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Estimation of the Effect of Food Irradiation on Total Dietary Vitamin Availability as Compared with Dietary Allowances: Study for Argentina*†

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Abstract: The purpose of this work was to evaluate whether irradiation treatment of all foods, for which this treatment is of recognised technological usefulness, would have any detrimental effect on total dietary vitamin availability for consumption by the Argentinian population. Per capita availability of foods produced in or imported into Argentina that could be usefully irradiated and which are usually consumed in the country was recorded from FAO food balance sheets. The vitamin content of the foods and the vitamin losses occurring under good irradiation practices were gathered from the literature. The nutritional impact of vitamin losses due to irradiation was estimated by comparing results to the Recommended Dietary Allowances of the US National Research Council. The vitamins studied were: A, D, E, K, ascorbic acid, thiamine, riboflavin, niacin, pyridoxine, biotin, cyanocobalamin, folacin and pantothenic acid. Results showed that, even if irradiation was applied to every food which could be usefully treated, vitamin availabilities would exceed 100% of the respective RDA and so no adverse nutritional impact would be expected, except for folacin and vitamin D. However, typical availabilities of folate and vitamin D are less than the RDA. Synthesis of vitamin D in the skin from 7-dehydrocholesterol would suggest no nutritional problem. Available data on folic acid losses due to food irradiation are incomplete and suggest the need for further experimental research. © 1998 SCI.

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Key words: vitamins; food irradiation; dietary allowances;, Argentina

INTRODUCTION

The wholesomeness of food irradiation is a subject which has been examined extensively by many scientists around the world for several decades (WHO 1989). These studies were compiled and reviewed, among others, by the Joint Expert Committee on Food Irradiation (JECFI) organised by Food and Agriculture Organization (FAO), World Health Organization (WHO), and the International Atomic Energy Agency (IAEA), their final conclusion being that the irradiation of any food commodity up to an overall average dose of

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TABLE 1
Estimated per capita vitamin content of the Argentinian food supply

Food class	*Per capita available (kg day^{-1})*	*Vitamin content (mg kg^{-1}) (per capita vitamin availability (mg day^{-1}))*											
		Ascorbic acid	*A*	*Thiamine*	*Niacin*	*Riboflavin*	*Pyridoxine*	*Cyanocob*	*Biotin*	*Pantothenic acid*	*Folacin*	*E*	*K*
1. Cereals	0·380	Negligible	Negligible	0·38 (0·14)	17 (6·5)	0·5 (0·2)	2·4 (0·9)	Negligible	0·015 (0·0057)	3 (1·14)	0·1 (0·038)	15 (5·7)	Negligible
2. Roots and tubers	0·225	200 (45)	0·12 (0·03)	1·1 (0·25)	12 (2·7)	0·47 (0·11)	2·1 (0·47)	Negligible	0·004 (0·0009)	4 (0·9)	0·07 (0·0158)	0·6 (0·14)	0·5 (0·113)
3. Pulses	0·005	20 (0·1)	2 (0·01)	4·3 (0·02)	22 (0·11)	2·5 (0·01)	3 (0·02)	Negligible	0·05 (0·000 25)	10 (0·05)	0·5 (0·0025)	3 (0·02)	0·2 (0·001)
4. Nuts	0·005	15 (0·08)	0·1 (0·01)	8 (0·04)	100 (0·5)	1·5 (0·008)	4 (0·02)	Negligible	0·34 (0·0017)	26 (0·13)	0·53 (0·0026)	90 (0·45)	Negligible
5. Fruits	0·210	400 (84)	0·6 (0·13)	0·7 (0·15)	4 (0·84)	0·45 (0·1)	0·5 (0·1)	Negligible	0·02 (0·0042)	2 (0·42)	0·2 (0·0378)	3 0·63	0·025 (0·0052)
6. Meat and poultry	0·300	Negligible	0·3 (0·09)	2 (0·6)	75 (22·5)	2·3 (0·7)	4·2 (1·3)	0·05 (0·015)	0·03 (0·009)	7 (2·1)	0·15 (0·045)	5 (1·5)	0·2 (0·06)
7. Egg (powder)	0·005	Negligible	13 (0·06)	4·4 (0·02)	2·5 (0·01)	13·8 (0·07)	0·8 (0·004)	0·09 (0·0004)	0·85 (0·0042)	74 (0·37)	1·8 (0·009)	27 (0·135)	0·4 (0·02)
8. Fish and seafood	0·020	Negligible	0·1 (0·002)	1 (0·02)	30 (0·6)	2 (0·04)	4 (0·08)	0·015 (0·0003)	0·008 (0·000 16)	4·6 (0·092)	0·11 (0·0022)	12·5 (0·25)	Negligible
9. Vegetables	0·200	200 (40)	5 (1)	0·6 (0·12)	7 (1·4)	0·5 (0·1)	0·8 (0·16)	Negligible	0·04 (0·008)	3 (0·6)	0·4 (0·08)	7 (1·4)	0·08 (0·016)

