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Effect of Irradiation on Vitamin C Content of Strawberries and Potatoes in Combination with Storage and with Further Cooking in Potatoes

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Abstract: The vitamin C content of four varieties of strawberry was determined before and after treatment with ionising radiation at doses of 1, 2 or 3 kGy and after storage for 5 and 10 days at 6°C, and also in potatoes which, having been allowed a period of one month to recover from the effects of post-harvest stress, were irradiated at a sprout inhibition dose of 0·15 kGy, followed by storage and cooking. Total ascorbic acid (TAA), ascorbic acid (AA) and dehydroascorbic acid (DHAA) concentrations were measured using the technique of ion-exclusion high-performance liquid chromatography. Results from analysis of the strawberry samples showed the DHAA content increased immediately following irradiation and must, therefore, be taken into account when reporting vitamin C levels in irradiated produce. In addition it was observed that whilst irradiation did affect the vitamin C concentration in all varieties of strawberry, the change was small in comparison with the large variations observed between varieties. With regard to potatoes results showed that, whilst irradiation, storage and cooking all had the effect of reducing vitamin C concentration, irradiated samples stored for 5 months had similar or marginally higher levels than their non-irradiated counterparts. Cooking did not markedly reduce TAA content of irradiated potatoes compared to non-irradiated potatoes and it was also noted that microwave cooking was more destructive than boiling in lightly salted water.

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INTRODUCTION

Fresh strawberries have a relatively short shelf-life, mostly because of fungal spoilage (Dennis 1978). Storage at a low temperature (Browne *et al* 1984), modified atmosphere packaging (Woodward and Topping 1984) and low-dose irradiation (Farkas *et al* 1972) have been shown to limit this type of deterioration. In their review on the irradiation of strawberries, Quaranta and Piccini (1984) concluded that, in general, doses of 2–3 kGy combined with refrigeration were useful for extending the shelf-life of strawberries. However, the detrimental effects of irradiation on the vitamin content of foods has been raised by those opposed to this process (Webb and Lang 1989).

During storage after harvesting, potatoes tend to sprout but this problem is generally controlled by low temperature storage or treatment of the tubers with chemicals such as maleic hydrazide (Wills *et al* 1989).

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Dedication: Mr William D Graham wishes to dedicate this paper to his co-author, the late Dr M Hilary Stevenson OBE (1947–1994).

However, as some of the chemicals currently being used for this purpose are under scrutiny, and their availability in the future cannot be guaranteed, an alternative approach could be the use of low doses (0·075–0·15 kGy) of γ-radiation which are very effective in inhibiting sprouting during post-harvest storage (Thomas 1984). Since the potato is an important source of vitamin C in the total diet, contributing as much as 34% of the total vitamin C intake (Thomas 1984), it is important that any preservation method used to extend its shelf-life will not markedly affect vitamin C content.

The effect of ionising radiation on vitamin C content has produced contrasting results for both strawberries and potatoes. In the case of strawberries, either no effect (Beyers *et al* 1979) or a decrease in ascorbic acid content (Wells *et al* 1963; Kurasaki 1970) have been reported. Although some loss of vitamin C has been observed in potatoes soon after irradiation (Maltseva *et al* 1967), there were no significant differences between irradiated and non-irradiated samples after a period of prolonged storage (Salkova 1957). On the other hand, several studies have reported a reduction in ascorbic acid (AA) content of potatoes following irradiation and storage (Thomas 1984; Joshi *et al* 1990).

However, it has been noted that when reporting vitamin C levels, a number of workers have not taken into consideration the fact that ionising radiation can cause a partial conversion of AA to dehydroascorbic acid (DHAA; Diehl 1990; Kilcast 1994). Since both of these compounds have vitamin C activity in the body it is important that both are measured. In addition, in the case of potatoes, the majority of analyses have been on raw samples and the effect of subsequent cooking has not been evaluated. The present experiment was, therefore, designed to study the effect of irradiation on vitamin C content (AA, DHAA and consequently total AA (TAA)) in strawberries and potatoes in combination with storage and, additionally, with further cooking in potatoes.

