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PRESERVATION OF TROPICAL FOODSTUFFS BY IRRADIATION

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Preservation of foods by irradiation affords one of the most promising outlets for the peaceful use of atomic energy in Latin America. A large amount of food is lost annually due to microbial spoilage, insect infestation, enzymatic deterioration and other physiological changes. The usual methods to reduce such losses include treatments with various chemicals, storage, sanitation, and low temperature storage, among others. Any economy in the cost of food will be of great benefit to the world, especially in areas of high population and low food supply. However, any method of food preservation employed should ensure a final product of high nutritional quality. In this respect, irradiation stands up remarkably well.

The radiation preservation of foods may be accomplished either by radiation sterilization or radiation pasteurization. In radio sterilization the objective is to destroy spoilage organisms. If this is achieved, then the product, if properly packaged to prevent recontamination, may be kept without refrigeration for extended periods of time.

In the preservation of foods by radiation pasteurization, the product is exposed to relatively low doses of ionizing radiation to reduce the amount of spoilage microorganisms to such a level that product spoilage is delayed and its shelf-life is extended. In this case, post-irradiation refrigeration is usually needed to achieve the fullest benefit. The major successes in this field have been realized with fruits, for example, strawberries, oranges, sweet cherries, apples, peaches, papayas, bananas and mangoes.

A program in the preservation of tropical fruits and foodstuffs at the Puerto Rico Nuclear Center in Mayaguez has directed its attention to the use of irradiation to preserve tropical fruits. This Food Irradiation Project aims to determine the feasibility of radiation preservation to crops of importance in the tropics. Its emphasis has been placed on bananas, plantains and mangoes because of their potential importance in the United States market. These fruits and vegetables of great nutritional value are produced in Puerto Rico in large quantities. However, microbial spoilage and physiological breakdown limit their storage life. In addition, the mango is a valuable seasonal fruit which is available to market only for a few months each year.

Considerable work has been done at the Puerto Rico Nuclear Center on the general problem of radiation preservation, with emphasis on two main aspects: (*a*) To determine those factors of pre-irradiation condition, radiation dose, and post-irradiation treatment which produce maximal delay of ripening and extension of shelf-life; and (*b*) To evaluate the effect of radiation treatment on food quality, through chemical analysis for various factors.

As a part of this research, bananas of known age and variety (Montecristo) have been irradiated with from 10 to 50 Kilorad doses of gamma radiation. In all cases irradiation was done within 20 hours of fruit harvest. On the basis of daily

Puerto Rico Nuclear Center, Mayaguez, Puerto Rico. Operated by the University of Puerto Rico for the U.S. Atomic Energy Commission.

observations for ripening and chemical determinations done each week on irradiated and control fruit, the following general conclusions for this banana variety were drawn (Cf. Tables 1 and 2):

(1) A 5 to 6 day delay in ripening, that is, extension in shelf life, may be obtained when fruit are irradiated with 40 Krad doses and stored at 68° F. after irradiation treatment.

(2) Fruit age, i.e. the time between its formation at flowering and its harvest, is an important factor for this banana variety; fruit younger than about 100 days or older than 130 days do not show significant shelf life extension within normal storage temperatures.

(3) There is no appreciable loss of vitamin C in fruit given 40 Krad gamma doses.

(4) Changes in sugar content, starch, and total acidity correlate with observed ripening.

Similar studies have been carried out with plantains, (*Musa paradisica*) the so-called "cooking banana". This fruit is an important food source in the humid tropics and large quantities are shipped regularly to the United States mainland. Guayabero variety plantains were exposed to 0, 10, 15, 20, 25, or 30 Krad levels of gamma radiation. Remarkable retardation of ripening was induced at the 10-25 Krad levels. Delay in complete ripening (shelf-life extension) was about 9 days. This delay, coupled with the insignificant losses of vitamin content, indicated a very favorable response of plantains to radiation treatment (Cf. Tables 3 and 4). That there is a difference in the levels of radiation necessary to induce retardation of ripening in the plantain and the banana, though both plants belong to the same genus, is a very interesting problem and may possibly be used to clarify the mechanism of radiation effect. Experiments with mango varieties found in Puerto Rico have been conducted to determine the minimum and optimum doses of gamma irradiation. Mature or almost-ripe mangoes were selected and given 50, 100, 150 or 200 Kilorad gamma doses and then held at 68° F. The fruits were observed daily for ripening, softening or any other defects due to irradiation treatment. Chemical analysis for sugar, starch, acidity, ascorbic acid and crude carotenoids were done to supplement the visual and tactual determinations of ripening.

