Vol.52, n. 5: pp. 1267-1278, September-October 2009
ISSN 1516-8913 Printed in Brazil

BRAZILIAN ARCHIVES OF
BIOLOGY AND TECHNOLOGY
A N I N T E R N A T I O N A L J O U R N A L

Ionizing Radiation Effects on Food Vitamins – A Review

Ana Paula Dionísio[1*], Renata Takassugui Gomes[2] and Marília Oetterer[2]
[1]Departamento de Ciência de Alimentos; Faculdade de Engenharia de Alimentos; Universidade de Campinas; Campinas - SP - Brasil. [2]Departamento de Agroindústria; Alimentos e Nutrição; Escola Superior de Agricultura "Luiz de Queiroz"; Universidade de São Paulo; C. P.: 9; Piracicaba - SP - Brasil

ABSTRACT

Ionizing radiation has been widely used in industrial processes, especially in the sterilization of medicals, pharmaceuticals, cosmetic products, and in food processing. Similar to other techniques of food processing, irradiation can induce certain alterations that can modify both the chemical composition and the nutritional value of foods. These changes depend on the food composition, the irradiation dose and factors such as temperature and presence or absence of oxygen in the irradiating environment. The sensitivity of vitamins to radiation is unpredictable and food vitamin losses during the irradiation are often substantial. The aim of this study was to discuss retention or loss of vitamins in several food products submitted to an irradiation process.

Key words: Irradiation, vitamins, foods

INTRODUCTION

Similar to other food processing techniques, irradiation can induce certain alterations that can modify the chemical composition and nutritive values of food (Wiendl, 1984). These changes depend on the factors such as irradiation dose, food composition, packaging, and processing conditions such as temperature and atmospheric oxygen saturation (Wiendl, 1984; Crawford and Ruff, 1996; Kilcast, 1994; Giroux and Lacroix, 1998).

While some vitamins such as riboflavin (B2), pyridoxine (B6) and biotin are usually stable, others such as Thiamin (B1) and vitamins A, C and E are relatively labile (Wiendl, 1984; Kilcast, 1994; Giroux and Lacroix, 1998). Although radiation is one of the conservation techniques that cause fewer damages to food nutrients, vitamin losses resulting from the food irradiation can be substantial. Several studies have been conducted on the effects of radiation on food vitamins between the early 1950 and the late 1960, as a tool for food sterilization processes. In these, doses significantly exceeding 10 kGy were applied. There is an ordinary scientific interest to learn the effects of unrealistically high doses of radiation on foods (Kilcast, 1994). However, not only foods are not ordinarily irradiated with doses superior to 10 kGy, but actually most foods are exposed to much smaller dose.

The use of low irradiation doses combined with other lighter treatments is a way to minimize the effects of irradiation on organoleptic changes and minimize food vitamin losses. The aim of this study was to discuss the retention or loss of vitamins in several food products submitted to an irradiation process.

[*]Author for correspondence: annadionisio@yahoo.com.br

General considerations about irradiation of food

Ionizing radiation has been widely used in industrial processes, specially in sterilization of medicals, pharmaceuticals, cosmetic products, and in food processing (Crawford and Ruff, 1996; CENA, 2006). The technique is extensively used in industrialized countries and is gaining interest in developing countries (Kilcast, 1994; IPEN, 2005).

Irradiation of food consists of submitting the foods, either bulk or packaged, to a precisely controlled quantity of ionizing radiation, during a pre-established period of time and with specific purposes (CENA, 2006). The process does not increase regular radioactivity of the food for ionizing radiations have an energy threshold inferior to that of nuclear reactions that could increase the radioactivity in irradiated material and foods (Siqueira, 2001; Diehl, 1992a). Irradiation can only stop the growth of the microorganisms that cause food deterioration, e.g. bacteria and fungi, change molecular structure, and inhibit the ripeness of some fruits and vegetables, altering the physiological process of plant tissues (CENA, 2006). In Brazil, the resolution RDC nº 21 of January 26, 2001, establishes that the minimum dose should be high enough only to reach the target purposes, and the maximum dose should be inferior to those that alter the functional properties or sensory attributes of the food (ANVISA, 2005).