MATERIALS AND METHODS

Sample preparation

Strawberries

Strawberries of the varieties Pantagruella (1), Hapil (2), Cambridge Vigour (3) and Cambridge Favourite (4) were picked on a local commercial strawberry farm and transported to the laboratory in a refrigerated van maintained at 4 ± 1°C. Approximately 100 g of strawberries were weighed into 16 punnets, four of which were irradiated at each of 1, 2 or 3 kGy doses or not irradiated to serve as controls. Vitamin assays were carried out immediately following irradiation and after storage for 5 and 10 days at 6°C. Depending on size two to four strawberries were selected from each punnet on each sampling day, cut into eight sections and sub-sampled to provide approximately 10 g of material for analysis.

Potatoes

Potatoes of the variety Pentland Dell were collected from a commercial plot on 3 consecutive weeks and stored at 12°C for a period of 1 month prior to irradiation in order to allow recovery from any mechanical damage sustained during harvesting. Each week, 192 potatoes were randomly allocated to two groups, one of which was irradiated to a dose of 0·15 kGy, while the other was not irradiated and served as controls. Potatoes were placed on cardboard egg trays to prevent contact between individual tubers during storage. On three consecutive weeks, TAA, AA and DHAA concentrations of raw, boiled and baked potatoes were determined immediately after irradiation (0 months) and then after storage for 1, 2 and 5 months. At each sampling period, 24 potatoes were selected at random from both the control and irradiated samples and these were then sub-divided to give three groups of eight potatoes which were analysed in either the raw, boiled or baked state. Boiled potatoes were prepared by boiling approximately 1·2 kg of whole tubers for 30 min in 1·2 litres of water while baked potatoes were obtained by microwaving at 650 W for 15 min. Duplicate samples of raw and cooked potatoes (skin and flesh) were obtained by sub-sampling four pooled cores (10 mm diameter) from each of the eight potatoes in each treatment. Complete cross-sectional cores were used in order that skin from both sides of potato was included and 30 g used for sample analysis.

Irradiation and dosimetry

Cobalt-60 was used as the source of ionising radiation (Gammabeam 650, Nordion International Inc, Kanata, Ontario, Canada) at a dose rate of 0·65 kGy h^{-1} and an environmental temperature of 10–12°C. In order to measure the average dose absorbed by the samples, either Gammachrome YR (0·15, 1 and 2 kGy doses) or amber perspex type 3042B (3 kGy dose) (UK Atomic Energy Agency (UKAEA), Harwell, UK) were used and the change in absorbance was measured spectrophotometrically at 530 nm and 603 nm, respectively. The corresponding doses were obtained from calibration graphs provided by the National Physical Laboratory (NPL), Teddington, Middlesex, UK.

Vitamin C determination

Each sample was homogenised for 3 min with 80 g of 5% (w/v) metaphosphoric acid (MPA). The homogenate was transferred to a beaker along with any 5% (w/v) MPA required to wash the homogeniser. The total weight of homogenate and washings was made to 150 g with 5% (w/v) MPA, centrifuged at $6500 \times g$ for 15 min and filtered through Watman No 541 filter paper. A quantitative amount of this filtrate, sufficient to give between 5 and 20 ng ml^{-1} of AA in the final volume, was diluted to 25 ml with 5% (w/v) MPA and AA was determined in duplicate using ion-exclusion HPLC according to the method by Graham and Annette (1992). The chromatographic column employed was a $300 \times 7{\cdot}8$ mm Aminex HPX–87H organic acids column fitted with a microguard cation H^+ cartridge (Bio-Rad Laboratories Ltd, Watford, UK). The mobile phase consisted of 0·0045 M sulphuric acid at a flow rate of 0·5 ml min^{-1} and the injection volume was 10 μl. AA was monitored using a diode-array detector at 245 nm.

