Technology Section

Pakistan J. Sci. Ind. Res., Vol. 15, Nos. 4–5, August–October 1972

INDUCTION OF RIPENING DELAY IN MANGOES (VAR. DUSEHRI) BY GAMMA IRRADIATION AND REFRIGERATION

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(Received March 10, 1972)

Abstract. Effect of gamma irradiation alone and in combination with curing (pal) and refrigeration was studied for causing delay in ripening of 'dusehri' mangoes. Biochemical and physiological parameters investigated during storage included ethylene production, pectic substances, ascorbic acid, sugars, acidity, total carotenoids and total soluble solids. A radiation dose of 30 Krad was found to be optimum for causing a ripening delay of 7 days in mangoes when stored at room temperature (35–38°C). Visual observations revealed that refrigeration did not appear to have any added benefit with irradiation for extending the shelf life of this fruit. Both irradiated and unirradiated mangoes ripened normally under various curing conditions, although the delaying effect of irradiation was maintained. *Aspergillus niger* and *A. flavus* were primarily responsible for the spoilage of mangoes.

Mango (*Mangifera indica*) is one of the abundantly grown fruits and is an important dietary source because it contains appreciable quantities of vitamins and minerals. The fruit is rapidly acquiring importance as an export item. Mango is a highly perishable commodity and needs ultimate disposal within 5–7 days after picking. This short market life is a limiting factor in its export and extended local distribution.

The utility of ionizing radiations in causing a ripening delay in mangoes has been examined by various workers.[1–6] Present investigation included following objectives: (i) to examine the suitability of 'dusehri' mangoes for processing by gamma irradiation and to determine an optimum radiation dose for causing a ripening delay; (ii) to determine the effect of optimum radiation dose on curing characteristics and to find out the best curing treatment for this fruit; (iii) to determine whether refrigeration in combination with irradiation has any additive or synergistic effect on the shelf life extension of 'dusehri' mangoes; and (iv) to study the behaviour of irradiated mangoes under actual market conditions. The findings on the above mentioned objectives are reported.

Materials and Methods

Fully mature in size but still green in colour, 'dusehri' mangoes were procured from the Punjab Agricultural Research Institute, Lyallpur, and were carefully sorted for uniformity of size, colour and free from damage. The mangoes were transported to Atomic Energy Centre, Lahore, and a gamma cell 220 was used for irradiation,[7] the dose rate being 4 Krad/min. They were transported back to NIAB Lyallpur for storage and further analyses.

Part I. Irradiation was carried out at 0, 10, 20, 25, 30, 35, 50 and 60 Krad. Mangoes of each treatment were stored at room temperature (35–38°C, R. H. 75–90%) in perforated wooden-crates with a single layer of fruits at the bottom.

Part II. Mangoes were processed at 30 Krad (optimum dose determined in the first part). The irradiated and control mangoes were treated as follows: (i) kept one row over another in wooden boxes having a layer of wheat straw at the bottom and lined with newspaper sheets. This treatment is termed as 'curing' commonly called as 'pal'. These boxes were then placed in the basement of the building (37–40°C, R.H., 80–96%); (ii) packed as above and placed in an air-conditioned laboratory (28°C, R.H. 80–85%); (iii) placed in a refrigerator (5°C); (iv) placed in an incubator at 40°C and the atmosphere was saturated with water vapours (100% R.H.); and (v) packed as in (i) and placed in a city market shop (39–42°C, R.H. 80–90%).

For biochemical analyses, four fruits from each treatment were selected at random, peeled, cut into small pieces and homogenized in a Waring blender. Aliquots from this pool were used for analysing ascorbic acid, total soluble solids (T.S.S.) and titratable acidity, according to the methods described in A.O.A.C.[8] Total carotenoids were determined as reported by Higby.[9] Sugars were determined colorimetrically after Ting.[10] Pectic substances were determined by the method of Rouse and Atkins.[11] For ethylene determination method of Young *et al.*[12] was followed in which it was trapped in mercuric perchlorate solution and released by 10M LiCl and determined using Warburg's respirometer.

Ripening studies were conducted by visual observations. Organoleptic evaluations were carried out by a panel of 20 judges using a hedonic scale rating.[13]

Statistical analyses of the data was carried out by the analysis of variance technique.[14] For isolation of spoilage fungi, Czapek dox agar and malt-extract agar were used. The medium was prepared by adding 2% agar to 200 g of mango slices and autoclaved at 15 lb/in^2 pressure for 15 min. A standard amount of inoculum was placed at the centre of poured petri plates, incubated at 28°C and colony diameter measured after 48 hr intervals.

