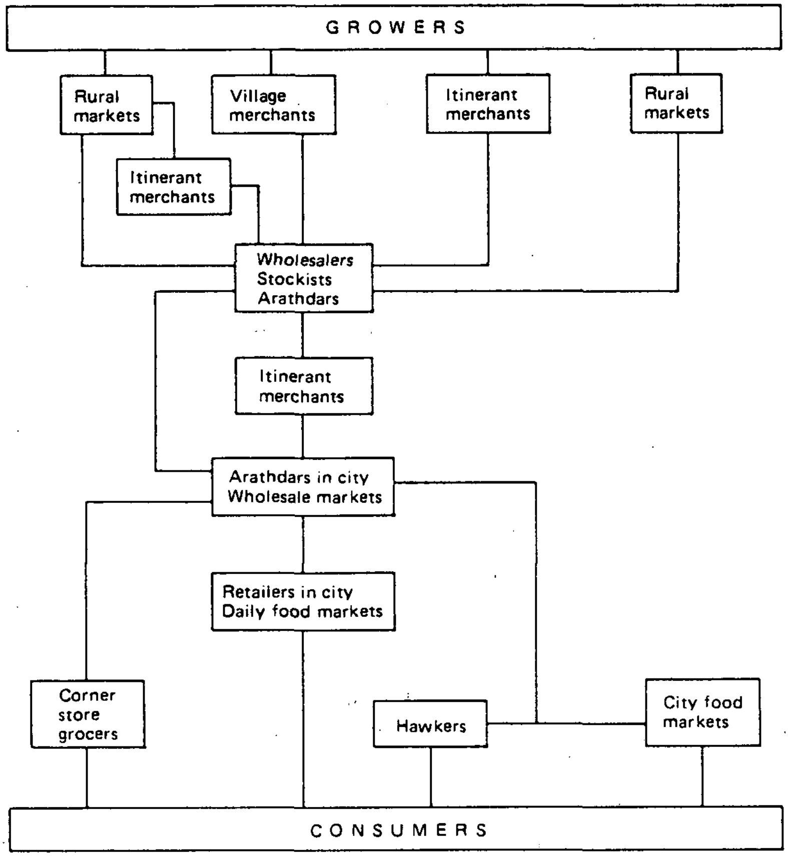

FIG. 3. Marketing channels for onions in Bangladesh.

Price spread of onions — a case study [17]

The growing area is situated about 130 miles[3] from Dhaka city and the channels of marketing are as follows: grower — faria — arathdar — bepari — retailer — consumer. Price spread is shown in Table IX.

Storage loss and seasonal price fluctuations

Losses incurred in storage and handling are attributable to:

(a) *Moisture loss*: Rapid drying takes place during the first 2 months (15%) followed by slow drying (15%) during the remaining 6 months of the 8 month storage period. Total estimated moisture loss is 30%.

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[3] 1 mile = 1.609×10^0 km.

TABLE IX. HANDLING AND TRANSPORTATION PRICES (per 40 kg)

Channels of marketing	Itemized costs (Tk)
Net price received by the grower in rural market	55.60
Expenses paid by growers (packing, transportation and toll)	8.80
Price paid by faria/paikar	*64.40*
Expenses paid by faria/paikar (toll, packaging, transportation and an additional toll)	11.50
Faria/paikar's margin of profit	4.10
Price paid to faria/paikar by arathdar	*80.00*
Commission paid to arathdar by bepari	5.00
Loss suffered by arathdar (clearance)	2.00
Price paid by bepari	*87.00*
Expenses paid by bepari (packaging, taxes, loading and unloading, transportation, communication to arathdar, loss due to drying and rotting)	24.20
Bepari's margin of profit	8.80
Wholesale price paid by retailer	*120.00*
Expenses paid by retailer (transportation and handling, toll/rent, etc.)	5.00
Retailer's margin of profit	25.00
Retail price in Dhaka market (Grower's share of consumer's price is 37%)	*150.00*
(i) Total cost for transportation and handling	22.80
(ii) Total packaging cost	1.50
(iii) Total paid for toll and taxes	8.20
Total (i), (ii) and (iii)	32.50
(iv) Profit shared by intermediaries	69.00

(b) *Sprouting and rotting*: After a dormant period of 3–4 months, sprouting occurs followed by rotting. Heavy sprouting occurs when the temperature goes down in October. Total loss due to sprouting and rotting is around 50% in the 8 month storage period.

The price of onions varies around Tk 2[4] per kg in the peak season. It usually increases by a factor of between 2 to 3 times. Sometimes, owing to losses the price increases by 8 times. The high price during the off-season is due to a limited supply caused by losses of the bulbs because of the lack of suitable storage. At least 40% of the bulbs need to be stored for consumption during the off-season.

2.1.3. *Fisheries in Bangladesh*

Over a million persons are engaged in fishing, 40% of whom are in the marine sector of the country. Fishing is well organized. In 1983–1984 there were 80 trawlers and 4500 mechanized boats, compared with 28 trawlers and 2000 motorized boats in 1979–1980. Some 77 000 country boats are engaged in fishing both in inland and marine sectors.

The country has 1.47 million ha of inland water consisting of rivers, streams, canals, ponds, tanks, dams, natural depressions, lakes and estuaries, etc., and about 2.8 million ha rice fields which remain submerged for about 6 months in the year. In addition, over 40 000 km^2 of sea are available for fishing.

Fish production

Fish production in inland waters is almost static but in the marine sector it has increased substantially. Table X gives data on fish production in Bangladesh.

Marine fishing has a great potential in Bangladesh. A special survey by a United Nations body in 1973 revealed that the probable potential in the Bangladesh shelf area is about 264 000–373 000 t. Another survey carried out in 1981–1982 indicated that the possible annual production is 360 000–450 000 t of fish and 4000–6000 t of shrimps.

About 100 000 t are still caught by coastal small scale fishing boats. Organized fishing in the private sector has increased particularly in shrimp culture. In 1982–1983, 2300 t of shrimps were caught by trawlers and 2500 t were produced from coastal culture.

Sixty per cent of the marine landings are in Chittagong, 20% in Khulna, 10% in Cox's Bazar and 10% in Barisal and Dhaka. 'Hilsa' (shad) and shrimps are two

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[4] The taka is the basic monetary unit of Bangladesh. Tk 25 correspond to US $1. In this paper large sums of money are expressed in lakh (1 lakh = 100 000) and crore (1 crore = 10 000 000).

TABLE X. FISH PRODUCTION IN BANGLADESH

Year	Inland (t)	Marine (t)	Total (t)
1976–1977	541	100	641
1977–1978	533	110	643
1978–1979	527	118	645
1979–1980	524	122	646
1980–1981	525	125	650
1981–1982	566	130	686
1982–1983	600	172	772

TABLE XI. FRESH FISH, SHRIMP AND FROG LEG PROCESSING PLANTS IN BANGLADESH

Locations	Number
Chittagong	21 (+1 under construction)
Khulna	9 (+1 under construction)
Sylhet (Ajmerigonj)	1
Barisal	1
Cox's Bazar	2
Dhaka (Pagla)	1

important types. Hilsa constitutes 33% of all landings and 67% of all boat landings.

Fish processing and export

The fish processing industry has developed tremendously in Bangladesh. There are now 35 processing factories in existence (Table XI). These are freezing plants, mostly for shrimps and frog legs. The main port city, Chittagong, is the principal area for processed fish production. In 1972–1973 processed fish with an estimated value of Tk 35 million were exported (see Table XII) [18]. In 1982–1983, the figure was Tk 1763.8 million. Earlier, processed fish was known as a non-traditional exportable product. Now, in the list of exportable items, fish and fishery products are second in earning foreign exchange for the country (jute and jute products always have been number one). The importance of processed fish in the national economy is clear.

Dried fish, and salted and dried fish

Sun drying is the traditional method of processing of fish in Bangladesh. Although it is difficult to obtain an estimate of the volume of dried fish, it may be assumed that about 25 000 t of marine fish and 50 000 t of freshwater fish, worth US $50–60 million, are dried. Important centres of dried fish production are the offshore islands, the coastal belt near Cox's Bazar and Dubla Island near Khulna. Major centres of dried freshwater fish production are haor[5] areas of Sylhet and Mymensingh.

Recently, salted and dried fish have been produced in the country (in Cox's Bazar), primarily for export to Hong Kong (United Kingdom) and Singapore. According to the Dry Fish Exporter Association, export of dried fish increased from 108 t in 1977–1978 to 600 t in 1981–1982. The target for 1983–1984 was 600 t, with an estimated value of Tk 60 million.