Mayaguezano variety mangoes treated with gamma radiation showed a storage life extension of about one week over non-irradiated controls. The 150 and 200 Kilorad treatments, while effecting retardation of ripening, caused considerable fruit softening and blackening of the skin. For this reason treatments above 100 Kilorads were eliminated and further investigations were conducted with lower dose treatments. This low dose range included 25, 50, 75 and 100 Kilorads. From these investigations it was established that 50–100 Kilorads of gamma irradiation retarded ripening for 5 to 7 days in Mayaguezano variety of mangoes stored at 68° F. room (Cf. Tables 5 and 6). At the same time, this dose range delayed the action of pathological organisms leading to decay of mango fruits.

Retardation of ripening is dependent on the stage of maturity of the fruit at the time of irradiation. In order to establish a parameter for ripeness, the ratio of the sugar to acid content of mangoes was selected as the best possible measure for prediction of irradiation response. Four distinct stages were selected for this experiment, very green but mature, green but mature, almost-ripe, and ripe. Chemical assays were done and the sugar/acid ratio (S/A value) and shelf-life extension determined. The results from these studies (Table 7) indicated that the sugar/acid ratio serves as a useful guide to permit a more precise basis for fruit selection for irradiation treatments.

The effect of a hot water-irradiation combination treatment on the Redondo variety mango was also studied. This treatment consisted of dipping almost-ripe fruits for 7 min. in 120° F water and then cooling for 7 min., followed by irradiation to 50, 75, or 100 Kilorad. Such treated fruits were kept in a 68° F storage room and examined periodically for appearance, texture, and chemically assayed for sugar, ascorbic acid, and acid content. Complete control of fruit spoilage due to anthracnose infection was obtained in the heat-irradiation combination treatments. In addition, these fruits retained a firmer texture than those irradiated only. As shown in Table 8 the combination treatment at these doses does not reduce the sugar or vitamin levels significantly, except at the 75 and 100 Krad doses, where roughly a 15 per cent decrease in ascorbic acid was noted.

Federal quarantine regulations exclude Puerto Rico's excellent mangoes from the continental United States, since most of the fruits have on their surface microorganisms the removal of which normally requires fumigation treatments. Such fumigation with ethylene dibromide may interfere with the normal ripening of the mango. However, the low doses of radiation used in radio pasterization are sufficient to inactivate or destroy most of the insect pests that attack mangoes. With this in mind, shipping experiments were conducted with Puerto Rican mangoes to explore the possibility of using low doses of gamma radiation to accomplish deinfestation and thus avoid fumigation treatment. Mango fruits in the almost-ripe stage were selected and irradiated at 0, 50, 75 and 100 Krad and then packed in a crate and sent by airfreight to Miami. After a short interval, the mangoes were returned to Puerto Rico by air. Chemical assays for sugar, ascorbic acid and acidity, were done before and after the air shipment. Doses of 50–100 Krad caused a delay in ripening of about half of the fruits during the travel period. This was a remarkable effort, since during this period the temperature under the crate was in the range of 82–84° F. During the first 4–5 days after shipment, the non-irradiated fruits developed symptoms of anthracnose disease. The irradiated fruits were free of these symptoms and maintained a firmer texture.

Without exception, the experimental results found in the Food Irradiation Program at the Puerto Rico Nuclear Center have indicated positive response to radiation treatment of the banana, plantain, and mango varieties studied. Utilization of such radio pasteurization offers such advantages as delayed ripening and hence decreased spoilage before marketing. In addition, chemical fumigation may be avoided, a particular advantage in these days of increasing awareness of chemical residues. The radiation has little or no adverse effect on vitamin content and nutritional quality of the product.