Results and Discussion

Visual Observations. The ripening trend of mangoes is given in Fig. 1. No difference could be detected between control and irradiated mangoes up to second day of storage. After that, the unirradiated samples started developing yellow colour, the pulp became soft and they were fully ripe on the fifth day. The irradiated mangoes were still hard and green. The mangoes irradiated with 30–35 Krad showed a delayed ripening up to 14 days of storage while untreated mangoes had shrivelled, decayed and were not fit for consumption. There was progressive deterioration with an increase in radiation dose beyond 35 Krad as evidenced by more spotting and an early texture deterioration. Similar effects of irradiation were reported by Dharkar *et al.*[3] and Ali *et al.*[5] while working on 'alphanso' (25 Krad) and 'desi' (30 Krad) varieties of mangoes respectively, but Mathur and Lewis[1] found that 12 Krad was an optimum dose for causing a delay in ripening for 8 days in 'alphanso. Herrera and Valencia[2] reported lower radiosensitivity of 'filipino' (variety carabao) as compared to Indian mangoes. Hossain *et al.*[6] did not find any delay of ripening in 'fazli' irradiated up to 30 Krad but spoilage was slightly reduced. This may be due to the advanced physiological stage of the fruit prior to irradiation.

It was observed that due to refrigeration, a delay in ripening effect was obtained up to a maximum period of 21 days in both control and irradiated mangoes. After that period, the unirradiated mangoes underwent skin shrivelling while irradiated ones were still better. Upon subsequent curing, a normal yellow colour developed at the same time in both the cases but skin shrivelling was clearly visible. Curing under various conditions revealed that both irradiated and unirradiated mangoes ripened normally. The mangoes placed in an incubator at 40°C and saturated with water vapours were best in general appearance and other quality attributes. Unirradiated mangoes placed at city shops were ripe after 4 days while irradiated ones ripened on 10th day.

Pectic Substances. Some of the most marked changes during ripening occur in the walls of fruit cells resulting in the softening of the fruits. The effect of radiation and other treatments on different pectin fractions and total pectin was studied because these are related to texture development during maturation of fruits. There was an increase in the water

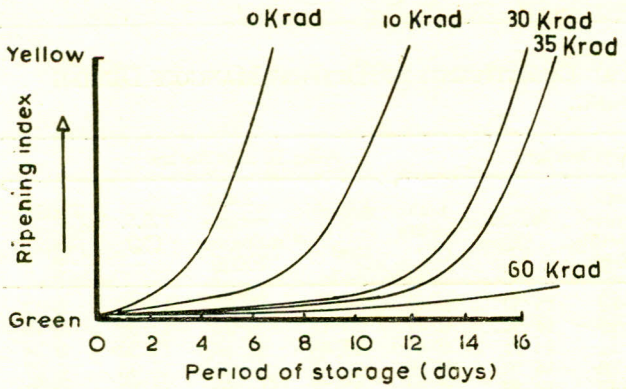

Fig. 1. An arbitrary expression of ripening behaviour of irradiated and unirradiated mangoes. (60 Krad samples although were green in colour underwent a texture deterioration hence observations discontinued.)

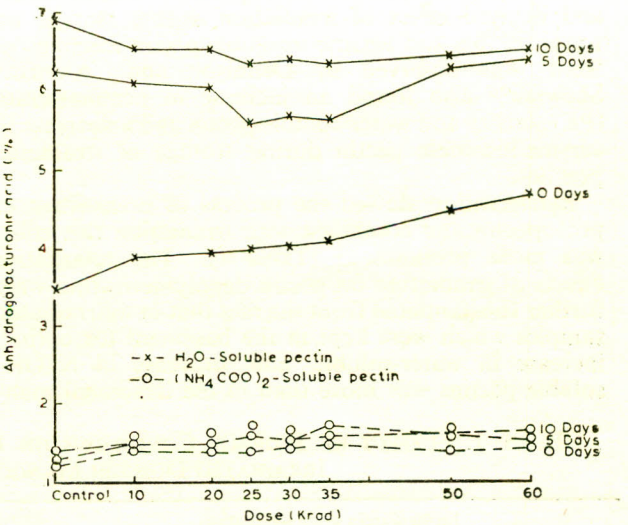

Fig. 2 (a) The effect of gamma radiation on H_2O-soluble and $(NH_4COO)_2$-soluble pectin of ripening mangoes at room temperature.

