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Preservation of Apples by Irradiation

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ABSTRACT

'Granny Smith' apples were irradiated with 0·43 and 0·65 kGy of ^{60}Co in a semi-industrial plant, in order to verify: (a) the effectiveness of this treatment for increasing their storage life under refrigeration temperatures (4 ± 3)°C and normal atmosphere and (b) the tolerance of this fruit to the disinfestation treatment.

Physico-chemical and sensory analyses were undertaken for the 6 months storage time. Weight loss, pH, acid content, soluble and total pectins, texture and volatile compound determinations showed no improvement in the shelf life due to the applied treatment. Irradiation affected external odour, flavour and general acceptability, but not external and internal appearance, internal odour or texture (sensory test).

Irradiated apples exhibited an increased susceptibility to 'superficial scald', a disease characterized by dark spotting on the pericarp.

INTRODUCTION

The purpose of this work was to verify the effectiveness of gamma radiation from ^{60}Co in extending apple shelf life under refrigeration and normal atmosphere as well as to evaluate whether these irradiation doses, which are within the range for disinfestation treatment, had any deleterious effect on the fruit itself. This first subject has already been studied by many investigators whose final conclusions on its feasibility do not always agree

(Massey *et al.* 1964; Rogachev, 1966; Clarke, 1968; Thomas & Sreenivasan, 1970; Tobback *et al.* 1973).

With regard to the second subject, this treatment has been found suitable by Moy *et al.* (1983) for disinfestation of stone fruits from 'Mediterranean fly', and by Rigney *et al.* (1985), for disinfestation of 'Granny Smith' apples from 'Mediterranean fly', 'codling moth' and 'Queensland fly'.

We carried out physico-chemical and sensory evaluations on control and irradiated samples so as to verify whether some undesired modifications had taken place, such as changes in colour, odour, flavour or softening. These drawbacks are dose-dependent (Drake *et al.*, 1960; Johnson *et al.*, 1965; Merkley *et al.*, 1968; Pablo & Manalo *et al.*, 1971) and can be minimized by an appropriate selection of the energy employed.

MATERIALS

'Granny Smith' apples, harvested in the Río Negro valley, were packed in board boxes without being waxed or wrapped, and conveyed by truck, under refrigeration, 1000 km to the Ezeiza Atomic Center, Buenos Aires. There, the fruits were arranged in commercial wood cases and kept at (4 ± 3)°C for 24 h until irradiated in a ^{60}Co semi-industrial plant, with doses of $(0{\cdot}43 \pm 0{\cdot}03)$ kGy* and $(0{\cdot}65 \pm 0{\cdot}03)$ kGy, respectively, with a dose rate of (90 ± 10) Gy/h. Dosimetric techniques used were Fricke for the first dose and ferrous sulphate–cupric sulphate for the second.

Control and irradiated samples remained under the cold storage conditions already mentioned during the whole experiment, under normal atmosphere. Also, a small group of control and irradiated fruits was kept at room temperature (between 20 and 25°C) in board boxes.

METHODS

Physico-chemical analyses were performed once a fortnight for 6 months on samples consisting of six apples each, from control and irradiated lots kept under cold storage.

The following determinations were carried out:

(1) Weight loss: some fruits were identified, weighed and kept for further weight measures throughout the storage time.
(2) pH: pH meter measurement.

* kGy or kilo Gray = 10^3 Gray (Gy). Gy is the unit of absorbed dose of ionizing radiation, being equal to one joule of energy absorbed per kilogram of matter undergoing irradiation.

(3) Acid content: expressed as malic acid, titrimetric determination with NaOH 0·1N until pH 8·25.
(4) Total pectins: by ethanol digestion, filtering and heating of the resulting residue to constant weight in a vacuum stove at 50°C overnight.
(5) Soluble pectins: measured as galacturonic acid, method of McCready & McComb (1952).
(6) Volatiles: by gas–liquid chromatography of the headspace from glass desiccators containing 4–6 whole apples. These were submitted to partial vacuum and were left standing for 2 h at room temperature so as to reach equilibrium, before measurements were made. Column: 10% Carbowax 20 M on Chromosorb W-HP, 80/100 mesh, 2 m. Injector temperature = detector temperature = 200°C. Column temperature: from 60°C to 120°C, with a heating rate of 3°C/min. Gas carrier: N_2, with a flow rate of 30 ml/min. Injected volume: 1 ml.
(7) Texture: apples were compressed on their equator by means of a 15 cm diameter disc with an Instron Universal Testing Machine. Samples consisted of six fruits each. The force necessary to cause cracking of the fruit was measured, under standardized conditions of compression speed, and the resulting deformation was also put down.