To irradiate the food it is important to use the radiations that can reach the core of the irradiated food, so that not only the microorganisms and enzymes located in the surface are affected. Of all the ionizing radiations, only gamma rays and beta particles drive interest for food conservation purposes (Gava, 1983). Gamma radiations, which present high and homogeneous penetration competence in tissues, do not significantly increase the temperature of food during the processing, a rather beneficial condition (Evangelista, 2000; Farkas, 2006).

Irradiation doses depend on many conditions that involve exposure to the rays (type, quantity, and radiation time) and behavior of the irradiated environment (absorption capacity, physical, chemical and biological modifications, and secondary reactions) (Evangelista, 2000). Microorganisms, enzymes, insects and vegetable sprouting have different degrees of sensitivity to radiation, and that justifies the need for dosage diversification to reach efficacy (Evangelista, 2000). There are three food radiation processes comparable to thermal methods of conservation according to radiation dosage (Crawford and Ruff, 1996; CENA, 2006; Evangelista, 2000). Doses are measured in kilograys (kGy) (1 Gy = 1 J/kg)

Radurization

Low doses (under 1 kGy) – inhibits the sprouting of produce (onion, potato and garlic); retards the ripening and fungi deterioration of the fruits and vegetables (strawberry, tomato), and promotes insect disinfestations in cereals and vegetables.

Radicidation (pasteurization)

Typical doses (1 to 10 kGy) – controls the presence of pathogenic organisms, especially in fruit juices; retards the deterioration of fishes and fresh meat, and controls Salmonella in poultry products.

Radapertization (industrial sterilization)

High doses (over 10 kGy) – little used in food processing is rather important to the sterilization of health and personal hygiene products.

The quantity of radiation to be used depends on the food type and targeted results (CENA, 2006; Gava, 1983) (Table 1). Healthiness of irradiated food (toxicological, nutritive and microbiological) has been carefully evaluated and tested for over 50 years. Results of innumerous studies (Farkas, 2006; Wang and Chao, 2002) assure that the intake of irradiated food is absolutely safe for the consumers (Farkas, 2006; Marin-Huachaca et al., 2002). Although irradiated foods have become reality in Brazil, it is still necessary to carefully analyze all the possible alterations of irradiated foods. This review addresses the vitamin losses and retention in processed foods submitted to irradiation.

Table 1 - Food treated by ionizing radiation.

Objectives	Foods
1.Microbial and enzyme decontamination	Meat (red meat, pork, poultry and fish). Liquid food (milk, juices).
2.Sprout inhibition	Bulbs and tubers (garlic, potato, onion).
3.Fruit maturation control	Banana, papaya fruit.
4.Insect disinfestations	Cereals and their products Dry vegetables
5.Extension of storage	Meat Vegetables

Irradiation and nutrient stability

Ionizing radiation can safely and effectively eliminate the pathogenic bacteria from the food (Crawford and Ruff, 1996; CENA, 2006; Evangelista, 2000; Loaharanu, 1996; Sommers et al., 2004), disinfest the fruits and vegetables (Crawford and Ruff, 1996; CENA, 2006; Evangelista, 2000; Sommers et al., 2004; Moy and Wong, 2002; Fan and Mattheis, 2001; Patil et al., 2004; Pellegrini et al., 2000; Hallman, 1999), extend the shelf life of many products through ripening delay (Crawford and Ruff, 1996; Kilcast, 1994; CENA, 2006; Evangelista, 2000; Moy and Wong, 2002), inhibit the sprouting of bulbs and tubers (CENA, 2006; Aziz et al., 2006; Rios and Penteado, 2003; Pezzutti et al, 2005, Pellegrini, 2000; Curzio et al., 1986), and reduce or totally eliminate the parasitic microorganisms (Crawford and Ruff, 1996; Kilcast, 1994; CENA, 2006; Evangelista, 2000; Moy and Wong, 2002; Pezzzutti et al., 2005). Food conservation methods have been well accepted by the consumers. However, some disadvantages are frequently associated with them, especially regarding unwanted changes in the organoleptic characteristics and nutrient loss (Kilcast, 1994).

It is well known that heat tretament can improve the nutritional value of foods. Similar effects of irradiation have been occasionally reported, but they are less common and usually less pronounced than the beneficial effects of heating (Diehl, 1991). Thermal treatments can cause significant deterioration in sensory properties of food. Mild treatments, such as pasteurization can cause substantial changes in the flavor of products such as milk. Slow freezing can alter texture of the vegetables, such as strawberries. Modern processing techniques such as the use of modified atmosphere cause minor changes in the sensory quality of the products, but represent a higher cost and do not assure long shelf life (Kilcast, 1994).