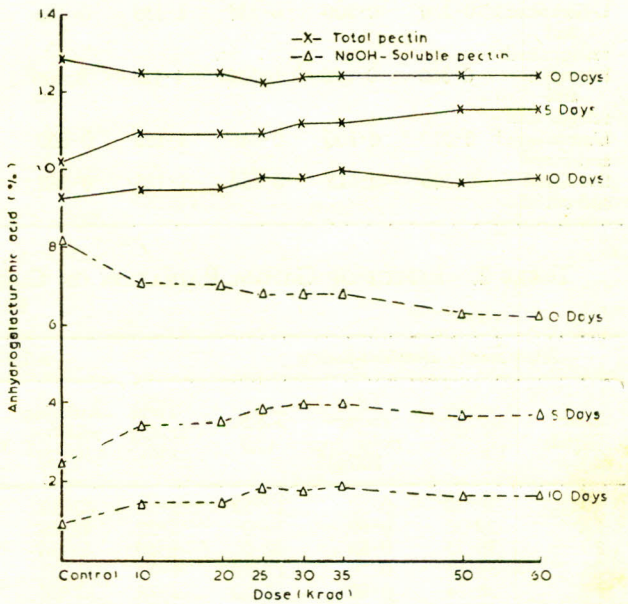

Fig. 2 (b). The effect of gamma radiation on sodium hydroxide-soluble and total pectin of ripening mangoes at room temperature.

and ammonium oxalate soluble pectins and decrease in NaOH and total pectin during ripening of mango (Fig. 2 a and b, Table 1). This clearly indicates that protopectin was gradually converted to pectates and pectinates during ripening and the effect was statistically significant on either side. Thus degradation of higher molecular weight pectins to lower molecular weight ones is associated with ripening process.[15] Just after irradiation mangoes contained higher water-soluble and lower NaOH-soluble pectins as compared to unirradiated fruits. This may be due to the direct effect of irradiation. The delay in ripening observed due to irradiation during storage was reflected in less increase in water-soluble pectin and comparatively less decrease in NaOH-soluble pectin. Similar direct and delayed effect of irradiation during storage on water-soluble and versine-insoluble pectin fractions of 'kent' was observed by Dennison and Ahmed.[4] Shewfelt[16] also found an increase in pectinesterase (PE) activity and water-soluble pectin and a decrease in versine-insoluble pectin during storage of irradiated peaches.

Refrigeration slowed the process of breakdown of protopectin and combined with irradiation this effect was more pronounced (Table 1). The retardative effects of irradiation on pectin depolymerization were further substantiated from the fact that in unirradiated samples which were kept in the basement for curing, increase in water-soluble and decrease in NaOH-soluble pectins was more than in the irradiated mangoes. Shewfelt[16] while working on irradiation of peaches found that low temperature storage had reduced the rate of increase in PE activity and water-soluble pectin. This may be due to the inhibiting effect of low temperature on ripening process of fruits.

Ascorbic Acid. A slight decrease was observed in vitamin C contents of irradiated samples as compared to control (Table 2). Ascorbic acid initially increased slightly and then decreased during subsequent storage. A slight decrease due to irradiation in vitamin C contents of different varieties of mangoes has been reported by various workers.[1,2,3,5] Refrigeration considerably reduced the loss in ascorbic acid content during ripening of the fruit while there was no significant loss in this constituent due to curing (Table 4).

Total Carotenoids. The data on total carotenoids (Table 2) determined immediately after irradiation indicate a dose-dependent increase in carotenoids. There was a rapid increase in this content during storage and this increase was more in the irradiated fruits than in the untreated ones. The carotenoids increase naturally during ripening process but it is difficult to explain why the net contents increased due to irradiation. This may be due to increased extractability of carotenoids rather than net synthesis. Our results are in agreement with the findings of Dharkar *et al.*[3], Ali *et al.*[5] and Hilker and Wong[17] who studied the effect of irradiation on carotenoid synthesis during ripening of different varieties of mangoes. It is also clear from Table 4 that refrigeration and curing did not

TABLE 1. EFFECT OF STORAGE CONDITIONS ON DIFFERENT PECTIN FRACTIONS AND TOTAL PECTIN OF IRRADIATED DUSEHRI MANGOES (AGA %) DURING RIPENING.