For determination of TAA, DHAA was reduced to AA using a slight modification of the method by Hughes (1956). To 3 ml of the extract used for AA determination was added 0·5 ml of 30 mM DL-homocysteine solution and the pH adjusted to 6·8–7·0 by slow addition of 1·5 ml of 2·6 M dipotassium hydrogen phosphate. After 30 min the reaction was stopped by the addition of 1 ml of 50% (w/v) MPA. This extract was analysed as described for AA. DHAA was calculated as the difference between TAA and AA content.

Dry matter content of samples was determined by oven drying (100°C) duplicate 10 g samples to a constant weight. The vitamin C concentrations were calculated on both fresh and dry matter basis.

Statistical analysis

The experimental results were subjected to analyses of variance using a Genstat 5 software package.

RESULTS AND DISCUSSION

Statistical analysis of the vitamin results expressed on either a fresh matter or dry matter basis yielded similar results; therefore, only the concentrations based on fresh weight are presented (Tables 1–4; Fig 1).

Strawberries

Overall, with strawberries it was found that all three variables examined, that is, irradiation, storage and variety, significantly effected TAA, AA and DHAA concentrations (Tables 1–3). Irradiation had the effect of increasing DHAA content in accordance with dose while the concentrations of TAA and AA were significantly ($P < 0{\cdot}001$) reduced. However, the decrease observed in TAA was less than that of AA due to the contribution made by the increase in DHAA. During storage the TAA and AA levels significantly ($P < 0{\cdot}001$) increased whilst DHAA content decreased and, as was the case for irradiation treatment, this change in DHAA content influenced the levels of TAA and AA.

The variety of strawberry exhibited a very highly significant effect ($P < 0{\cdot}001$) on vitamin C content. Whilst TAA and AA concentrations were reduced and DHAA levels increased following irradiation in all varieties analysed, the extent of these changes was less pronounced in variety 4 which exhibited less changes in TAA and AA with time than the other three varieties. The effect of the interaction between storage and variety on DHAA was more variable with variety 2 showing a significant decrease in concentration between days 5 and 10 compared to a decrease during the initial 5 days of storage observed in the other varieties. Most important, however, is the fact that there is a difference in the initial vitamin C content of the different strawberry varieties. It was found that variety 4 had a lower concentration of the vitamin initially than varieties 1 to 3 even after irradiation with doses of up to 3 kGy and a storage period of 10 days.

The interaction between irradiation dose and storage time also proved to be significant ($P < 0{\cdot}05$) with samples given an irradiation dose of 3 kGy exhibiting a non-significant change in TAA throughout the experimental period compared to the increase observed in the control and other irradiated samples.

When the results over the three storage times are pooled, there was no significant effect of the interaction of variety and irradiation dose on TAA and AA concentrations. On the other hand, the DHAA concentration in varieties 3 and 4 showed a consistent increase with dose while the response in varieties 1 and 2 was similar at irradiation doses of 1 kGy and 2 kGy.

Potatoes

Irradiation, storage and cooking, both boiling and baking, all significantly ($P < 0{\cdot}001$) effected TAA, AA and DHAA concentrations (Table 4; Fig 1) in the particular variety of potatoes analysed. TAA and AA concentrations decreased following irradiation while there was no significant difference in the DHAA content between irradiated and non-irradiated samples which was most likely due to the low dose of 0·15 kGy used. During storage, TAA, AA and DHAA concentrations were significantly ($P < 0{\cdot}001$) reduced. Cooking produced the same effect, with microwaving proving to be more destructive than boiling, although it was not as significant for DHAA compared to TAA and AA.

During post-irradiation storage, TAA and AA concentrations decreased significantly ($P < 0{\cdot}001$) after 2 to 3 months with the rate of diminution being greater than that observed for the non-irradiated potatoes. However, after 5 months this trend was reversed and although vitamin C content was lower than that measured immediately after irradiation (0 months), both irradiated and non-irradiated potatoes had comparable concentrations. These changes in the irradiated samples during storage were reflected in the statistical analysis which

TABLE 1

Effect of irradiation dose and storage on the total ascorbic acid (TAA) concentrations (mg per 100 g FW) of four varieties of strawberry