A man-made lake, the Kaptai Lake, produces around 4000 t of fresh fish in a 10 month period; most of it is transported to big cities and interior areas for consumption. In addition, about 200 t of dried fish are also produced in the vicinity of the lake.

Storage and transportation

The fish is immediately processed on receipt of shipment and thus the product is kept in cold storage for export. For home consumption little fish is frozen. In the case of marine fish and fish found in the Kaptai Lake, about 95% is transported fresh in trucks and 5% in insulated vans. Substantial quantities of freshwater fish are transported also by railway. Dried fish for export is kept in cold storage. Storage cost is Tk 400 per ton per month of storage and for a minimum quantity of about 15 t. This method is used to keep the product free from insect infestation. Table XIII shows a cost analysis for the transportation of fresh fish from Cox's Bazar to Dhaka.

Insulated vans are being used by the Bangladesh Fishery Development Corporation (a government department) for transportation of Kaptai Lake fish and marine fish from Chittagong. The retail price is fixed. The price per kilogram in the private sector fluctuates below and above this fixed price depending upon the supply of raw material in the landing centres.

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[5] Agricultural and fishing areas which are under water during the monsoon and remain partly submerged during the dry season.

TABLE XII. SEAFOOD EXPORTED FROM BANGLADESH (crore) [18]

Items	1972–1973	1973–1974	1974–1975	1975–1976	1976–1977	1977–1978	1978–1979	1979–1980	1980–1981	1981–1982
Shrimps	2.26	3.33	2.38	14.50	24.62	26.31	44.64	52.93	54.95	90.44
Frog legs	0.12	0.24	0.01	1.18	1.62	2.14	7.14	3.21	5.00	11.21
Frozen fish	—	—	—	0.06	0.08	1.72	0.46	1.20	5.34	4.18
Fresh fish chilled	1.10	2.69	1.14	1.30	0.01	0.22	0.05	—	—	—
Dried fish	—	0.04	0.01	0.02	0.09	0.80	0.13	0.20	0.09	0.36
Salted and dried fish	—	—	—	—	—	0.16	1.44	3.07	2.27	1.31
Shark fins and fish maws	0.02	0.02	0.02	0.15	0.03	0.09	1.97	0.37	0.88	1.28
	3.50	6.32	3.56	17.21	26.45	31.44	55.83	60.98	68.53	108.78

TABLE XIII. PROCUREMENT, TRANSPORTATION AND OTHER COSTS OF 5 t OF FRESH HILSA FROM COX'S BAZAR TO DHAKA [19]

Items	(Tk)
Purchase of 5 t	70 000
Truck fare	7 000
Icing (1:1)	2 000
Labour (loading and unloading)	1 000
Arathdar's commission (4%)	4 000
	84 000
Wholesale price in Dhaka[a] (Price: Tk 22.3 per kg)	94 775
Retail price in Dhaka (Price: Tk 25 per kg)	106 250

[a] The amount includes 15% spoilage (i.e. 750 kg) during handling, transportation and marketing.

Price fluctuations and storage loss

During the dry season, a heavy catch of fish is obtained both in inland and marine sectors. As mentioned earlier, freezing of fish is only for export. As the processing is expensive this technology is not acceptable to the home market because the consumers cannot pay the extra cost.

It is evident from Table XIII [19] that about a 15% loss is incurred during transportation. In the case of refrigerated vans a loss of up to 10% has also been reported. During retail sale there is also loss in quality of the fish but this factor has not been studied extensively.

A huge loss of dried fish occurs due to pest infestation. Improper use of pesticides has been observed. Losses of dried products have not been reported. Our experimental results, however, indicate a loss of 45% in 6 month's storage (Fig. 4). In the open market the price fluctuates by 200–300% in the off-season. Exporters store the dried fish in cold storage in order to keep it free of insects. The export price of dried fish is Tk 100 per kg, compared with Tk 50–60 per kg in the open market during the off-season. Exporters pay about Tk 25–30 per kg for storage and packaging.

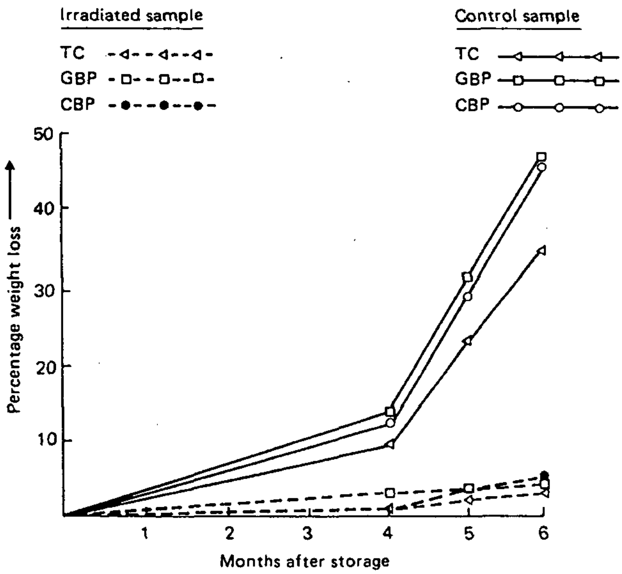

FIG. 4. Weight loss of dried fish stored six months in different packages. (TC: tin container; GBP: gunny bag lined with polyethylene; CBP: carton box lined with polyethylene.)

2.2. Radiation preservation of potatoes, onions, dried fish and fishery products

2.2.1. Potatoes

Annual losses of potatoes in Bangladesh could be around 0.1 to 0.2 million t based on a very conservative estimate of 15–20%. The loss mainly occurs owing to lack of a proper storage method. As mentioned previously (Table VIII), a tremendous increase in the cold storage capacity in Bangladesh has occurred in the last 2 years, but factors such as (i) the high price of machinery and building materials (Table XIV) and (ii) the high cost of energy often prohibit the use of cold storage. In addition, cold storage owners rent the facility on a seasonal basis, i.e. for 7–8 months. Therefore, short term storage is made at ambient conditions and results in huge losses due to moisture loss, sprouting and rotting. As early as 1965 we anticipated that sprout inhibition of potatoes by radiation could be a solution for preservation of potatoes.

Irradiation of potatoes

Laboratory experiments proved that sprout inhibition by irradiation at a dose of 0.10 kGy is possible with all varieties of potatoes produced in Bangladesh. However, storage of the irradiated potatoes at ambient conditions is not possible.

TABLE XIV. ESTIMATED COST OF CONSTRUCTION OF A 1000 t CAPACITY COLD STORAGE FOR POTATO STORAGE (lakh)

Requirements	Local currency	Foreign exchange	Total
Land	4.0	—	4.0
Procurement of machinery	—	28.0	28.0
Insulation (purchase, fitting and fixing)	11.0	—	11.0
Rack fabrication	11.0	—	11.0
Installation of machinery and equipment	13.0	—	13.0
Construction of cold storage and ancillary office building (750 ft^2)[a]	1.5	—	1.5
Sorting shed (3600 ft^2)	1.44	—	1.44

[a] $1\ ft^2 = 9.290 \times 10^{-2}\ m^2$.

Technological studies on a semi-commercial scale were completed recently. Short term storage at room temperature and long term storage in cooled warehouses with different storage conditions were evaluated. The time of harvesting was also considered in evaluating the shelf life of potatoes. Five tonnes of potatoes of the Multa variety were used in experiments in 1983.

Ambient temperature storage: potatoes were irradiated at 0.06–0.08 kGy and stored on a bamboo platform at room temperature (25–34°C) and at relative humidity (40–100%) for 3½ months; storage losses of 29.10% and 39.40% were observed in the control[6] and irradiated potatoes respectively due to rotting and moisture loss (Table XV). This plainly explains why farmers in Bangladesh like to clear their stocks by June.

Organoleptic evaluation studies rated the irradiated potatoes superior to controls (Table XVI). All the potatoes were sold in the 4th month. The irradiated potatoes received a good response from buyers.

Cool temperature storage: two batches were irradiated, (i) 3 weeks after harvest and (ii) 8 weeks after harvest. The potatoes were in gunny bags and crates. They were stored in cold room units at 12–14°C. Increasing weight loss was observed in the control samples. The wooden crates were slightly better than the gunny bags for 5 months of storage. In Table XVII, the results of both of the times after harvest are combined as there was little difference between them. Owing to extensive sprouting of the controls no record was maintained of their weight loss.