Treatment	Immediately after irradiation				After 5 days storage				After 10 days storage			
	H_2O-soluble	$(NH_4COO)_2$-soluble	NaOH-soluble	Total pectin	H_2O-soluble	$(NH_4COO)_2$-soluble	NaOH-soluble	Total pectin	H_2O-soluble	$(NH_4COO)_2$-soluble	NaOH-soluble	Total pectin
Unirradiated and refrigerated	0·310	0·100	0·745	1·155	0·420	0·110	0·560	1·090	0·430	0·110	0·500	1·040
Irradiated and refrigerated	0·360	0·115	0·650	1·125	0·400	0·115	0·600	1·115	0·400	0·120	0·580	1·100
Unirradiated and cured	0·310	0·100	0·745	1·155	0·600	0·110	0·290	1·000	0·615	0·115	0·090	0·820
Irradiated and cured	0·360	0·115	0·650	1·125	0·560	0·120	0·400	1·080	0·600	0·125	0·175	0·900

TABLE 2. EFFECT OF GAMMA RADIATION ON CHEMICAL CONSTITUENTS OF DUSEHRI MANGOES DURING RIPENING.

Dose (Krad)	Immediately after irradiation				After 5 days storage				After 10 days storage			
	Ascorbic acid (mg/100 g)	Total carotenoids (mg/100 g)	T.S.S. (%)	Total acidity (%)	Ascorbic acid (mg/100 g)	Total carotenoids (mg/100 g)	T.S.S. (%)	Total acidity (%)	Ascorbic acid (mg/100 g)	Total carotenoids(mg/100 g)	T.S.S. (%)	Total acidity (%)
0	39·50	0·70	12·50	1·12	42·50	6·80	15·50	0·42	35·60	10·00	18·50	0·12
10	39·30	0·60	12·0	1·22	42·36	6·90	15·50	0·47	34·17	10·24	17·50	0·19
20	39·75	0·60	12·0	1·20	40·46	7·20	14·75	0·47	34·48	12·50	17·50	0·24
25	39·85	0·70	12·50	1·10	41·07	7·60	14·50	0·58	34·22	14·40	17·00	0·27
30	38·85	0·80	12·50	1·10	41·08	7·60	14·50	0·54	33·78	14·40	16·50	0·27
35	39·42	0·90	12·0	1·20	40·19	8·00	14·50	0·52	34·50	14·80	17·00	0·29
50	38·07	1·00	12·0	1·10	41·60	9·00	15·00	0·55	34·43	15·00	16·50	0·27
60	38·50	1·20	12·50	1·18	40·60	9·50	14·50	0·59	33·45	16·00	17·0	0·26

influence carotenoid formation and it increased in spite of refrigeration and curing of irradiated mangoes.

Ethylene Determination. In unirradiated mangoes maximum ethylene was produced on fifth day after storage (Fig. 3). This was followed by a decline until the observations were discontinued. Fruits irradiated at 10 Krad showed an increased production of ethylene when compared with the control. However, higher radiation doses (20–60 Krad) resulted in a suppression of ethylene production and this suppressive effect was more pronounced in 50–60 Krad irradiated samples. It is now known that ethylene plays a vital role in the process of ripening and this gas triggers a multitude of complex biochemical changes.[18] Smock and Sparrow[19] showed that doses of 20–40 Krad of gamma rays decreased ethylene production in postclimacteric apples. Pears irradiated at climacteric peak showed a decreased rate of ethylene production and 300–400 Krad doses inhibited the ripening of this fruit.[20] Irradiation has slowed down the production of this gas in mangoes also, thereby causing a ripening delay.

Sugars, Total Soluble Solids and Acidity. There was no immediate effect of irradiation on these constituents of mangoes (Tables 2, 3). Alongwith ripening process total sugars and T.S.S. increased while acidity decreased because of utilization of organic acids either for sugar synthesis or in respiration. The increase in sugars and T.S.S. is at the expense of starch which disappears during ripening of mangoes.[21,22] Increase in T.S.S. and decrease in acidity are indices of ripening. Retardative increase in T.S.S. and decrease in acidity in irradiated mangoes was due to the delay in ripening. Similar effect of irradiation on these constituents were reported by Dharker *et al.*[3] and Ali *et al.*[5] on 'alphanso' and 'desi' respectively. Refrigeration supplemented the effect of irradiation on these constituents but curing had no such effect (Tables 4, 5).