Variety	*Storage (days)*	*Dose (kGy)*				*Mean*
		0	*1*	*2*	*3*	
1	0	68·7	60·9	57·2	59·9	61·7
	5	70·9	63·3	67·4	60·9	65·6
	10	78·9	77·1	77·4	61·0	73·6
Mean		72·8	67·1	67·3	60·6	
2	0	81·2	70·1	71·7	71·3	73·6
	5	83·6	87·7	83·7	80·4	83·8
	10	93·4	87·0	101·9	80·3	90·6
Mean		86·1	81·6	85·8	77·4	
3	0	85·4	81·8	85·0	79·9	83·0
	5	92·8	91·4	86·1	85·8	89·0
	10	100·0	94·9	97·3	86·4	94·7
Mean		92·7	89·4	89·5	84·0	
4	0	59·1	60·8	58·1	55·4	58·3
	5	65·8	60·0	51·9	52·5	57·8
	10	65·0	62·6	57·1	52·3	59·2
Mean		63·3	61·6	55·7	53·4	

Standard error of the mean/statistical significance of effect

Variety	(V)	($n = 48$)	1·01/***	S × I	($n = 16$)	1·75/*
Storage	(S)	($n = 64$)	0·88/***	V × S × I	($n = 4$)	3·51/NS
Irradiation	(I)	($n = 48$)	1·01/***	NS, not significant; * $P < 0{\cdot}05$; *** $P < 0{\cdot}001$.		
V × S		($n = 16$)	1·75/***	FW = fresh weight.		
V × I		($n = 12$)	2·03/NS			

TABLE 2

Effect of irradiation dose and storage on ascorbic acid (AA) concentrations (mg per 100 g FW) of four varieties of strawberry

Variety	*Storage (days)*	*Dose (kGy)*				*Mean*
		0	*1*	*2*	*3*	
1	0	67·3	57·1	48·0	47·7	55·0
	5	68·2	60·6	62·6	53·1	61·1
	10	72·6	69·2	74·5	58·1	68·6
Mean		69·4	62·3	61·7	52·9	
2	0	79·5	63·7	62·0	56·8	65·5
	5	76·5	78·6	77·9	71·3	76·1
	10	92·0	82·9	96·4	76·5	87·0
Mean		82·7	75·1	78·8	68·2	
3	0	82·8	74·2	73·9	64·8	73·4
	5	89·2	87·0	78·1	74·4	82·2
	10	97·9	92·8	92·9	80·2	91·0
Mean		90·0	84·7	81·7	73·1	
4	0	56·5	54·0	47·4	41·1	49·8
	5	63·4	57·7	47·4	44·1	53·1
	10	63·3	60·5	50·8	43·7	54·6
Mean		61·1	57·4	48·5	43·0	

9t10 Standard error of the mean/statistical significance of effect

Variety	(V)	($n = 48$)	1·00/***	S × I	($n = 16$)	1·72/*
Storage	(S)	($n = 64$)	0·86/***	V × S × I	($n = 4$)	3·45/NS
Irradiation	(I)	($n = 48$)	1·00/***	NS, not significant; * $P < 0{\cdot}05$; *** $P < 0{\cdot}001$.		
V × S		($n = 16$)	1·72/***	FW = fresh weight.		
V × I		($n = 12$)	1·99/NS			

TABLE 3
Effect of irradiation dose and storage on the dehydroascorbic acid (DHAA) concentration (mg per 100 g FW) of four varieties of strawberry

Variety	*Storage (days)*	*Dose (kGy)*				*Mean*
		0	*1*	*2*	*3*	
1	0	1·4	3·9	9·2	12·2	6·7
	5	2·7	2·7	4·7	7·9	4·5
	10	6·3	7·9	2·8	2·9	5·0
Mean		3·5	4·8	5·6	7·7	
2	0	1·7	6·4	9·8	14·5	8·1
	5	7·0	9·0	5·8	9·1	7·8
	10	1·3	4·0	5·4	3·8	3·7
Mean		3·4	6·5	7·0	9·2	
3	0	2·6	7·6	11·1	15·1	9·1
	5	3·6	4·4	7·9	11·3	6·8
	10	2·1	2·1	4·4	6·3	3·7
Mean		2·8	4·7	7·8	10·9	
4	0	2·6	6·9	10·7	14·3	8·6
	5	2·6	2·3	4·5	8·4	4·4
	10	1·7	2·0	6·2	8·6	4·6
Mean		2·2	3·8	7·1	10·4	