[6] Control: not irradiated.

TABLE XV. LOSS OF POTATOES DUE TO ROTTING AND MOISTURE LOSS AT AMBIENT TEMPERATURES

Storage time (months)	Types of loss	Percentage loss	
		Control	Irradiated
1 (May)	Rotting	0.50	0.40
2 (June)	Rotting	0.65	0.30
3 (July)	Rotting	4.00	8.70
3½ (May to mid-Aug.)	Rotting	4.00	18.00
3½ (May to mid-Aug.)	Moisture loss	20.55	12.00
Total		*29.70*	*39.40*

TABLE XVI. ORGANOLEPTIC EVALUATION OF VARIOUS PREPARATIONS OF POTATOES

Potato preparations	Average score on a 9-point hedonic scale			
	Colour	Texture	Odour	Taste
Potato curry (control)	6.79	6.89	7.18	7.22
Potato curry (irradiated)	6.92	6.74	7.14	7.31
Mashed potato (control)	7.62	6.69	6.78	6.78
Mashed potato (irradiated)	4.99	5.87	6.20	5.66
Boiled potato (control)	7.25	6.75	6.87	6.37
Boiled potato (irradiated)	5.68	6.75	5.67	5.99
Crisped potato (control)	5.24	5.37	6.24	5.74
Crisped potato (irradiated)	4.47	5.90	6.53	6.99
French fries (control)	6.75	6.50	6.87	5.87
French fries (irradiated)	5.75	5.50	5.87	6.25

Potatoes stored on platforms in layers 3–4 in[7] deep suffered a 4% weight loss after the 7th month of storage.

The organoleptic rating of irradiated potatoes of the first batch (treated after 3 weeks of harvest) after 5 months was comparable with that of the control. Potatoes from the second batch (treated after 8 weeks of harvest) had a poorer rating due to sprout growth before irradiation.

[7] 1 in = 2.54×10^1 mm.

TABLE XVII. WEIGHT LOSS OF COOL STORAGE POTATOES DUE TO MOISTURE LOSS

Storage time (months)	Cumulative weight losses (%) Control		Irradiated	
	G.B.[a]	W.C.[b]	G.B.	W.C.
2	1.61	1.24	0.63	0.51
3	4.40	4.46	2.37	1.45
4	7.63	6.24	2.60	2.18
5	9.60	7.88	3.74	2.43
6	Profuse sprouting	—	4.23	5.30
7	Profuse sprouting	—	7.40	7.39

[a] G.B.: Gunny bags.
[b] W.C.: Wooden crates.

The irradiated potatoes after the 7th (final) month of storage were evaluated for organoleptic and culinary properties by preparing French fries, potato curry, crisps, mashed and boiled potatoes (Table XVI). Non-irradiated cold storage potatoes served as control. With the exception of the colour of mashed and fried samples, the irradiated potatoes in all other parameters were comparable with cold storage potatoes. Physical parameters such as density, hardness and total soluble solid were also comparable in both groups. Customers preferred those potatoes irradiated 3 weeks after harvest to those of the second batch irradiated 8 weeks after harvest.

Transportation studies using rail, road and boats also showed that irradiated potatoes were better than the controls.

A limited trial marketing in 1987 showed that potatoes from the first batch (irradiated 3 weeks after harvest) bring a price 3 times higher than the procurement cost. Those from the second batch (irradiated 8 weeks after harvest) brought a price 2 times higher than the procurement cost, although it is a little less than the market price. Buyers bought a large number of 1500 kg units of potatoes. Overall acceptance by consumers obtained in the open sale of irradiated potatoes in 1984 was highly encouraging.

Technological feasibility

It has been established both in the laboratory and by pilot scale irradiation that, in Bangladesh, potato irradiation is technologically feasible. The process reduces spoilage losses and in this way can be profitable to use.

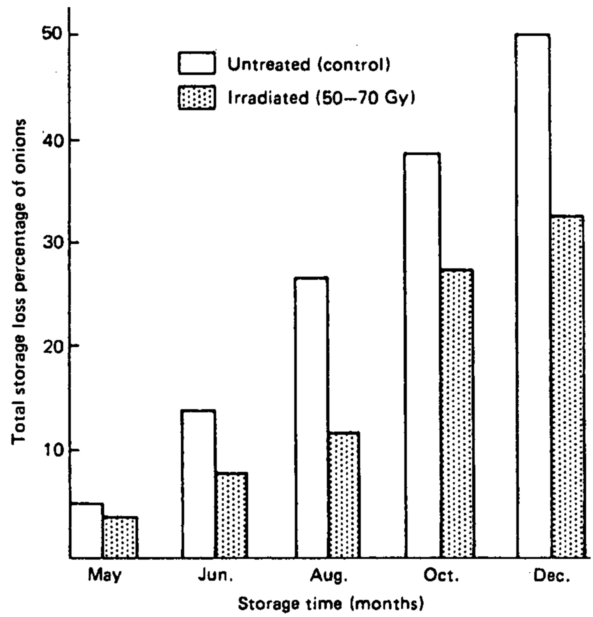

FIG. 5. Reduction in storage losses of irradiated and unirradiated onions in 1983. (Onions spread on split bamboo platforms at ambient temperatures.)

2.2.2. *Onions*

Cultivation and storage of onions are less organized than those of potatoes. No scientific method has been developed in onion preservation. Onion production remains more or less static, although demand increases. Foreign exchange is spent for importation of onions to make up the shortfall. Losses in onions are due to sprout development, and loss of weight is due to moisture loss and to microbial spoilage. Losses due to sprouting and moisture loss are particularly high in the later part of the season (October–January). The exact magnitude of loss is not known, but may vary between 30–50%. An improved scientific method is needed for the storage of onions. The storage of onions for off-season consumption is still in the hands of farmers and stockists. Although cold storage capacity is being increased, technology to utilize low temperature storage of onions has not been developed in Bangladesh.

As with potatoes, we established in the mid-1960s in laboratory experiments that Bangladesh onions could also be preserved longer by inhibiting sprouting by irradiation with a low dose of gamma rays (0.04–0.08 kGy). In the last few years semi-commercial irradiation of onions was carried out involving over 20 t in order to establish the technological feasibility of irradiation preservation of Bangladesh onions.

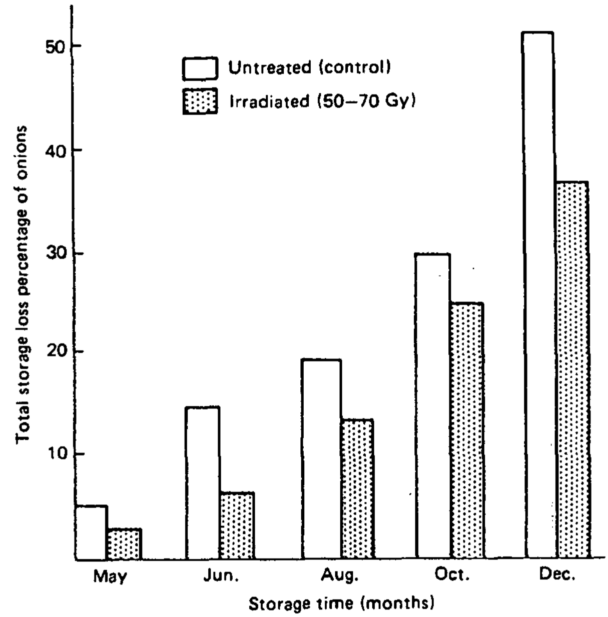

FIG. 6. Reduction in storage losses of irradiated and unirradiated onions in 1983. (Onions in net bags of 20 kg each at ambient temperatures.)

Irradiation of onions

Onions were irradiated at 0.05–0.07 kGy and stored at ambient as well as cool temperatures. Figure 5 shows losses of irradiated and unirradiated onions stored at ambient conditions and spread on split bamboo platforms as used by farmers. Irradiated onions had a smaller loss than untreated onions. With elevated-shelf storage of irradiated onions, around a 20% reduction in loss was obtained before December. The difference in loss between treated and untreated onions in net bags was less (see Fig. 6 and Table XVIII). No advantage was gained in storing onions at a cool temperature (12–14°C). At the end of August all onions stored at the cool temperature sprouted and spoiled.

The organoleptic properties of treated onions were as acceptable as those of untreated onions (see Table XIX). The overall reaction of consumers to the irradiated onions which had been stored for 10 months was favourable (Table XX).