Food irradiation processes have been widely studied and are as well known as any other food processing method, such as dehydration and freezing (Crawford and Ruff, 1996). Nutritional value of the foods submitted to various processing techniques, especially food irradiation, has been questioned by both the activists and consumers (Crawford and Ruff, 1996; Kilcast, 1994). One of the main obstacles for the development of this technique in many countries is the mistaken ideas consumers have concerning excessive nutrient denaturation, along with the myth of food becoming radioactive and generation of toxic compounds (Kilcast, 1994). However, research results back to the 1950's have already shown the absence of radioactivity inducement in the food treated by ionizing radiations (Wiendhl, 1984).

The main advantages of irradiation are the small alterations in food components (Kilcast, 1994). Studies have shown that the macronutrients such as proteins, carbohydrates and fat are quite stable to the doses up to 10 kGy. Micronutrients, especially vitamins, can be susceptible to any food treatment method (Crawford and Ruff, 1996; WHO, 1994). Water soluble vitamins are sensitive to any processing method, although fat soluble vitamins are particularly destroyed by the irradiation, and tocopherol are more sensitive to pasteurization doses (Diehl, 1992a; Fox et al., 1989). According to Kilcast (1994), the different sensitivity levels of food vitamins to processing are shown in Table 2.

Table 2 - Different sensitivity levels of food vitamins to processing.

Highly Sensitive	Moderatly Sentitive	Little Sensitive
A (retinol)	β-carotene	Folic Acid
B_1(thiamin)	K (in meat)	Pantothenic Acid
C (ascorbic acid + dehydro-ascorbic)		B_2 (Riboflavin)
E (α-tocopherol)		B_3 (Niacin)
		B_6 (Pyridoxine)
		B_{10} (Biotin)
		B_{12} (Cobalamin)
		Choline
		D
		K (in vegetables)

A has been reporter that folate contents of vegetable remain stable under irradiation processing, that is, little is lost because of the ionizing energy treatment. The relative folate stability to irradiation is contrasted by the losses registered in the conventional processing and cooking, which destroy nearly 50% of total folate concentration in the diet (Müller and Diehl, 1996).

Bulbs and Tubers

Conservation of the potato (*Solanum tuberosum*) is very important because similar to rice, wheat and corn, it is one of the most consumed base foods worldwide. However, the main inconvenience in potato storage, same as for onion and garlic, is sprouting, which causes substantial product damage, and consequently sizable economical loss (Evangelista, 2000; Moy and Wong, 2002; Janave and Thomas, 1979; Rios and Penteado, 2003). Alterations in vitamin C contents in potatoes can be proportional to the irradiation dosage. The biggest vitamin C losses are registered during stockpiling; after four to nine months of storage, the ascorbic acid contents of an irradiated potato equals control potatos (Evangelista, 2000). However, after six months storage irradiated potatoes presented higher concentrations of vitamin C in comparison to control (Diehl, 1992a).

The effect of gamma irradiation on the quality of dried potato was also studied. Experiments were conducted to study the influence of different doses, air temperatures, slice thickness of potatoes on some parameters, such as vitamin C content. With a higher dose, the lesser the vitamin C content was observed (Wang and Chao, 2003).

The changes in sugar and vitamin C content of five potato cultivars subjected to gamma irradiation (100 Gy) to control sprout inhibition were compared with nonirradiated control tubers during storage at 27–32°C (ambient temperature) and 15°C, and also with control tubers stored at 2–4°C—the commercial cold storage temperature. During the first two months vitamin C levels were lower in irradiated potatoes stored at 15°C than in the controls stored at 2–4°C, but were subsequently higher (Joshi et al., 1990).

Regarding β-carotene, potatoes irradiated with doses of 0.1 kGy and stored for six months, registered 50% losses in pro-vitamin A contents (Janave and Thomas, 1979). Considering the fat soluble vitamins, the most sensitive to irradiation was γ-tocopherol (vitamin E). Ionizing irradiation significantly affected the γ-tocopherol contents of garlic samples only when the doses reached 0.2 to 0.25 kGy (Rios and Penteado, 2003). However, doses used to inhibit the sprouting and extend storage period of garlic was much lower than those that caused vitamin loss to the product (Pellegrini et al., 2000).