Standard error of the mean/statistical significance of effect

Variety (V)	($n = 48$)	0·21/***	S × I	($n = 16$)	0·37/***
Storage (S)	($n = 64$)	0·19/***	V × S × I	($n = 4$)	0·75/***
Irradiation (I)	($n = 48$)	0·21/***	*** $P < 0·001$.		
V × S	($n = 16$)	0·37/***	FW = fresh weight.		
V × I	($n = 12$)	0·43/***			

showed a significant ($P < 0·001$) interaction between irradiation and storage for TAA and AA although the effect was not significant for DHAA.

When the irradiated potatoes were cooked, TAA, AA and DHAA concentrations were reduced as was the case for non-irradiated potatoes. However, it is noteworthy that cooking did not decrease the vitamin C content of irradiated potatoes to any greater extent than that of their non-irradiated counterparts. Therefore, irradiated potatoes will not suffer a further reduction in their nutritional value as a result of cooking.

A combination of cooking and storage significantly effected ($P < 0·001$) both the TAA and DHAA content of the potatoes although it did not appear to effect the AA content. It was observed that the vitamin C content in both irradiated and non-irradiated cooked potatoes showed similar changes on storage to those of raw potatoes.

CONCLUSIONS

Whilst TAA and AA concentrations changed throughout the storage period of the strawberries, the extent of

TABLE 4
Statistical effect of irradiation and storage on the total ascorbic acid (TAA), ascorbic acid (AA) and dehydroascorbic acid (DHAA) concentrations in raw and cooked potatoes

Standard error of the mean/ statistical significance		*TAA*	*AA*	*DHAA*
Cooking (C)	($n = 96$)	0·11/***	0·11/***	0·10/*
Irradiation (I)	($n = 144$)	0·06/***	0·07/***	0·08/NS
Storage (S)	($n = 72$)	0·09/***	0·11/***	0·12/***
I × S	($n = 36$)	0·13/***	0·15/***	0·16/NS
C × I	($n = 48$)	0·14/*	0·15/***	0·14/NS
C × S	($n = 36$)	0·20/***	0·21/NS	0·20/***
C × I × S	($n = 12$)	0·29/*	0·30/NS	0·28/NS

NS, not significant; * $P < 0·05$; ** $P < 0·01$; *** $P < 0·001$.