Technological feasibility

It has been established that a low dose of radiation reduces the spoilage loss of Bangladesh onions. It has also been established that cool temperature (14°C)

TABLE XVIII. LOSS IN ONIONS DUE TO MOISTURE LOSS AND ROTTING DURING STORAGE (Storage trial 1983–1984)

Storage time (months)	Storage conditions	Type of loss	Loss in percentage Control	Irradiated
May 1983	Ambient condition spread on platforms	Moisture loss	5.0 ± 0.7	3.6 ± 2.2[a]
		Rotting	2.0 ± 0.3	0.2 ± 0.1[a]
	Ambient condition net bags	Moisture loss	5.8 ± 1.2	1.5 ± 0.8[b]
		Rotting	2.0 ± 0.2	0.8 ± 0.3[b]
	15°C spread on platforms	Moisture loss	5.3 ± 2.9	1.5 ± 0.8
		Rotting	1.0 ± 0.4	0.6 ± 0.3[c]
	15°C net bags	Moisture loss	2.1 ± 0.5	2.3 ± 0.3
		Rotting	2.1 ± 0.3	2.2 ± 0.6
Jun. 1983	Ambient condition spread on platforms	Moisture loss	4.8 ± 0.5	4.3 ± 0.8[d]
		Rotting	1.9 ± 0.3	0.1 ± 0.7[a]
	Ambient condition net bags	Moisture loss	5.3 ± 1.8	2.0 ± 0.5
		Rotting	2.0 ± 0.2	3.2 ± 0.5
	15°C spread on platforms	Moisture loss	5.9 ± 0.6	2.9 ± 1.6
		Rotting	0.9 ± 0.2	1.0 ± 0.2
	15°C net bags	Moisture loss	1.8 ± 0.4	1.04
		Rotting	1.2 ± 0.8	1.34 ± 0.3
Aug. 1983	Ambient condition spread on platforms	Moisture loss	15.17 ± 2.83	2.50 ± 1.04[c]
		Rotting	2.80 ± 0.78	2.30 ± 0.50[b]
	Ambient condition net bags	Moisture loss	3.80 ± 1.60	2.90 ± 0.70
		Rotting	1.86 ± 0.28	3.60 ± 0.57
	15°C spread on platforms	Moisture loss	9.28 ± 0.80	4.26 ± 0.40[c]
		Rotting	0.86 ± 0.40	1.03 ± 0.01
	15°C net bags	Moisture loss	7.29 ± 3.07	2.46 ± 0.32
		Rotting	5.33 ± 4.95	0.85 ± 0.19[d]
Oct. 1983	Ambient condition spread on platforms	Moisture loss	13.67 ± 1.65	13.02 ± 2.76[c]
		Rotting	0.94 ± 0.05	0.61 ± 0.24
	Ambient condition net bags	Moisture loss	9.88 ± 5.37	10.65 ± 4.22[c]
		Rotting		
	15°C spread on platforms	Moisture loss	55	14.92 ± 2.70[c]
		Rotting		9.23 ± 0.40
	15°C net bags	Moisture loss	55	13.58 ± 9.61[c]
		Rotting		9.90 ± 5.43

TABLE XVIII. (cont.)

Storage time (months)	Storage conditions	Type of loss	Loss in percentage	
			Control	Irradiated
Dec. 1983	Ambient condition spread on platforms	Moisture loss	16.23 ± 5.75	11.55 ± 0.42
		Rotting	1.58 ± 0.30	1.54 ± 0.24
	Ambient condition net bags	Moisture loss	23.67 ± 2.08	12.57 ± 1.16[c]
		Rotting	7.33 ± 2.89	3.53 ± 0.78[c]
	15°C spread on platforms	Moisture loss	Discarded	15.09 ± 3.19
		Rotting		14.20 ± 1.60
	15°C net bags	Moisture loss	Storage loss	11.96 ± 0.60
		Rotting		18.33 ± 7.08

[a] Significant at 0.5% level.
[b] Significant at 2.5% level.
[c] Significant at 1% level.
[d] Significant at 5% level.

storage is not necessary for the storage of irradiated onions. Irradiated onions stored on a split bamboo platform in a well ventilated warehouse had 20% less spoilage than that of the controls. Bulk storage results with the platform were better than those of storage using net bags.

2.2.3. *Dried fish*

The value of the production of dried fish exceeds US $60 million. Most of the dried fish is processed during winter months when the heavy catch of both inland and marine fish is obtained. Apart from the need to supply fish for consumption during the processing months, fish needs to be stored during the off-season. Technologically the use of pesticides such as diazinon, malathion, fenthion, etc., is not feasible. These pesticides, however, have been used injudiciously. Disinfestation of dried fish by irradiation can provide protection of dried fish.

Radiation effects on insects

A dose around 0.30 kGy is considered enough to kill all stages of the hide beetle and other insect pests associated with dried fish [20].

TABLE XIX. EFFECT OF IRRADIATION AND STORAGE AT AMBIENT CONDITIONS ON ORGANOLEPTIC PROPERTIES OF ONIONS DURING THE STORAGE TRIAL IN THE HARVESTING SEASON (1982–1983)

Storage condition	Sample preparation	Colour[a]		Texture[a]		Odour[a]		Taste[b]	
		Control	Irradiated	Control	Irradiated	Control	Irradiated	Control	Irradiated
On platform	Raw	5.3 ± 1.25	6.8 ± 0.63	5.2 ± 1.17	6.7 ± 0.67	5.5 ± 1.35	5.9 ± 0.70	5.7 ± 1.34	5.9 ± 0.70
	Fried	6.3 ± 1.97	7.1 ± 0.88	6.0 ± 1.25	6.6 ± 0.52	6.6 ± 0.52	6.1 ± 1.50	6.2 ± 1.55	6.8 ± 0.92
	Boiled	5.0 ± 1.25	6.0 ± 1.15	5.4 ± 1.07	6.7 ± 0.60	5.3 ± 1.25	6.0 ± 1.25	5.2 ± 1.17	6.2 ± 1.02
Basket	Raw	5.6 ± 1.07	5.9 ± 1.10	5.0 ± 1.25	6.3 ± 1.06	5.2 ± 1.14	5.9 ± 1.10	5.5 ± 1.25	5.9 ± 1.10
	Fried	6.4 ± 0.97	6.2 ± 1.55	6.3 ± 1.07	5.9 ± 1.10	5.1 ± 1.37	6.4 ± 0.97	6.5 ± 1.19	6.9 ± 1.20
	Boiled	5.7 ± 1.34	7.3 ± 0.08	5.8 ± 1.32	6.6 ± 0.51	5.3 ± 1.25	6.2 ± 0.9	5.1 ± 1.37	5.4 ± 1.26

[a] Mean ± standard deviation.

[b] 9-point hedonic scale used for scoring by a trained panel of judges.

TABLE XX. CONSUMER ACCEPTANCE OF IRRADIATED ONIONS[a] STORED FOR 10 MONTHS AT A TEMPERATURE OF 15°C

Remarks	Before cooking Appearance (%)	Odour (%)	Taste (%)	After cooking Appearance (%)	Odour (%)	Taste (%)
Dislike	13.79	27.58	19.34	6.89	10.34	10.34
Like slightly	55.17	51.72	65.51	31.03	34.48	27.58
Like	31.03	20.68	24.23	62.02	55.17	62.06

Note: Because of heavy storage loss a sufficient quantity of untreated onions was not available for evaluation of consumer acceptance.

[a] Onions were spread on platforms.

Packages to prevent reinfestation

Suitable packaging material is needed for prevention of reinfestation of irradiated dried fish. Both rigid and flexible packaging materials can be used. Traditionally flexible sacks, such as gunny bags, are used for packaging, storing and transporting dried fish. These sacks are not suitable as packaging material for dried fish, as insect penetration studies have shown that gunny bags, polyethylene material as well as polypropylene material lined with kraft paper do not prevent reinfestation [7, 8]. High density polyethylene, both white and clear, prevents reinfestation. Rigid materials e.g. tin containers and plywood boxes are excellent materials for long term storage of irradiated dried fish. Although the initial cost of rigid containers is high, repeated use reduces the cost in the long run.

Insect damage

Figure 4 shows the pattern of weight loss of dried fish stored 6 months due to feeding of insects. The loss increased sharply after 3 months and at the end of the experiment a 45.5% loss was observed. In the 6 month period 3 generations of insects were completed. Some of the unirradiated samples were totally spoiled owing to insect infestation and fungal growth and were unfit for human consumption. Irradiated samples showed no fungal growth and were in good condition and recorded a loss of only 3–5%. Repeated experiments, including even storage for 9 months, showed similar results (Table XXI). Semi-pilot-scale studies of irradiated dried fish also showed similar results.