On those apples stored at room temperature, only weight loss determination was performed.

These results were statistically analyzed by means of a Student '*t*' test ($p \leq 0{\cdot}05$).

Sensory tests were fulfilled by a nine member panel, who were selected by means of the triangle method. (ASTM No. 434, 1968; Amerine *et al.*, 1965). A whole fruit and a fourth part, corresponding to each dose and storage temperature, were given to each panelist, once a fortnight, for their evaluation. Seven point preference and facial hedonic structured scales were used. The analyzed attributes were: external and internal appearance, external and internal odour, texture, flavour and general acceptability (Ellis, 1968; Merkley *et al.*, 1968). These results were statistically analyzed by means of the Dunnett test ($p \leq 0{\cdot}05$) (ASTM No. 434, 1968).

RESULTS

Physico-chemical evaluation

Figure 1 shows the weight loss observed for control and irradiated apples kept under refrigeration and room temperatures, respectively, during the

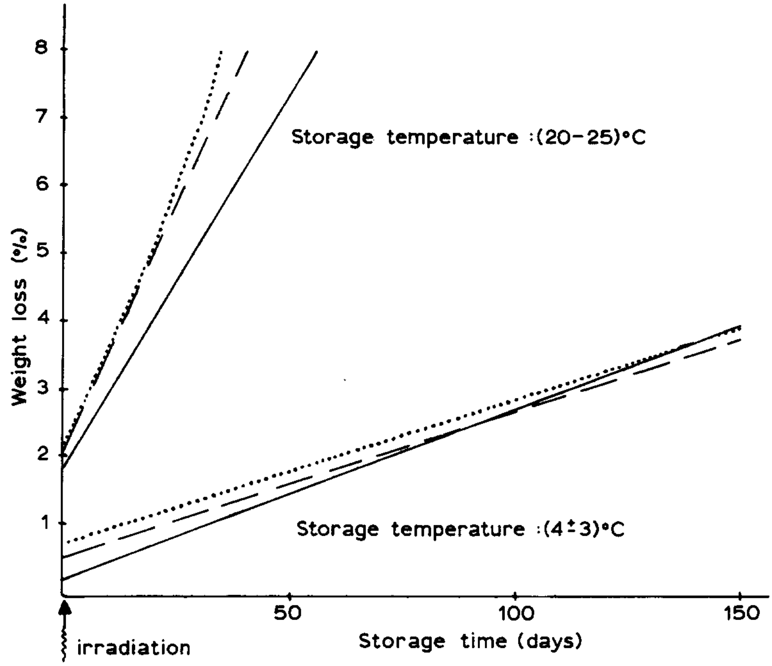

Fig. 1. Weight loss of irradiated and control apples kept at (4 ± 3)°C and (20–25)°C, respectively, during storage time. Results represent percentage of first day value. —— Control samples; ----- 0·43 kGy samples; ..... 0·65 kGy samples.

storage period. Fruits normally lose water and many volatile substances during their maturation and senescence. Weight loss is an expression of this behaviour, and follows a linear relationship with the time elapsed from harvest. Initially, irradiation causes a small weight loss, this effect being proportional to the applied dose. At the end of the storage period, however, this reverts, but differences are slight.

Acid content of apples is expected to diminish with increasing storage time. Figure 2 supports this and shows that irradiated samples have lower values than control ones. Similar results were obtained with the pH determination. Figure 2 also shows the evolution of the ratio: soluble pectins/total pectins, with storage time. It is well known that soluble pectins increase as maturation develops. Initially, there is an increment of soluble pectins due to the depolymerizing effect of irradiation. But, by the end of the analyzed period, 0·65 kGy samples showed similar, and even lower, values than control ones.