Regarding vitamin C, no alterations were registered in the garlic and onions receiving irradiation doses enough for sprouting inhibition (Kilcast, 1994). Garlic (*Allium cepa* L.) irradiated at 0.05 kGy gamma radiation and stored for 300 days, presented decreases in vitamin C contents similar to that registered for non-irradiated garlic (Croci et al., 1995).

Several chemical parameters were investigated in red variety garlic, irradiated to inhibit sprouting, with doses of 30 Gy and kept under warehouse conditions. The studies were conducted between 210 and 270 days post harvest (critical marketing periods) when this variety was not normally available for raw consumption. During the storage, the irradiated garlic showed a significant increase in ascorbic acid content but no change in dry matter content compared with non-irradiated garlic. Compared with non-irradiated garlic, at 270 days' storage, the irradiated garlic had a higher index of flavour, measured as enzymatic pyruvate, a higher acidity and a lower content of water-soluble carbohydrates. From these observations, the irradiated garlic should be suitable for prolonged storage with the object of marketing it during the critical periods (Curzio et al., 1986).

Another study evaluated the effects of different radiation doses applied in both dormant and post-dormant onions (*Allium sativa* L.). Elevated irradiation dosages (0.03 to 0.15 kGy) lead to complete inhibition of sprouting and mitosis of onion, independent of the application moment, while low doses (0.002 to 0.01kGy) did not result in any desirable effects on food (Pellegrini et al., 2000). In addition, studies with dehydrated garlic and onions, seeking product sanitation, showed that doses between 5-10 kGy were enough to reduce the micro flora to desirable levels, and making these products viable to use in the hospitals and in immuno-impaired people diets (Pezzutti et al., 2005).

Fruits and Vegetables

It is advisable to quarantine the fresh foods to prevent the migration of insects and other organisms to new areas. Traditional quarantine involves chemical treatments (fumigation) and/or the use of high or low temperatures. However, these treatments have some disadvantages. Fumigation may cause environmental concern and public health problems; both high and low temperatures treatments require more than 12 days to be effective (Hallman, 1999).

Food irradiation for the insect and microorganisms decontamination has been studied for more than 40 years. Doses lower than 1.0 kGy effectively control a large number of insects (Patil et al., 2004) and have already been used in many countries. Studies with Gala and Fuji apples irradiated with quarantining dosages showed that 0.6 kGy was enough for this purpose, did not cause physical-chemical damages, and did not alter sensory quality of the fruit (Dionísio et al., 2004).

These are reports describing gradual loss of ascorbic acid in apples (*Pyrus malus* L.) irradiated with more than 2 kGy (Saito and Igarashi, 1970; Chunyao et al., 1993; Lastarria-Tapia and Sequeiros, 1985). However, after six months of storage at 0°C, no alterations in the ascorbic acid content of the fruits were observed (Saito and Igarashi, 1970). Destruction of vitamin C is a consequence of alteration of fruits metabolic oxidation pathways by radiation, which can convert vitamin C into dehydro-ascorbic acid, which can still be metabolized as vitamin C (Snauwart, 1973).

Papaya and mango rot caused by fungi is a major problem during the storage and marketing. Gamma irradiation treatment was studied to determine its effect on the quality of papaya and mango irradiated at 0.5 to 0.95 kGy. The content of vitamin C were not significantly affected by the irradiation (Lacroix et al., 1990).

Star fruit, mango, papaya, rambutan, and lichia were irradiated with 0.75 kGy and evaluated the vitamin C retention. Only star fruit presented significant vitamin C loss (Moy and Wong, 2002).

Capsicums (green and red), cucumbers, custard apples, lemons, lychees, mandarins, mangoes, nectarines, papayas, peaches, persimmons, and zucchinis were irradiated at 0, 75, or 300 Gy. Commodities were analyzed shortly after the irradiation and again after 3 to 4 weeks of storage at 1–7°C for some parameters, such as vitamin C and dehydroascorbic acid. Significant ($p < 0.05$) small changes were recorded in some variables for some commodities. However, storage effects were higher than irradiation effects (Mitcheell et al, 1992).