We feel encouraged as to the long-range future of radio pasteurized fruits of the "exotic" type such as mangoes grown here in the Caribbean and exported to the continental United States. To further research in this field of endeavor, we wish to extend to all of you the opportunity to use our facilities and know-how in this radio pasteurization technique.

TABLE 1

Content of sugar and acidity in bananas as function of dose and post-irradiation storage. Montecristo variety bananas approximately 115 days old at irradiation

Dose in Kr.	Days storage at 68°F.	gm. of total sugars per 100 gm pulp	ml. of NaOH required per 100gm.pulp	State of Bananas
0 ...	0	0.42	0.15	green
	11	2.20	0.24	light green
	25	47.00	0.32	ripe
25 ...	0	0.43	0.18	green
	11	2.32	0.21	light green
	25	50.00	0.48	ripo
30 ...	3	2.02	0.23	green
	11	3.00	0.29	light green
	25	41.20	1.68	ripe
35 ...	3	2.50	0.22	green
	13	2.08	0.18	light green
	25	33.80	0.46	ripo
40 ...	3	2.05	0.25	green
	13	3.40	0.17	light green
	25	43.00	0.13	ripe

TABLE 2

Content of ascorbic acid and carotene in bananas as function of dose and post-irradiation storage

Montecristo variety bananas approximately 115 days old at irradiation

Dose in Kr.	Days storage at 68°F.	mg. of ascorbic acid per 100 gm. pulp	mg. of earotene per 100 gm. pulp	State of Bananas
0	0	17.28	18	green
	11	17.40	47	light green
	25	7.15	49	ripo
25 ...	0	17.67	21	green
	11	18.35	29	light green
	25	10.15	40	ripe
30	3	16.58	52	green
	11	21.45	27	light green
	25	12.57	40	ripe
35 ...	3	16.47	16	green
	13	20.05	32	light green
	25	11.15	51	ripe
40 ...	3	10.93	43	green
	13	21.00	24	light green
	25	8.80	28	ripe

Table 3

Content of starch, sugar, and acidity in plantains as function of dose and post-irradiation storage.

Guayabero Variety, Batch No. 4

Dose in Kr.	Days storage at 68°F.	gm of starch per 100gm of pulp	gm of sugar per 100gm pulp	Ml of NaOH required per 100gm pulp
0 ...	0	27.0	0.88	0.11
	11	27.5	4.08	0.27
	20	5.6	32.00	1.40
10 ...	0	23.4	0.82	0.14
	11	23.2	3.40	0.22
	20	10.2	72.40	1.39
15 ...	3	38.2	2.96	0.18
	12	32.5	2.44	0.25
	21	25.0	40.00	1.19
20 ...	3	16.2	2.30	0.18
	12	22.5	2.92	0.22
	21	10.0	36.00	1.33
25 ...	3	31.2	2.90	0.18
	12	26.5	3.48	0.23
	21	28.0	48.80	1.15

Table 4

Content of ascorbic acid and carotene in plantains as function of dose and post-irradiation storage.

Guayabero Variety, Batch No. 4

Dose in Kr.	Days storage at 68°F.	mg of ascorbic acid per 100gm of pulp	mg of carotene per 100gm of pulp	State of Plantain
0 ...	0	30.2	136	green
	11	24.3	147	light green
	20	23.4	204	ripe
10 ...	0	39.2	94	green
	11	18.6	200	light green
	20	22.2	155	ripe
15 ...	3	20.0	164	green
	12	22.4	196	light green
	21	27.0	160	ripe
20 ...	3	20.8	176	green
	12	21.6	172	light green
	21	19.7	135	ripe
25 ...	3	20.8	146	green
	12	22.4	176	light green
	21	19.7	136	ripe

TABLE 5

Content of starch, sugar, and acidity in mangoes as a function of dose and post-irradiation storage.