The compression curves obtained from the textural assays provide two parameters: the force required to crack the apple, and the deformation suffered by the fruit until that happens. Figure 3 plots their ratio versus storage time. It can be seen that, though control samples are firmer than

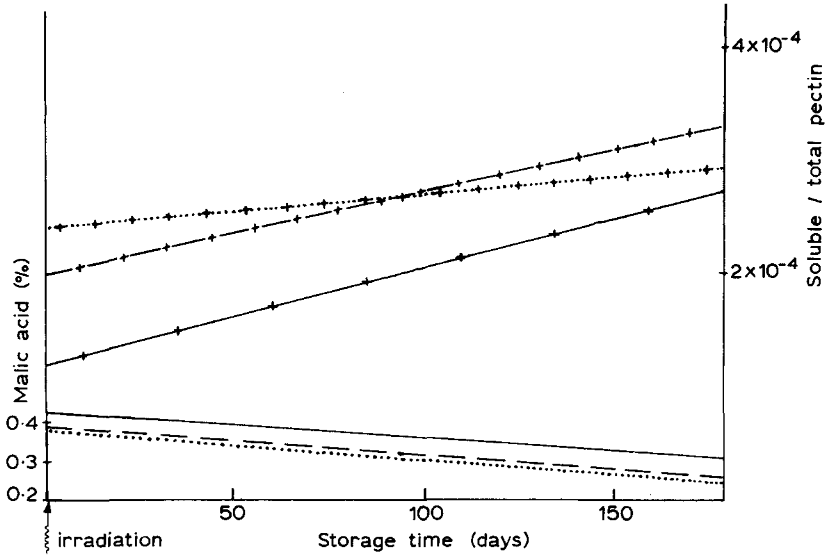

Fig. 2. Acid content of irradiated and control apples kept at (4 ± 3)°C, expressed as grams of malic acid per 100 g of pulp, during storage time. —— Control samples; ----- 0·43 kGy samples; ..... 0·65 kGy samples. Soluble pectin/total pectin ratio for irradiated and control apples kept at (4 ± 3)°C, during storage time. +——+ Control samples: —+—+— 0·43 kGy samples; +·····+ 0·65 kGy samples.

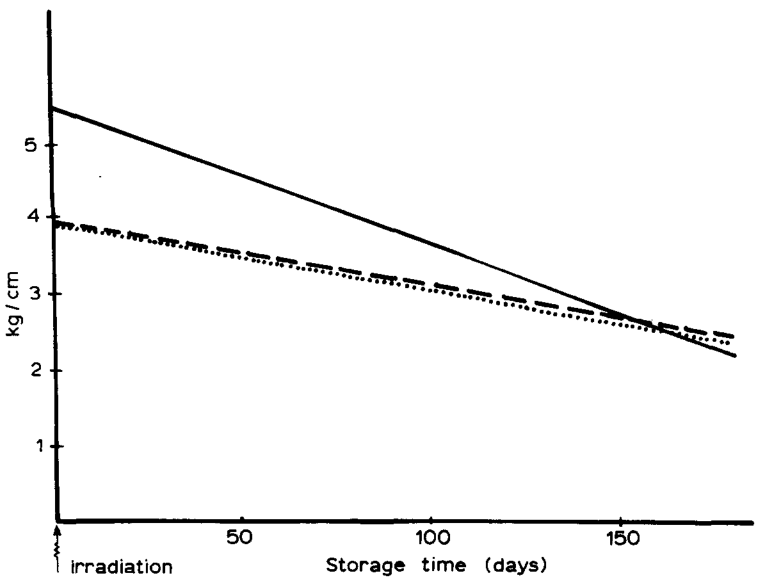

Fig. 3. Strength/deformation ratio for irradiated and control apples kept at (4 ± 3)°C, during storage time. —— Control samples; ----- 0·43 kGy samples; ..... 0·65 kGy samples.

irradiated ones at first, both reach similar values by the end of the storage period.

Regarding the determination of volatiles, the results did not help to show differences among the samples. Nevertheless, an increased liberation of amyl acetate could be detected after the third storage month and it was greater in the irradiated fruits. By that time, about 25% of control apples and 75% of irradiated ones showed brown spots on the skin, without affecting the flesh, this disease being identified by phytopathologists from the Buenos Aires University as 'superficial scald', which involves a pronounced liberation of amyl and caprylic esters.

Sensory evaluation

The apples were evaluated until they passed the borderline of general acceptability (value number 4). That period is shown in Table 1.

TABLE 1
Storage Days of Control and Irradiated Apples during Storage Time

Sample	*Storage conditions*	*Days*
Control	Refrigeration temperature	163
0·43 kGy	Refrigeration temperature	142
0·65 kGy	Refrigeration temperature	122
0·43 kGy	Room temperature	48
0·65 kGy	Room temperature	33

All the following results do not include those of samples irradiated and stored at room temperature, because their storage life was too short to be considered significant.