10 kGy induces no special nutritional or microbiological problems in foods (WHO 1981). The irradiation process should be performed under GIP (Good Irradiation Practices) which involves choosing the appropriate radiation dose, temperature, oxygen exclusion where necessary, and packaging. While losses of macronutrients (carbohydrates, proteins, fats) are not significant in food irradiated under GIP, some micronutrients, the vitamins, are destroyed to some extent. Although these losses are described as completely acceptable and comparable with those of other food preservation methods (IAEA 1982; Thayer *et al* 1990), the effect of food irradiation on vitamins is still a matter of discussion by opponents of the process, among others. Responding to these statements, some authors (ANON 1988) have pointed out that the 'significance of these effects can only be determined if an examination is made of the sources of these nutrients in foods which will be irradiated'.

The aim of the present work was to examine, for a particular population (in this case, the population of Argentina), whether commercial food irradiation would have an impact on vitamin availability.

At this point, some comments about Argentina would be useful. The area of the continental region (excluding the Antartic territories) is 2·8 million km^2. The last census (1991) reports a population of 32·7 million inhabitants; 35% of this concentrated in Buenos Aires and its neighbourhood. The annual population growth rate is 1·5%, and life expectancy is 67 years for men and 74 years for women. The percentage of illiterates was 6% in 1980, and the ratio of inhabitants/physicians was 370 in 1984. Urban population constitutes 84% of the total, with a 'concentrated rural population' of 5%, and a 'disperse rural' of 11% (INDEC 1992). Regarding food consumption surveys, there is no up-to-date information comprising the whole country. Therefore, in this work, data for Argentina from the Food Balance Sheets (FAO 1991) were taken as estimates of food available for consumption. These were derived from the total quantity of food items produced in a country plus the total quantity of the same food items imported, which represents the food supply available for the population.

EXPERIMENTAL

Per capita availability of foods produced in or imported into Argentina were recorded from FAO Food Balance Sheets (FAO 1991) which, although considered to be an adequate approach for this work, reflect only an apparent and not a real food consumption (Portela 1993). However, they would be expected to be a slight overestimate of the average intake.

Those food products for which irradiation is a recognised technological treatment and has been approved by the various countries in the world (WHO 1989) and which, additionally, are usually consumed by the Argentinian population were gathered into classes. These data are summarised in Table 1.

The vitamin content of the foods were recorded from literature. Several references were used, some of them of Argentinian origin, including data from local industries (Mazzei and Puchulu 1991), other foreign (INCAP 1969; FAO 1984; Souci *et al* 1989). In order to establish the vitamin content of a food class, it was necessary to consider those products actually consumed by the Argentinian population (FAO 1992).

Radiation doses recommended by the International Consultative Group on Food Irradiation (ICGFI) and which are presently considered to be under the scope of good irradiation practices were taken (ICGFI—IAEA 1991). A dose range was considered when the radiation treatment of foods within a class could serve several purposes (eg fruits: quarantine treatment, ripening delay, mould decontamination).

Vitamin losses occurring under GIP were also gathered from literature. International Nuclear Information System (INIS), Chemical Abstracts, and *Bibliography on Irradiation of Foods* (Anon 1979–1993) databases were searched and 164 reports describing experimental conditions presently accepted as being GIP and data from these reports were used for the calculations. The only exceptions were some papers which, although referring to work with radiation doses higher than required under GIP, reported little or no damage of the vitamin under study and so their data were included in this work.