Experiments with different storage temperatures were also carried out. At 20°C normal insect damage occurred as in untreated fish. However, for irradiated dried fish low temperature storage is not necessary.

TABLE XXI. WEIGHT LOSS (%) OF DRIED MACKEREL AND GONIA AFTER 6 AND 9 MONTHS OF STORAGE

Types of packaging materials	Mackerel				Gonia (*Labeo gonius)*			
	6 months		9 months		6 months		9 months	
	Irrad.	Unirrad.	Irrad.	Unirrad.	Irrad.	Unirrad.	Irrad.	Unirrad.
Interwoven polypropylene lined with kraft paper	14	27	21	35	13	19.5	20	29.5
HDP (High density polythene) white	4	29	4	52	3	16	4	33.6
HDP transparent	5	31	5	46	3	10.5	3	21.5
Plywood box	5	18	5	55	2	21.4	3	30.8

Organoleptic evaluation studies revealed the superiority of irradiated dried fish. At 0°C, dried fish became tougher in texture and was darker in colour, as reported by some judges (Table XXII). Dried fish was free from *Salmonella* and other pathogenic bacteria.

Technological feasibility

Storage losses of dried fish may be avoided by disinfestation with radiation and by use of proper packaging materials. Radiation disinfestation appears to be the only practical method for enabling the storage of dried fish in Bangladesh. Now export products are held in cold storage at a high cost. Because of added cost, cold storage cannot be used for products for home consumption. Irradiation, however, may be economically feasible for the home market.

If radiation disinfestation is internationally accepted, it can remove the need for storage of export products at low temperatures.

Other fish and fishery products

Salmonella contamination occurs in frozen fish and fishery products from the developing countries. Since 1981 remarkable improvements have been made in the handling and processing of frozen fishery products for export. However, elimination of pathogenic bacteria could be done by radiation. Once irradiation is internationally accepted, an exporting country such as Bangladesh will benefit from its use.

TABLE XXII. EFFECT OF DIFFERENT ENVIRONMENTAL CONDITIONS ON THE ORGANOLEPTIC QUALITY OF IRRADIATED DRIED FISH

Samples treatment	Ratings (9-point hedonic scale)[a] Colour	Texture	Odour/flavour	Taste
Irradiated				
Ambient temperature	7.20 ± 0.43	6.60 ± 0.54	7.60 ± 0.54	7.00 ± 0.71
0°C	7.40 ± 0.54	7.40 ± 0.54	7.60 ± 0.54	7.60 ± 0.54
10°C	7.40 ± 0.54	7.20 ± 0.43	7.40 ± 0.43	—
20°C	7.00 ± 0.71	7.60 ± 0.54	7.60 ± 0.54	7.00 ± 0.01
Unirradiated				
Ambient temperature	3.80 ± 1.30	6.40 ± 0.54	6.20 ± 0.54	6.20 ± 0.43
1°C	7.40 ± 43	7.60 ± 0.54	7.60 ± 0.54	7.60 ± 0.54
10°C	7.00 ± 0	7.40 ± 0.54	7.60 ± 0.54	7.20 ± 0.43
20°C	5.80 ± 0.54	7.20 ± 0.43	7.20 ± 0.43	7.20 ± 0.54

[a] Mean ± standard deviation.

2.3. Plant and machinery for radiation preservation of foods

2.3.1. Radionuclide source

An irradiation plant consists of:

(a) Major facilities: the irradiator and its shielding, controls, conveyor and working areas;
(b) Minor facilities: product conveyor system, electric power supply, air conditioning, cooling water system, de-ionizer, etc.;
(c) Irradiation apparatus: source elevator mechanism, source conveyor, protective glass window, television monitor, control equipment;
(d) Source: ^{60}Co or ^{137}Cs;
(e) Operating equipment: fork lift, product containers, pallets, boxes, etc.

This is the type of irradiation plant most commonly used for processing of foods. An irradiation system can be categorized on the basis of its general features, as follows: (i) source type, e.g. radionuclide, (ii) use, e.g. sprout inhibition, disinfestation, radurization, etc., (iii) product, e.g. type of food, medical supplies, etc., (iv) conveyor system design, e.g. stationary, single-pass continuous, multiple-pass continuous, multi-pass shuffle–dwell, etc.

2.3.2. *Bremsstrahlung and X rays*

In contrast to monoenergetic radionuclide sources, bremsstrahlung and X ray radiators emit a broad band spectrum consisting of photons of various energies. These energies can also be used for processing of food.

2.3.3. *Electron beams from accelerators*

Electrons emitted by accelerators (Linca, Van de Graaff) have fairly narrow spectral energy limits. Owing to low penetration power, electron accelerators can irradiate products only in thin layers or they can be used for surface irradiation.

Most commercial plants have ^{60}Co as the radionuclide. Recently a number of ^{137}Cs sources have also been built.

2.3.4. *Other facilities*

A commercial plant should have a small refrigerated room and storage for incoming and outgoing products. A stand-by electric generator is also essential where there are frequent power problems. In addition, radiation survey meters, small laboratory equipment for quality control of products and for dosimetry, and other facilities are needed in an irradiation plant.

2.4. Safety and acceptability of irradiated food items

The safety of irradiated food has been considered over the last 30 years. In 1980 the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Foods reported on the safety of irradiated foods. It was clearly declared that foods irradiated up to an overall dose of 10 kGy are wholesome. In addition, the Committee stated that radiation processing is a physical method for treating foods. No further testing for wholesomeness is required. This was accepted by many countries for implementation. In 1983 the Codex Alimentarius Commission also adopted standards for irradiated foods and recommended their acceptance to the Member States.

Bangladesh has been working on food irradiation for the last 19 years. A good number of food items have been treated by radiation for disinfestation, sprout inhibition and shelf life extension. Semicommercial studies have been conducted for the last 4 to 5 years. Irradiation as a process of food preservation had been well publicized earlier. Our research and development work entered into the phase for commercialization at the time when we also received the recommended Codex General Standard for Irradiated Foods. We approached the Bangladesh Standard Institute (BDSI) to secure acceptance of the Codex General Standard for Irradiated Foods by

Bangladesh. The standards were adopted for irradiated foods in Bangladesh by BDSI on 29 December 1983 in line with the Codex Alimentarius Commission. We are now ready for commercialization of irradiated foods.

2.5. Location in Bangladesh of facilities for radiation preservation of foods

The radiation facility should be established in an area where:

(a) Production centres for the food items are near by;
(b) Adequate storage facilities are in existence;
(c) Transportation to the irradiation plant is available, i.e. it can be reached by roads, waterways and, if possible, railways;
(d) A consumption centre is near.

The production of potatoes, onions and dried fish in Bangladesh is very scattered geographically; however, there is adequate concentration of production areas associated with storage facilities which could justify the establishment of irradiators. Transportation of most of the food is by boats, steamers and other facilities available on rivers and in the coastal belts. The use of such transportation is more important owing to the high cost of fuel. Therefore, riverside or seaside locations are considered most important in the establishment of irradiators in Bangladesh.

Before full commercialization of radiation processing occurs, the availability of facilities, such as storage and major consumption centres, has been considered an important factor in establishing service oriented irradiators. At this stage, it cannot be expected that a complex for food storage and processing will be established only on the basis of irradiation processing in a country where food processing itself is in its infancy. Besides, major consumption centres, such as big cities, have adequate storage facilities and organized marketing channels and also customers who could pay extra for high quality products. For continuous use of an irradiation plant, enough products have to be available. A single purpose irradiator is not foreseen. Mobile irradiators, of course, could be considered but road and waterway conditions do not allow at this stage the undertaking of such a venture.

In our feasibility studies for the establishment of commercial irradiators we have identified the following centres (Fig. 7).

Dhaka: The needs of the area about Dhaka city justify the establishment of more than one irradiator. The Dhaka district produces more than 30% of the total national production of potatoes. This district has already 114 965 t (Table IV) of installed cold storage capacity and has 90 110 under construction. In and around the city there is already 37 000 t installed capacity of cold storage facilities and 7500 t under construction. Once the process is established, the storage facility and the customers will be ready to accept the technology. As it is the largest consumption centre in the country a large quantity of stored potatoes is marketed there.