Organoleptic Evaluation. Organoleptic evaluation of all the mangoes was carried out after 13 days storage. The mean score values, as determined on hedonic scale, are presented in Fig. 4. Samples irradiated at 30–35 Krad scored the maximum in acceptability while unirradiated samples were extremely disliked because they were shrivelled and decayed. The panel of judges could not find any undesirable effect at the optimum dose of irradiation. Samples irradiated at higher doses (50–60 Krad) were not liked by the judges due to their deleterious effect on the texture of fruit. Similar reponse of judges to irradiated 'desi' was observed by Ali *et al.*[5]

Microbiological Observations. Aspergillus niger and *Aspergillus flavus* were isolated from the decaying mangoes. Unirradiated samples were completely decayed 10 days after storage. The rate of growth of these fungi as determined by colony diameter, was significantly higher on medium prepared from irradiated mangoes. The results of these studies on *Aspergillus niger* are reported in Fig. 5. These fungi

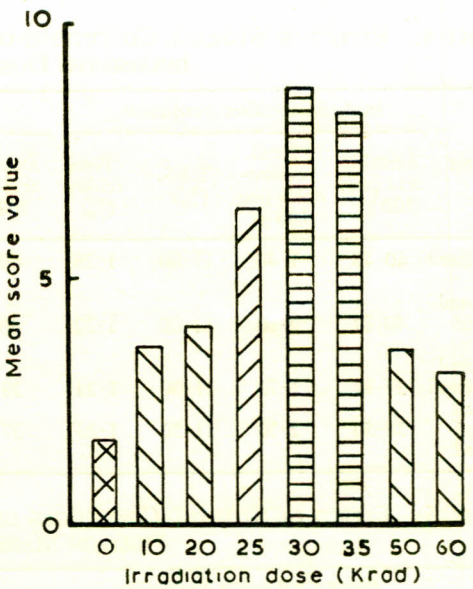

Fig. 4. Hedonic scalerating for mangoes, irradiated at different doses, after 13 days of storage. (Similar line pattern show nonsignificant differences, while dissimilar pattern show significant at 1% level.)

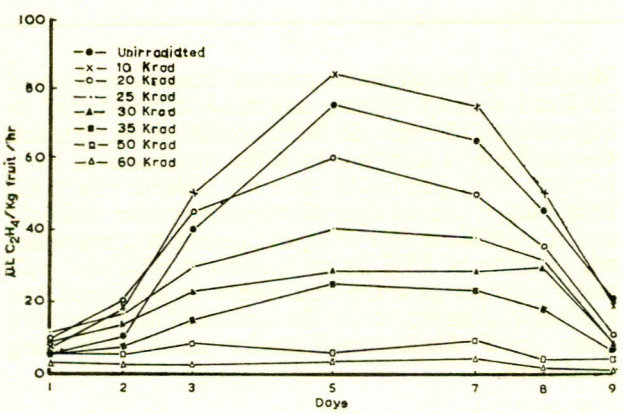

Fig. 3. Effect of gamma radiation on C_2H_4 production by mangoes.

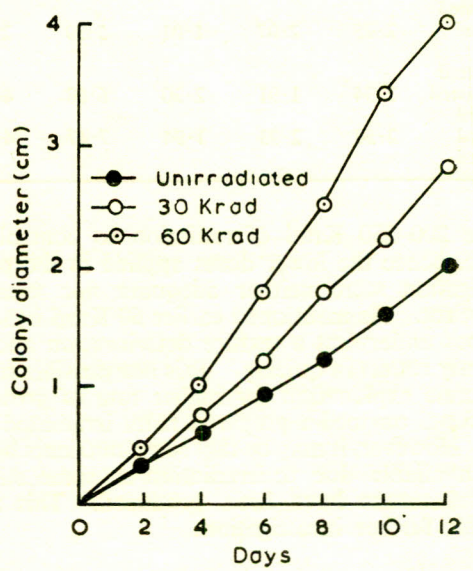

Fig. 5. Growth of *Aspergillus niger* on medium prepared from unirradiated and irradiated mangoes.

TABLE 3. EFFECT OF GAMMA RADIATION ON SUGAR CONTENTS (%) OF DUSEHRI MANGOES DURING RIPENING.