A bibliography of the 164 sources of data is available from one of the author (Narvaiz). The nutritional impact of vitamin losses due to irradiation was estimated by comparing results to the Recommended Dietary Allowances of the US National Research Council (NRC, 1989).

RESULTS

No more than 20 foods constituted the usual diet of the Argentinian population, corresponding to 80% of the available energy and nutrients: wheat, potato, beef, apple, tangerine, banana, orange, peach, tomato, squash, carrot, lettuce, wine, among others (FAO 1984; Portela 1993). Among the cereals, wheat was the most important member of the food class (93% of the total available cereal mass), followed by rice (4·5%), maize (2%) and oat (0·5%). Wheat flour is generally used in a fairly 'purified' state, which causes depletion of the B group vitamins due to the removal of bran. Potato was the main representative of the roots and tubers class (75%), followed by carrot (10%), sweet potato (10%) and cassava (2%). The pulses category consisted mainly of lentils (50%), beans (35%) and peas (15%). Availability of nuts and peanuts was equally distributed, being 50% for each one. The highest fruits consumption was represented by citrus (50%): orange, tangerine, grapefruit and lemon; then apple (20%), banana (10%) and peach (10%). Vegetable availability was very little, 40% of which consisted of tomato, then lettuce (30%), and squash (20%). The availability of meats was one of the highest in the world: 109 kg per inhabitant per year (1987), with a heavy predominance of red meat (70%), mainly beef. Poultry (mainly chicken) constituted about 15%, pork 6%, fish 3% and mutton 2%. Only dehydrated egg (egg powder) was considered in this study as representative of the egg class. Hake (70%) constituted the principal member of the fish and seafood class, then mackerel (10%), other sea fish (10%), molluscs and crustacea (5%), and sweet water fish (5%) (FAO 1991, FAO–PAHO 1992; Portela 1993).

Among the individual percentage vitamin losses reported in literature after irradiation, those which did not fall within the range $x \pm 2\sigma$ were discarded. The aim of the present work was to report on maximum percentage losses in the most unfavourable situations. However, some of the maximum percentage losses reported in the literature did not seem to be reliable in view of other referenced data which indicated, with little dispersion, much lower figures. In this work, therefore, vitamin loss under GIP was calculated as $x + \sigma$.

Corrected vitamin availability resulted from the reduction in per capita vitamin available (Table 1) after considering the corresponding percentage vitamin loss under GIP. These data are recorded in Table 2.

Total daily vitamin availability for consumption from the Argentinian food supply, if a generalised irradiation treatment were applied to every suitable product, is shown in Table 3. It also should be noted that in many cases the contributions of some food classes were not considered because no references were found in the literature on vitamin losses due to irradiation. In this report the real total per capita vitamin availability is, therefore, underestimated.

Results in the tables, with the exception of folic acid and vitamin D, show that even a general application of food irradiation would have no adverse impact on vitamin availabilities from the diet. Such a general application is extremely unlikely to occur. In the case of ascorbic acid it should also be pointed out that, very often, vitamin losses are reported due to the conversion of ascorbic acid to dehydroascorbic acid although the latter still has vitamin activity. If this analytical error were significant, values for ascorbic acid in Tables 2 and 3 would be larger than indicated.

Therefore, even supposing that every food in the various classes were irradiated, the vitamin availabilities for consumption would exceed 100% of the RDA.

It should be mentioned that when RDAs were expressed as ranges instead of a single value, the upper

TABLE 2
Effect of radiation treatment on per capita vitamin availability in Argentinian food supply