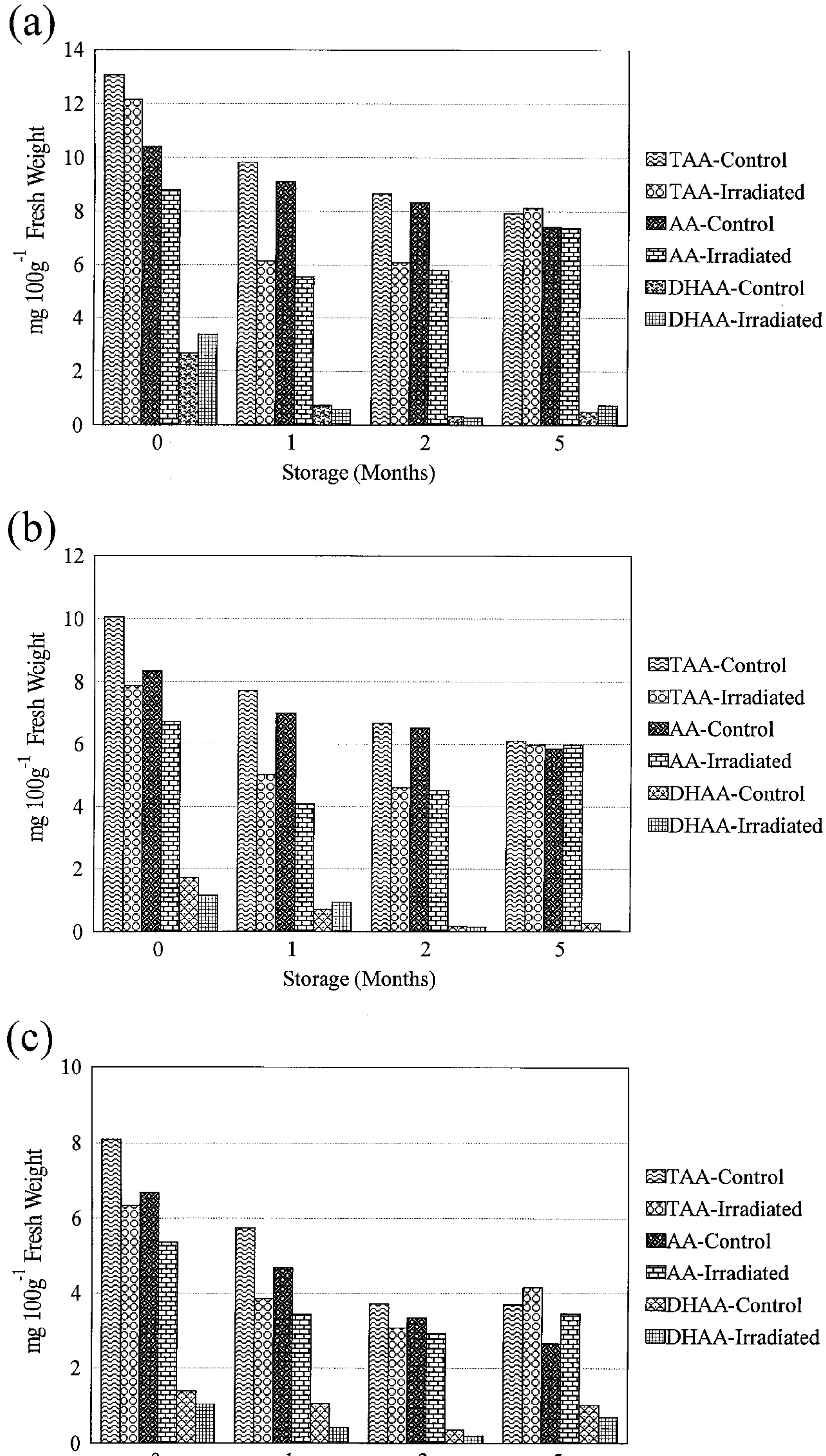

Fig 1. Effect of storage on the TAA, AA and DHAA content of control and irradiated (a) raw, (b) boiled and (c) baked potatoes.

these changes was dependent to a large extent on the contribution made by DHAA. Therefore, it is very important when studying the effect of irradiation on the vitamin C content of such fruits that DHAA is measured otherwise any reported losses may be exaggerated. Also important in relation to strawberries is the difference observed in vitamin C concentration between varieties. At the dose likely to be used commercially (2 kGy) the overall difference between varieties was up to 35% in TAA concentration and 37% in AA concentration. In comparison, the differences between irradiated and non-irradiated samples was 6% and 11%, respectively. Consequently, the contribution made by strawberries to vitamin C intake will be more dependent on the variety consumed than the effects of irradiation or storage.

In the case of potatoes, perhaps the most important point to note is the relatively small difference in vitamin C content between cooked irradiated samples compared with non-irradiated samples subjected to a similar treatment. Consequently, since potatoes are normally cooked prior to consumption, cooked irradiated potatoes will not be nutritionally less adequate. Any losses incurred as a result of cooking may well be related to the means of cooking as this study showed that microwaving tends to be more destructive than boiling. It is also noteworthy that since potatoes are likely to be irradiated with a view to long term storage the fact that irradiated potatoes had comparable vitamin C concentrations to their non-irradiated counterparts after a 5 month storage period indicates that the effect of irradiation on their vitamin content will be minimal on a nutritional basis.

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