Dose (Krad)	Immediately after irradiation				After 5 days storage				After 10 days storage			
	Fructose	Glucose	Sucrose	Total sugars	Fructose	Glucose	Sucrose	Total sugars	Fructose	Glucose	Sucrose	Total sugars
0	3·13	1·47	2·42	7·15	3·45	3·32	5·87	12·97	3·81	3·69	7·26	14·58
10	2·66	1·17	2·39	6·35	3·45	3·73	5·70	13·19	3·77	3·95	5·90	13·94
20	3·31	0·86	2·68	7·00	3·80	3·27	5·81	13·19	3·33	3·21	7·03	14·04
25	2·88	1·41	1·78	6·17	3·74	4·08	5·30	13·40	4·22	4·14	5·60	14·26
30	2·83	1·20	2·41	6·57	4·03	3·58	5·70	13·62	3·84	4·95	5·30	14·37
35	2·76	1·48	2·35	7·72	3·78	3·62	5·80	13·51	5·12	4·74	4·07	14·15
50	2·32	1·85	2·34	6·64	4·03	4·65	4·18	13·08	3·83	4·10	6·11	14·37
60	2·59	0·91	2·30	6·93	3·34	4·27	4·99	12·87	4·00	4·47	5·60	14·37

TABLE 4. EFFECT OF STORAGE CONDITIONS ON VARIOUS CHEMICAL CONSTITUENTS OF UNIRRADIATED AND IRRADIATED DUSEHRI MANGOES DURING RIPENING.

Treatment	Immediately after irradiation				After 5 days storage				After 10 days storage			
	Ascorbic acid (mg/ 100 g)	Total carote-noids (mg/ 100 g)	T.S.S. (%)	Total acidity (%)	Ascorbic acid (mg/ 100 g)	Total carote-noids (mg/ 100 g)	T.S.S. (%)	Total acidity (%)	Ascorbic acid (mg/ 100 g)	Total carote-noids (mg/ 100 g)	T.S.S. (%)	Total acidity (%)
Unirradiated and refrigerated	40·48	1·40	11·00	1·28	40·37	2·70	14·50	0·52	38·83	4·10	15·00	0·46
Irradiated and refrigerated	40·87	2·60	11·00	1·22	40·21	3·60	14·00	0·73	38·12	5·20	14·50	0·56
Unirradiated and cured	39·87	1·70	11·00	1·24	38·14	8·00	17·00	0·14	33·92	8·20	18·00	0·12
Irradiated and cured	39·50	2·70	11·50	1·23	37·37	8·90	16·50	0·19	32·70	10·00	17·50	0·19

TABLE 5. EFFECT OF STORAGE CONDITIONS ON SUGAR CONTENTS (%) OF UNIRRADIATED AND IRRADIATED DUSEHRI MANGOES DURING RIPENING.

Treatment	Immediately after irradiation				After 5 days storage				After 10 days storage			
	Fructose	Glucose	Sucrose	Total sugars	Fructose	Glucose	Sucrose	Total sugars	Fructose	Glucose	Sucrose	Total sugars
Unirradiated and refrigerated	2·58	2·06	1·22	5·93	3·53	2·69	1·15	7·44	3·65	2·57	1·92	8·25
Irradiated and refrigerated	2·25	2·07	1·01	5·39	2·44	4·63	1·52	8·68	4·29	2·74	2·04	8·58
Unirradiated and cured	2·34	1·91	2·30	6·68	4·15	3·25	4·27	11·90	4·84	3·95	6·55	14·69
Irradiated and cured	2·50	2·93	1·94	7·47	4·42	3·30	4·54	12·50	4·79	4·54	5·23	14·84

require 200–250 Krad of radiation to control their growth, hence the lower doses applied in the present investigation were neither adequate nor meant to control rot. As mentioned earlier 60 Krad irradiated mangoes underwent a texture deterioration and consequently rot set in quickly. It is not possible to offer a concrete explanation for higher rate of growth of these fungi on media prepared from irradiated mangoes. However, it may be that some nutrients became more available due to irradiation or some stimulatory substances have been produced. This aspect warrants further investigation.

Conclusion

(1) A ripening delay of one week can be caused in 'dusehri' by an optimum gamma irradiation dose of 30 Krad without causing any adverse nutritional or organoleptic changes. (2) Refrigeration alone extended the shelf life of mangoes by three weeks and in combination with irradiation had no additive effect. (3) Irradiated mangoes ripened normally under ordinary curing conditions, but delay in ripening was maintained. Curing at 40°C in an incubator saturated with water vapours gave the best results in irradiated and unirradiated mangoes. (4) The irradiated mangoes were quite good when stored under actual marketing conditions.

Acknowledgement. The help of Mr. Farooq Maqsood for statistical analyses of the data is highly appreciated.

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