Nutrient Food class[a]	*Radiation dose*[b] *(kGy)*	*Vitamin loss* (%)	*Corrected Availability* (*mg day*$^{-1}$)
Ascorbate			
2 (35)	0·1	10	40
5 (106)	0·3–3·0	10	75
9 (35)	0·3–3·0	10	36
Vitamin A			
2 (3)	0·1	9	0·025
3 (3)	1	14	0·0085
5 (21)	0·3–3·0	10	0·113
6 (4)	3	21	0·072
7 (4)	2	45	0·036
8 (2)	3	20	0·0016
9 (18)	0·3–3·0	5	0·95
Thiamine			
1 (31)	1	10	0·34
2 (5)	0·1	11	0·223
3 (4)	1	15	0·018
5 (12)	0·3–3·0	11	0·132
6 (20)	3	18	0·48
7 (3)	2	23	0·017
8 (13)	3	20	0·016
9 (1)	0·3–3·0	19	0·096
Niacin			
1 (18)	1	12	5·68
2 (1)	0·1	Negligible	2·7
3 (4)	1	7	0·1
5 (7)	0·3–3·0	16	0·7
6 (17)	3	5	21
7 (1)	2	9	0·011
8 (13)	3	8	0·55
Pyridoxine			
1 (6)	1	6	0·86
2 (1)	0·1	1	0·47
6 (11)	3	5	1·2
8 (2)	3	7	0·07
Riboflavin			
1 (23)	1	1	0·19
2 (4)	0·1	Negligible	0·106
3 (4)	1	11	0·011
5 (5)	0·3–3·0	21	0·075
6 (24)	3	9	0·628
7 (2)	2	Negligible	0·069
8 (13)	3	7	0·037
9 (1)	0·3–3·0	Negligible	0·1
Cyanocobalamin			
6 (5)	3	8	0·0138
8 (7)	3	9	0·0003
Biotin			
1 (2)	1	10	0·0051
6 (1)	3	Negligible	0·009
7 (1)	2	Negligible	0·0042

TABLE 2—*Continued*

Nutrient Food class[a]	*Radiation dose*[b] *(kGy)*	*Vitamin loss (%)*	*Corrected Availability (mg day*$^{-1}$*)*
Pantothenic acid			
1 (5)	1	10	1
6 (7)	3	1	2·1
7 (1)	2	Negligible	0·37
8 (3)	3	Negligible	0·09
Folacin			
6 (5)	3	Negligible	0·045
8 (2)	3	10	0·002
Vitamin E			
1 (11)	1	15	4·8
3 (1)	1	3	0·02
4 (2)	1	20	0·36
6 (13)	3	17	1·24
7 (1)	2	17	0·11
8 (4)	3	3	0·25
9 (1)	0·03–3·0	Negligible	1·4
Vitamin K			
2 (1)	0·1	Negligible	0·112
3 (2)	1	Negligible	0·001
9 (4)	0·3–3	Negligible	0·016

[a] Food classes are those used for the Food Balance Sheets (FAO 1991) and are identified by number in Table 1. Only food classes contributing >5% of a nutrient were included. Numbers in parentheses are the number of references found in the literature about the nutrient in that food class.
[b] Only data obtained under good irradiation practices were included.

limit was usually taken, again to represent the most unfavourable situation. The exception was biotin. Values for the availability of this vitamin by the Argentinian population, considering non-irradiated foods, reached only the lower RDA limit. As the RDA range for biotin is still a matter of discussion among specialists, the lower limit of RDA was considered acceptable and was chosen as the biotin RDA for the purposes of this work.

Regarding folic acid, references found in the literature on irradiation and vitamin losses only focused on two food classes: meat and poultry, and fish and seafoods. Information was too incomplete to ascertain the effect of irradiation on the total per capita daily availability of this vitamin. It should be noted that folic acid has been found to be fairly radioresistant even when irradiated in diluted aqueous solutions (Thayer *et al* 1990). Taking into account (a) the considerable lack of information on foods irradiated under GIP and folic acid losses, already pointed out by WHO (WHO 1981), (b) the fact that the intake of this vitamin in Argentina is considered by national researchers on nutrition as not being well documented, and (c) the suspicion that its dietary intake is not enough in view of insufficient consumption of leafy vegetables (Portela 1993), it would seem advisable to undertake some further experimental work.