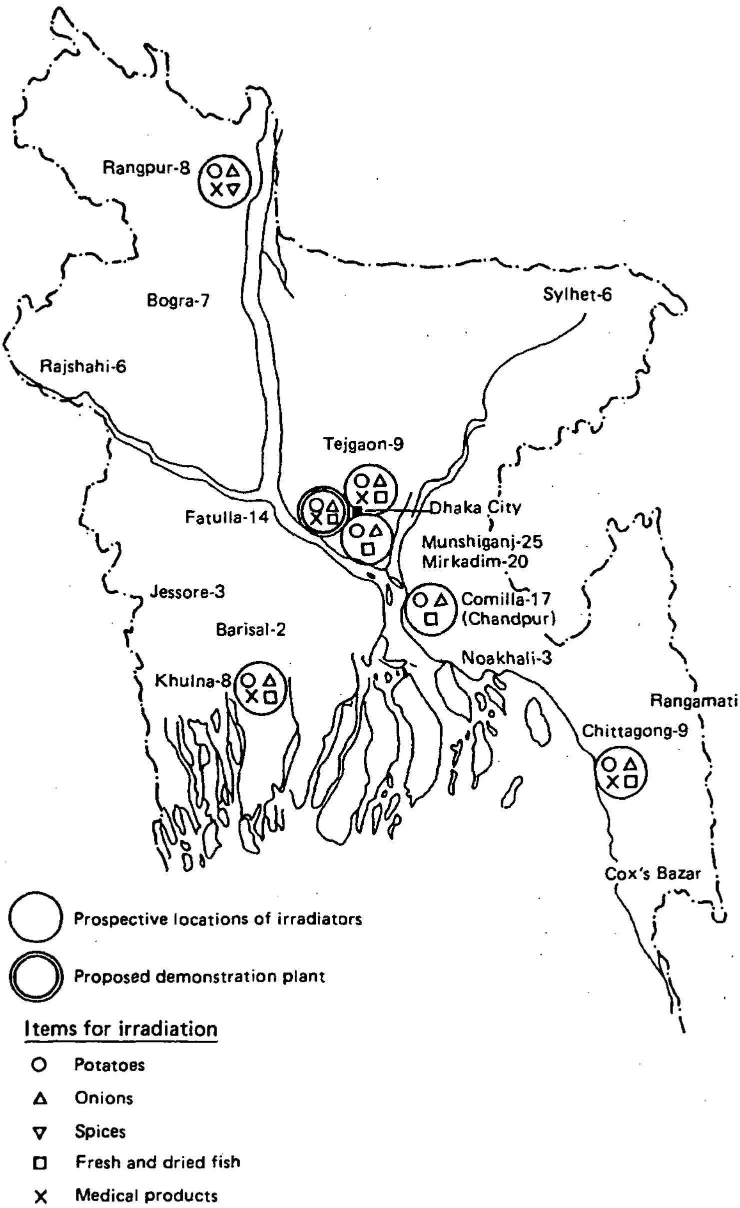

FIG. 7. Map of Bangladesh showing places with numbers of cold storages and possible locations of irradiation plants.

The largest onion producing centre is 130 miles from Dhaka city and is well connected with boats, launches, trucks and buses. Other major producing areas are within 50–100 miles and are also well connected with the city. Dhaka city receives 10 000–15 000 t of onions for consumption per annum.

Dried fish and fishery products could also be irradiated, since huge quantities are exported through Dhaka city. It has the largest international airport in the country. An export oriented food processing centre is also under construction near the international airport.

In addition other foods such as dried pulses and oil seeds are stored in Dhaka. All these commodities will be treated in the commercial irradiation plant in Dhaka.

Chittagong: About 60% of marine and fishery products land in Chittagong. It is the major centre for collection, marketing and distribution of dried fish. Even freshwater dried fish is transported to Chittagong for storage, distribution and marketing throughout the country. Dried fish is also exported from this port city to Hong Kong (United Kingdom), Singapore, the Middle East and Europe. Out of the 35 existing fish, frog leg and shrimp processing plants, 21 are in Chittagong. Most of the foreign exchange earnings in export of fish and fishery products are received through this largest port of the country.

Chittagong has a number of cold storage facilities for potatoes. Being the second largest consumption centre in the country, a commercial irradiator in Chittagong will draw a large number of customers to process their food materials.

Rangpur: The major agriculture centre in the northern part of the country, Rangpur produces substantial quantities of potatoes and onions. The existing cold storage facility has a capacity of 22 000 t, additional capacity of 18 500 t is under construction. Rangpur is the largest centre for ginger production. Prospects exist for exportation of this product in the future. Bangladesh is self-sufficient in the production of quality tobacco, most of which is grown in Rangpur. Disinfestation of tobacco by irradiation could also be an important application. Mangoes and lychees are produced in Rangpur and in the neighbouring districts. Owing to insect infestation and limited shelf life, substantial losses occur with these fresh fruits. Irradiation extends the shelf life of these tasty tropical fruits and makes available deliveries to other parts of the country, as well as exports through Dhaka.

Chandpur (Comilla district): Chandpur is situated in the second largest potato growing area of the country and is also one of the major inland fish landing centres (annual landing is around 10 000 t). The installed capacity of cold storage in the district is 47 000 t with an additional 15 000 t under construction. Some of the largest potato and onion growing areas of Dhaka and Faridpur are easily accessible from Chandpur by rivers. Chandpur is also well connected by railways and roads.

Khulna: Khulna is the second largest marine fish producing and processing centre in the country. A large quantity of dried fish is produced in Khulna. The city has the second largest port, Chalna, nearby for export of processed fish and fishery products. It is the third most highly populated city in the country. Large quantities of foods, such as potatoes, onions and pulses are stored for off-season consumption.

Rangamati: The fish landing centre of Kaptai Lake, Rangamati has an annual landing of about 4000 t. The fish is distributed through 10 months of the year. Because the lake is scientifically managed by the Bangladesh Fisheries Development Corporation, production is on the increase. Most of the catch is transported by trucks, refrigerated vans and buses to the remotest parts of the country. Shelf life extension is needed for distribution of high quality fish. Rangamati also produces over 220 t of dried fish. A small batch type irradiator would be ideal for installation in this area.

Another potential centre is Cox's Bazar, which is a major centre of dried fish production and the only centre of production of dried fish for export. Ten per cent of the total landings of marine fish is made in Cox's Bazar.

2.6. Personnel requirements and training facilities

Personnel requirements for the operation of a food irradiator are: one manager/director; one food technologist/microbiologist; five scientific assistants/ technicians; two assistants/accountants; one laboratory attendant; three drivers; six general attendants/security attendants; four skilled labourers.

The supplier of the irradiation plant will be responsible for training the local staff during and after construction. The Institute of Food and Radiation Biology (IFRB) will be in a position to support the facilities with technical know-how. Personnel may also be trained by the IFRB and other departments of the Atomic Energy Research Establishment whenever needed.

3. COMMERCIAL AND FINANCIAL FEASIBILITY OF A MULTIPURPOSE IRRADIATOR

3.1. Costs and earnings of a commercial irradiation plant

It has been decided that the first irradiator to be established in Bangladesh will be a multipurpose unit. In this way there will be sufficient product volume to operate the facility throughout the year and ultimately it would be cost effective. It was also decided that the location would be near Dhaka city, the capital of Bangladesh.

3.1.1. Assumptions for calculation of costs

Calculations were made on commercial irradiators operated with or without storage facilities. The calculations were based on the following assumptions that:

TABLE XXIII. RATE OF OUTPUT FOR DIFFERENT COMMODITIES TO BE TREATED AND DOSES TO BE GIVEN TO EACH COMMODITY

Items to be irradiated	Density (g/cm^3)	Output (t/h)	Dose rendered (kGy)
Potatoes	0.7	15	0.08
Onions	0.7	15	0.08
Dried fish	0.3	3.8	0.85
Fresh fish	0.5	2.0	2.00
Medical products	0.2	20.0	25.00

(a) 7.40 PBq of ^{60}Co be installed in order to maintain the rated capacity and that 0.74 PBq of ^{60}Co would be added each year;
(b) Construction of the facility would take 2 years;
(c) Operating time would be three shifts per day, each of 8 hours and 300 days per year, for a total operating time of 7200 hours per year;
(d) The economic life of the irradiator would be 20 years;
(e) The irradiation facility was either operated solely on a service charge basis or integrated with the warehouse facilities where part of the materials would be treated, stored and sold on a commercial basis;
(f) The utilization during the first year would be 80% of the rated capacity, namely 5798 hours of operation, and in the subsequent years 90% utilization or 6500 hours of operation per year;
(g) With a 7.40 PBq source the rate of output for different commodities to be treated and dose to be given to each commodity would be calculated as shown in Table XXIII.