External and internal appearances: control and irradiated samples kept their original values up to the 140th storage day, without significant differences.

External odour (Table 2): every sample increased this attribute up to the 50th storage day; after that, irradiated apples lose odour, compared with controls, with significant differences.

Internal odour: no significant differences were observed. This result, which disagrees with that of external odour, may be due to saturation conditions during the test.

Texture: no significant differences were observed between control and irradiated samples during the analyzed period; all developed a slight softening as time passed.

TABLE 2
External Odour of Irradiated and Control Apples during Storage Time

Storage (days)	*Refrigeration temperature*			*Room temperature*	
	0 kGy	*0·43 kGy*	*0·65 kGy*	*0·43 kGy*	*0·65 kGy*
0	1·5 ± 0·5	1·28 ± 0·46	1·42 ± 0·39	1·28 ± 0·65	1·42 ± 0·69
20	1·58 ± 0·51	2·08 ± 0·99	1·83 ± 0·39	2·45 ± 0·93	1·91 ± 0·51
33	3·37 ± 1·45	3·25 ± 1·77	3·33 ± 1·49	4·00 ± 1·63	3·18 ± 1·51
48	3·64 ± 1·27	3·5 ± 1·01	3·35 ± 1·44	2·85 ± 1·61	
63	4·33 ± 1·33	3·41 ± 1·72	3·00 ± 1·70[a]		
78	4·33 ± 1·92	2·5 ± 1·62[a]	2·33 ± 1·43[a]		
93	3·66 ± 1·73	2·5 ± 1·16[a]	2·58 ± 1·37[a]		
114	3·5 ± 1·41	1·6 ± 0·52[a]	2·05 ± 0·89[a]		
128	3·96 ± 1·66	2·46 ± 1·26[a]	1·92 ± 1·44[a]		
142	3·58 ± 1·72	2·58 ± 0·99[a]			
155	3·66 ± 1·30	3·04 ± 1·05[a]			
169	3·58 ± 1·16	3·16 ± 1·46			

[a] Significantly different from control samples.

Flavour: generally, the flavour of the control samples was a little better than that of the irradiated ones, but not significantly different.

General acceptability: in this attribute, as with flavour, control apples were slightly more preferred than both irradiated ones and, sometimes, significantly different.

DISCUSSION

The physico-chemical determinations performed show that irradiation caused an initial increase in the ripening of apples but, as storage time went on, it seemed to delay senescence processes. Nevertheless, by the end of the analyzed period (about 180 days), these differences were not significant.

The sensory evaluation shows that irradiation affects external odour, flavour, and general acceptability, but not external and internal appearance, internal odour and texture. 0·43 kGy and control samples, anyway, show very similar behaviour.

So, neither chemical nor sensory evaluations show any advantage for gamma radiation in this variety of apples to delay senescence processes. Perhaps higher radiation doses would have rendered better results, but our previous experience with apples and pears subjected to 1 and 2 kGy has shown adverse effects on textural properties. Also, it is possible that the irradiation treatment may not have been performed at the proper time.

Apples belong to the group of 'climacteric fruits'; that is, those which show a peak of ethylene production during their maturation, called the 'climacteric peak'. The time at which this phenomenon takes place depends on the fruit variety, the degree of ripening at which they are picked, the storage conditions, such as temperature and atmosphere, among others; but, generally, only a few days elapse from the normal date of harvest to the onset of the climacteric. According to some authors (Massey *et al.*, 1964; Rogachev, 1966; Clarke, 1968), who studied many different fruits, successful results due to the irradiation treatment are only attained if it is performed immediately before the occurrence of this 'climacteric peak'.

Our apples belonged to an early harvest and were kept under cold storage until irradiated, nine days later.

Irradiated fruits stored at room temperature behaved as expected, accelerating their senescence with respect to control ones, and confirming that any attempt at preserving them only by ionizing radiation should be complemented with cold storage.

Nevertheless, 0·43 kGy applied to these apples caused not very important deleterious changes in them, so this technology might be possible as a quarantine treatment; however, the radiation-induced increase in 'superficial scald' should be minimized. Perhaps this phytotoxic effect may be due to the accumulation of ozone in the irradiation area, as Moy (provate communication (1986)) points out; this could be avoided by replacing the air in the irradiation field continuously.

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