As far as vitamin D is concerned, its incorporation in the diet from foods consumed, at least, by the Argentinian population, is extremely low. Food classes as depicted in Table 1 provided negligible vitamin D with

TABLE 3
Total vitamin availability for consumption after extensive or projected irradiation of the Argentinian food supply

Vitamin	*Availability*			
	Irradiated[a] *(mg day*$^{-1}$*)*	*Not irradiated*[b] *(mg/d)*	*Total*	*(% of RDA)*
Ascorbic acid	151	8	159	265
Vitamin A	1·2	0·2	1·4	144
Thiamine	1·3	0·2	1·5	102
Niacin	30·7	0·4	31·1	156
Riboflavin	1·2	1·5	2·7	151
Pyridoxine	2·6	0·2	2·8	142
Cyanocobalamin	0·014	0·002	0·016	805
Biotin	0·02	0·02	0·04	120
Pantothenic acid	3·6	1·8	5·4	134
Folacin	0·047	0·03	0·077	38
Vitamin E	8·2	17·4	25·6	256
Vitamin K	0·13	0·02	0·15	188

[a] Total available from irradiated foods, sum of data in Table 2.
[b] Amount of vitamin contributed by foods not usually irradiated, which is 500 ml of milk for all nutrients except for vitamin E, which also includes the contribution of vitamin E from 35 g of oil.

the only exception of egg (powder): 0·05 mg kg^{-1}, which along with the contribution of milk attained only 6% RDA. However, vitamin D is known to be radioresistant even up to radiation doses of 10 kGy (Wilkinson 1985). On the other hand, low dietary source of vitamin D does not appear to be a drawback, considering that it is synthesized in skin from 7-dehydrocholesterol during exposure to the ultraviolet rays in sunlight. Brief, casual exposure of the face, arms and hands to sunlight is believed to be equivalent to ingesting 5 micrograms of vitamin D, that is, half the RDA (Haddad 1992). National researchers have measured plasma levels of 25-HO-cholecalciferol, a vitamin D_3 metabolite, and found adequate nutritional conditions in most of the country's regions and during the various seasons of the year (Portela 1993).

DISCUSSION AND CONCLUSIONS

From the results of this study it would appear that even an unlikely general application of irradiation treatment to all foods, where this can be done usefully, would result in decreases in vitamin available for consumption so small that attainment of RDAs, based on the population mean, would not be endangered. In fact, except for vitamin D and folic acid, the availability of vitamins in the Argentinian food supply under the conditions of this study is significantly higher than is required to maintain good health. It is extremely unlikely that all foods which can be usefully irradiated will, in fact, be so treated. It is, therefore, clear that the results obtained in this study represent a gross overestimation of the effects of irradiation on food. The foregoing conclusions are borne out from data on vitamins E, K, A, ascorbic acid, thiamine, riboflavin, niacin, pyridoxine, biotin, cyanocobalamin and pantothenic acid. As regards vitamin D, which is radioresistant, the dietary supply lower than the RDA is offset by synthesis of this vitamin in the skin from 7-dehydrocholesterol. Radiation treatment of foods is not likely to be of nutritional significance. As far as folic acid is concerned, data were not sufficient to make useful conclusions either on whether total dietary availability in Argentina from unirradiated food presents a problem or whether irradiation would have a significant effect on folic acid availability for consumption. It is suggested that further investigations on the total dietary intake of folic acid and on losses following irradiation of a wider range of relevant foods in the diet under GIP (Good Irradiation Practices) be carried out. It should be stressed that statements regarding the effect of irradiation on individual food items are meaningless, unless the significance of that item of food in the total diet is assessed. It is thought that the approach used in this study in estimating the total dietary vitamin available for consumption, considering the effects of irradiation treatment of food under grossly exaggerated extent of application of the process and in relation to the recommended dietary allowances (RDA) is a much better way to ascertain whether a general approval of food irradiation would have any nutritional significance on total dietary vitamin availability for consumption. The study has, in the opinion of the authors, laid to rest the question of whether irradiation would have any detrimental effect on the adequacy of individual total vitamin availabilities, at least in Argentina. This is supported by a consideration of the RDAs for the various vitamins for children, pregnant and lactating women and people over 65 years of age. Similar studies could be undertaken in other countries. The study also supports the conclusions of JECFI (Joint Expert Committee on Food Irradiation) concerning the nutritional adequacy of food irradiated at doses up to 10 kGy even if all food were irradiated in accordance with GIP.

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