With the proposed product-mix (Table XXIII) the irradiator would treat quantities of materials at 80% and at 90% utilization as shown in Table XXIV.

3.1.2. Investment cost and profitability of the irradiator without a warehouse facility

The total investment cost of a 7.40 PBq of ^{60}Co commercial irradiator without its own warehouse/cold storage facilities has been estimated to be Tk 47.558 million (US $1.90 million). The summary of the investment is given below:

- Preconstruction expenditure — 9.70 lakh;
- Construction engineeering cost — 81.14 lakh;
- Machinery and equipment — 316.55 lakh;
- Other costs — 68.19 lakh.

TABLE XXIV. TREATMENT OF QUANTITIES OF MATERIALS

Items	80% utilization Quantity (t)	80% utilization Hours	90% utilization Quantity (t)	90% utilization Hours
Potatoes	12 500	833.33	14 062	937.50
Onions	12 500	833.33	14 062	937.50
Dried fish	500	131.58	562	148.03
Fresh fish	3 000	1500.00	3 375	1687.50
Medical products	50 000 per ft^3	2500.00	56 250 per ft^3	281.50

[a] 1 $ft^3 = 2.832 \times 10^{-2}$ m^3.

The annual operating cost of the irradiator has been estimated to be Tk 10.872 million during the first year. It will reduce to Tk 8.082 million at the beginning of the 11th year of operation, by which time all the machinery will be completely depreciated.

At 80% capacity utilization in the first year and 90% during the years 2 to 20 the irradiator would earn revenue as shown in Table XXV.

The financial analysis shows that the net present value (NPV) of the project at 15% is Tk 448.15 and at 25% NPV it is Tk 121.13. The internal rate of return (IRR) of the project is 29.30% and the payback period is less than 4 years. At 80% utilization of the irradiator, i.e. 5798 hours of operation, the cost of irradiating 1 kg of potatoes, onions, dried fish and fresh fish is Tk 0.12, Tk 0.12, Tk 0.47 and Tk 0.89 respectively. The cost of irradiating a cubic foot[8] of medical products is Tk 88.0. As we are now charging less than Tk 40 per cubic foot on a subsidized rate, the calculation is based on Tk 40.00. It appears, however, that the service charge for medical supplies should be raised to at least Tk 88.00 which would add an additional income of Tk 20.00 to the yearly revenue.

The profitability calculations given above suggest that a commercial irradiator is a profitable venture and its rate of return compares very favourably with other investment opportunities.

An analysis of the operation of an irradiator without warehouse facilities shows a break even for costs and revenue as follows:

[8] 1 $ft^3 = 2.832 \times 10^{-2}$ m^3.

TABLE XXV. IRRADIATOR REVENUE EARNINGS

Items treated	Service charge (Tk[a]/t)	80% in the first year Quantity (t)	Revenue (lakh)	90% from 2 to 20 years Quantity (t)	Revenue (lakh)
Potatoes	200.00	12 500	25.00	14 062.5	28.13
Onions	300.00	12 500	37.50	14 062.5	42.18
Dried fish	5000.00	500	25.00	562.5	28.12
Fresh fish	2000.00	3 000	60.00	3 375.5	67.51
Medical products	40.00 per ft^3	50 000	20.00 per ft^3	56 250.0	22.50 per ft^3
			167.50 (US $0.67 million)		188.44 (US $0.75 million)

[a] Tk 25 correspond to US $1.

- Break even revenue — 106.41 lakh;
- Utilization — 156.57% of rated capacity at 90% capacity utilization;
- Utilization — 50.82% of rated capacity;
- Hours of operation — 3660.

The above data indicate that operation for 3660 hours per year is needed to obtain a break even situation for revenue and costs.

3.1.3. *Investment cost and the profitability indicator of the irradiator with warehouse facility*

The total investment cost of the 7.40 PBq of ^{60}Co irradiator with warehouse facilities for the storage of 1500 t potatoes, 800 t of onions, 100 t of dried fish and 600 t of fresh fish has been estimated at Tk 66.470 million (US $2.67 million). The summary of the investment costs is as follows:

- Preconstruction expenditure — 14.50 lakh;
- Construction engineering cost — 123.54 lakh;
- Machinery and equipment — 403.56 lakh;
- Other costs — 103.10 lakh;
- Working capital — 20.00 lakh.

The annual operating cost of the facility has been estimated at 306.19 lakh in the first 10 years of operation and would decrease during the years 11 to 20.

TABLE XXVI. REVENUE FROM IRRADIATION PLANT
(at 80% and 90% capacity utilization)

Items	Quantity (t) at 80%	Quantity (t) at 90%	(Tk[a]/t)	Revenue (lakh) at 80%	Revenue (lakh) at 89%
Potatoes	11 000	12 562	200	22.00	25.12
Onions	11 700	13 262	300	35.10	39.79
Dried fish	400	462	5000	20.00	23.13
Fresh fish	2 400	2 775	2000	48.00	55.50
Medical products	50 000 per ft^3	56 250 per ft^3	40 per ft^3	40.00 per ft^3	22.50 per ft^3
				165.10 (US $0.58 million)	166.04 (US $0.66 million)

[a] Tk 25 correspond to US $1.

The revenue from the irradiator at 80% and 90% capacity utilization, and with cold storage and warehouse facilities at 100% utilization, has been calculated as shown in Tables XXVI and XXVII.

Storage loss has been assumed to be 5% for potatoes and dried fish, 20% for onions and no loss for fresh fish. Therefore, total revenue for the first year equals 145.10 lakh + 267.23 lakh = 412.33 lakh (US $ 1.649 million). The total revenue per year in the years 2 to 20 equals 166.04 lakh + 267.23 lakh = 433.27 lakh (US $1.733 million).

The financial analysis of the operation shows that NPV at 15% is 725.03 lakh and that at 35% the NPV is still positive. The IRR of the project is 35.30% and the payback period is less than 4 years.

These calculations strongly suggest that a commercial irradiator integrated with warehouse facilities is a sound commercial proposition. The profitability of an irradiator operation improves if storage facilities are integrated with it. The break even analysis of the irradiator integrated with warehouse facilities gives the following data:

- Break even revenue — 224.87 lakh;
- Utilization — 51.90% of rated capacity at 90% utilization;
- Utilization — 46.71% of rated capacity;
- Hours of operation — 3365.

The above data indicate that operation for 3365 hours per year is needed to obtain a break even situation for revenue and costs.

TABLE XXVII. REVENUE FROM COLD STORAGE AND WAREHOUSES (at 100% capacity utilization)

Items	Quantity (t)	Selling price (Tk[a]/t)	Revenue (lakh)
Potatoes	1425	4 000	57.00
Onions	640	5 400	34.56
Dried fish	600	21 600	129.60
Fresh fish	95	48 500	46.07
		Total	267.23 (US $1.07 million)

[a] Tk 25 correspond to US $1.

3.2. Cost-benefit analysis

The analysis of an investment in an irradiator is on the basis of existing standards for commercial ventures in Bangladesh. From this analysis it has been concluded that installation of an irradiation facility near Dhaka is cost effective. A commercial irradiator has a large capital cost, requires an adequately large product throughput and has a low maintenance. It is clear that an adequate quantity of materials to be irradiated needs to be available. However, operation at about 50% of the rated capacity is sufficient to cover costs.

4. BENEFITS OF FOOD IRRADIATION

4.1. Savings in energy

Studies on the energy aspects of storage after irradiation of foods compared with the present practice of storage at low temperature shows that irradiation produces significant savings of energy. Table XXVIII presents the energy savings for irradiated products kept at different temperatures compared with refrigerated storage at 2°C for different outside conditions. Depending on the temperatures of the conditioned space and those on the outside, the energy savings vary from 30 to 83%. At the present cost of electricity, considerable savings on the cost for the preservation of food can be obtained by irradiation. The energy savings for storage of 1000 t of potatoes is about 90% if they are irradiated and stored at ambient temperatures instead of at 2°C [21].