Mayaguezano Variety, Batch No. 19

Dose in Kr.	Days storage	gm of starch per 100gm of pulp	gm of sugar per 100gm pulp	State of mango assayed	ml of NaOH required per 100 gm pulp	State of mango assayod
0 ...	0	11.00	6.7	green	2.21	green
	12	0.40	33.6	ripe	0.23	ripe
50 ...	0	11.90	5.5	green	2.20	green
	12	0.50	33.2	light green	0.52	ripe
100 ...	0	11.13	4.7	green	2.16	green
	12	0.40	28.8	light green	0.36	ripe
150 ...	3	9.25	10.4	green	2.38	light green
	12	0.59	36.0	ripe	0.79	light green
200 ...	3	6.40	14.5	light green	2.27	green
	12	0.45	33.2	light green	0.52	ripe

TABLE 6

Content of ascorbic acid and of carotene in mangoes as a function of dose and post-irradiation storage.

Mayaguezano Variety, Batch No. 19

Dose in Kr.	Days storage at 68°F.	mg of ascorbic acid per 100gm of pulp	State of mango assayed	mg. of carotene per 100gm of pulp	State of mango assayed
0 ...	0	125.5	green	128	green
	12	67.0	ripe	352	ripe
50 ...	0	113.0	light green	113	green
	12	83.3	ripe	158	light green
100 ...	0	102.2	light green	71	green
	12	51.2	ripe	268	light green
150	3	99.0	light green	84	green
	12	106.2	light green	352	ripe
200 ...	3	111.0	green	111	light green
	12	76.0	ripe	296	light green

TABLE 7

Shelf-life extension of irradiated mangoes (Mayaguezano variety) as function of sugar: acid ratio of fruits at irradiation time

Storage conditions: 68 °F. 80%RH

Batch Number	Dose in Kr.	Visual state of fruits at harvest	SUGAR: ACID RATIO		Shelf-life extension in days
			Average	Range	
31 ...	0	green, but mature	1.40*	1.02– 1.77	—
	25				6
	50				8
	100				7
32 ...	0	green, but mature	1.42†	1.25– 1.72	—
	25				8
	50				8
	100				8
33 ...	0	almost ripe	3.00*	2.34– 3.62	—
	25				4
	50				6
	100				6
34	0	ripe	50.3†	45.57–57.0	—
	25				0
	50				0
	100				0

*Based on 4 separate determinations.

†Based on 3 separate determinations.

TABLE 8

Content of sugar, ascorbic acid and acidity in irradiated and/or heat dipped "Redondo" mango (12 fruits per treatment).

Treatment	Days of storage at 68°F.	State of mango assayed	gm. of sugar per 100gm pulp	mg. of ascorbic acid per 100gm pulp	ml. NaOH per 100gm pulp
A. Non-dipped, non-irradiated	0	green	7.3	84.5	1.99
	8	ripe	30.0	96.2	1.14
	16	ripe	31.0	61.0	0.29
B. Hot water dipped, non-irradiated ...	0	green	9.2	73.5	2.52
	8	ripe	32.0	79.8	2.02
	16	ripe	27.5	50.5	0.29
C. Non-dipped, 50 Krad dose	0	green	4.8	66.0	3.40
	8	ripe	37.2	80.6	1.66
	16	ripe	26.5	65.4	0.45
D. Hot water dipped, 50 Krad dose ...	0	green	11.5	77.0	2.77
	8	light green	25.0	101.4	1.51
	16	ripe	19.5	68.8	0.35
E. Non-dipped, 75 Krad dose	0	green	8.2	88.7	3.28
	8	light green	34.8	104.8	2.19
	16	ripe	22.5	62.0	0.31
F. Hot water dipped, 75 Krad dose ...	0	green	10.2	58.2	4.07
	8	light green	33.5	90.0	1.31
	16	ripe	36.5	53.6	0.31
G. Non-dipped, 100 Krad dose	0	green	8.0	87.3	3.06
	8	ripe	40.0	106.1	2.16
	16	ripe	22.0	55.1	0.36
H. Hot water dipped, 100 Krad dose ...	0	green	8.5	73.2	2.34
	8	light green	24.0	99.8	2.02
	16	ripe	21.5	58.5	0.70