TABLE XXVIII. ENERGY SAVINGS IN PERCENTAGE FOR IRRADIATED PRODUCTS KEPT AT DIFFERENT TEMPERATURES COMPARED TO REFRIGERATED STORAGE AT 2°C FOR DIFFERENT OUTSIDE CONDITIONS

Outside temperatures	Inside temperatures				
0°C	12°C	14°C	15°C	20°C	22°C
26	41.7	50	54.2	75	83.3
28	38	46	50	69.2	76.9
30	35.7	42.9	46.4	64.3	71.4
32	33	40	43.3	60	66.7
34	31	37.5	40.6	56.3	62.5
35	30	36.4	39.4	54.5	60.6

Figure 8 shows the variations of energy savings with different outside temperatures and conditioned space temperatures. One set of curves shows the variations in energy savings with various outside temperatures for constant conditioned space temperatures while the other set shows the same variations with various conditioned space temperatures for constant outside temperatures.

4.2. Social benefits

Adoption of irradiation processing in Bangladesh will provide a number of benefits.

4.2.1. More food available

Owing to the lack of other conventional food preservation technologies, such as canning, freezing and refrigeration, irradiation can reduce huge losses of both dried and fresh foods. The quantity so saved will improve the overall supply of food and save foreign currency.

4.2.2. Better quality of food

Irradiated foods are hygienically and nutritionally superior to those obtained with the methods available in the country. They are free from preservatives, microbial contaminations and pesticides. They retain their nutritive quality.

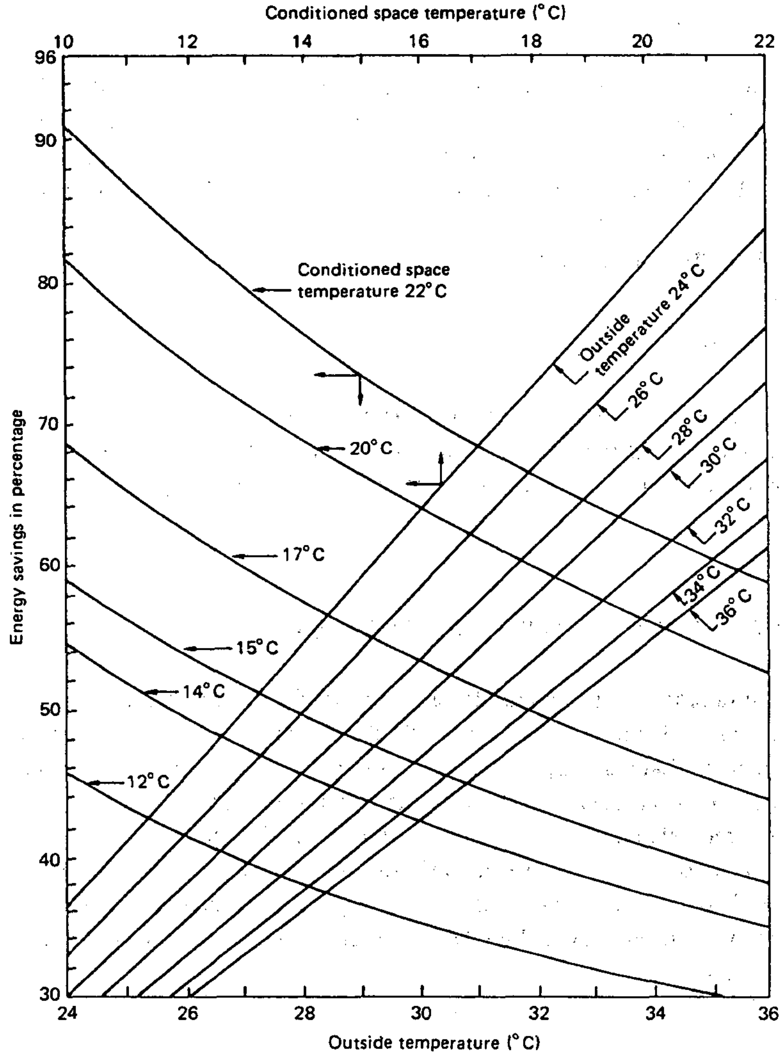

FIG. 8. Variations of energy savings with different outside temperatures and conditioned space temperatures.

4.2.3. Extension of storage period

Irradiation extends the storage period. Inhibition of sprouting in root and bulb foods increases possibilities for storing. Disinfestation of agricultural products and dried fish helps long term storage of these commodities. In a tropical country, such as Bangladesh, many seasonal foods preserved by irradiation will be available after their normal season is over.

4.2.4. *Improved distribution*

The production of some foods, e.g. fruits, vegetables and fish is localized. Owing to the lack of refrigerated transportation systems, good roads, railways and waterways and owing to the perishability, these fresh food products cannot be distributed. Irradiation extends the shelf life by at least three times and allows distribution of fresh food to the remotest corners of the country. This is particularly true for fresh fruits and fish in Bangladesh.

4.2.5. *Improved marketing*

After removal from cold storage, potatoes need to be marketed immediately because of severe sprouting. Irradiated potatoes, however, can be marketed without such problems. This could be true of other root and bulb crops.

5. DISCUSSIONS AND RECOMMENDATIONS

Considerable research and development work has been completed on irradiation technology for the preservation of food in Asian countries. Some of the countries, including Bangladesh, have done considerable work on semi-commercial-scale studies of irradiated potatoes, onions, pulses and dried fish. Bangladesh has special interest in the field because of the lack of suitable facilities for post-harvest preservation. Conventional food processing methods such as canning, freezing and refrigeration are almost non-existent for the home market. The brightest prospects for the introduction of irradiation in Bangladesh lie in the preservation of potatoes, onions and dried fish.

5.1. Potatoes

Potato production in the country could be increased with a view to reducing the pressure on rice consumption. The use of cold storage has increased tremendously and it is expected that this trend will continue. Storage in cold temperature (2°C) is expensive and energy consuming. Our studies show that untreated potatoes can be preserved at temperatures below 14°C. If demand develops for irradiated potatoes, the storage temperature can be raised to 14°C.

Precoolers used in cold storage constitute about 20% of the space of the cold rooms. These can be used for the storage of irradiated potatoes without any additional investment.

At present, establishment of a commercial irradiator in Dhaka is economically feasible. A cold storage capacity of over 37 000 t exists in and around Dhaka. Some of these facilities could easily be used only for irradiated potatoes. A potential for the processing of potatoes in Dhaka exists and we have now undertaken a project for the establishment of a commercial irradiator near this city.

5.2. Onions

Onion production in the country is more or less static. Owing to heavy storage losses and the lack of an effective post-harvest storage system, production cannot increase. Irradiation can improve the storage of onions and prevent at least 40–50% of the present losses. We have established that irradiated onions can be stored at room temperature.

5.3. Dried fish

Along with the upward trend in the production of marine fish, commercial fish drying is increasingly being carried out for export. The availability of an improved method for the preservation of dried fish is considered necessary. At present exporters of dried and salted fish store the product in cold storage at a cost of US $16.00/40 kg per month. With irradiation this expense may not be necessary.

Owing to insect infestation, losses of dried fish prepared for home consumption are about 45%. A low dose of gamma rays controls the insects. A packaging method also has been developed for prevention of reinfestation. The use of insecticides is both unhealthy and illegal. Laboratory and semi-commercial experiments have proved that radiation disinfestation is the only suitable method for preserving dried fish in Bangladesh [22, 23]. It is highly competitive with cold storage as used for export products. Traders have shown keen interest in the adoption of this process.

Frozen fish, shrimps and frog legs earn around Tk 2000 million per year. Rejection by the importing country because of contamination with pathogenic bacteria is a problem for the exporters. It is realized in the commercial circle that radiation can improve the microbial quality of the export products.

Experiments on the disinfestation of pulses have been carried out in Bangladesh. Radiation disinfestation reduces storage losses of these foods. Irradiation does not change the quality of those products that have been investigaged. Irradiation processing is highly beneficial in avoiding post-harvest losses of potatoes, onions, dried and cured fishery products. The process is economically feasible. Therefore, we recommend that action be taken for establishing commercial irradiators in Bangladesh in order to attain self-sufficiency in foods through control of post-harvest losses.

5.4. Proposed future programme of the Asian Regional Co-operative Project on Food Iradiation

We have now reached a very important phase of the Asian Regional Co-operative Project on Food Irradiation (RPFI). The following programme will enable the fulfilment of our research and development objectives for implementation of food irradiation technology in the countries of Asia and the Pacific:

(a) More activity in regional countries for commercialization of irradiation processing.
(b) Exchange of latest information for speedy implementation of the findings of the RPFI.
(c) Transportation studies on irradiated food among the regional countries.
(d) Prompt adoption of the standards for irradiated foods as recommended by the Codex Alimentarius Commission. This will help the regional trade in irradiated foods.

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