Strawberries (Shasta variety, *Fragaria* sp.) presented minute, non-significant decrease in vitamin C levels when submitted to 1.0-2.0 kGy doses, during two and 11 days of storage at 5°C (Maxie et al., 1964). Similar observations were reported by Lopez et al. (1967). A study using higher radiation doses (3.0 and 4.0 kGy), resulted in 62 and 81% losses of ascorbic acid, respectively (Clark, 1959). However, 1.0-2.0 kGy doses are deemed enough to extend the shelf life of the fruits. Fruits irradiated with 2.0 kGy doses presented immediate increase in niacin contents, while thiamin was unaltered (Maxie and Sommer, 1968). A study with Selekta and Parafit varieties irradiated with 2 kGy doses, showed non-significant differences in riboflavin, thiamin and niacin contents, evaluated after 24 h. of exposure to the treatment (Beyers et al., 1979).

In strawberry, vitamin C content was significantly affected by original content or the variety rather than treatments such as irradiation, heating or microwave. These results indicated that the losses of water-soluble vitamins, especially thiamin or vitamin C, were affected by the food temperature during the irradiation process (Chung and Yook, 2003).

Irradiation can be an alternative for quarantining the papayas. Hot water treatment (immersion of fruits in water at 46 ºC) can be used for the fruits smaller than 0.7 kg. However, it can harm fruit quality. It is not advisable to submit the mangos heavier than 0.7 kg to hot water treatment because of lack of efficiency and intolerance of the product to the binomial time/temperature, which increases according to the fruit size (Hallman, 1999). Mangos and papayas irradiated with 2.0 kGy doses showed no loss of carotenoid; however, papayas stored at low temperatures without any kind of ionizing energy treatment showed large losses of these nutrients (Beyers and Thomas, 1979).

Lycium, a popular fruit from China, was exposed to severe doses of gamma radiation (2-14 kGy), and decontaminating efficiency, changes in chemical composition and sensory characteristics were evaluated. Increasing the radiation dosage gradually decreased the fruits vitamin C concentration, but no alterations in β-carotene and riboflavin contents were registered (Wen et al., 2006). Reduction of vitamin C contents in irradiated Lycium is not a significant problem because this fruit is ordinarily used in traditional Chinese medicine for vision treatments, as an essential source of β-carotene and not vitamin C (Hsu et al., 1994).

The importance of physiological state on vitamin loss was demonstrated with Early Park nº 7 tomato fruits irradiated with 4.0 kGy doses at the green-ripe stage. After ripening, tomatoes presented 8.6 % loss of ascorbic acid, while ripe fruits irradiated with 3.0 kGy showed 20.4% loss. However, because ripe fruits contained almost twice as much ascorbic acid, even after high destruction percentage of vitamin C by irradiation, still contained 5mg/100g more vitamin C than the control, harvested at green-ripe stage (Maxie and Sommer, 1968).

The efects of irradiation on the microorganisms and physiological quality of the fresh-cut lettuce were evaluated during storage at 4°C. The loss of vitamin C of fresh-cut lettuce irradiated with 1.0kGy was signifcantly (a = 0.05) lower than that of non-irradiated. The best treatment of maintaining quality of the fresh-cut lettuce appeared to be 1.0kGy irradiation (Zhang et al, 2006).

Adequate doses for insect disinfestations showed non-significant effects in vitamin C contents of citric fruits (Fan and Mattheis, 2001). Non-significant losses of ascorbic acid were observed in the oranges irradiated and stored at 0ºC during 100 days. However, reduction of ascorbic acid content was observed in the lemons irradiated and stored at 15ºC during one month (Maxie et al., 1964).

Grapefruit Rio Red variety (*Citrus paradisi* Macf.) in different maturation stages, were irradiated to evaluate the influence of dose and storage period, showed the loss of some bioactive components and fruit quality. Fruit's response to irradiation depended on its maturation stage. Low irradiation doses (≤0.2 kGy) applied to fruit harvested in the early season at 35 days of storage, promoted the formation of bioactive components, including β-caroten. Non-significant changes were recorded on vitamin C. High doses (0.4 and 0.7 kGy) affected the quality of fruit harvested in the early season. However, non-significant effects were observed in the fruits harvested in the late one (Patil et al., 2004).

Quarantine treatments ordinarily used in citric fruits are fumigation with methyl bromide, or storage of the product at low temperatures. Alternative methods are being thought because these treatments can result in unacceptable fruit damages and also because of future unavailability of methyl bromide (Hallman, 1999).

Despite divergences regarding the effects of irradiation on ascorbic acid content of citric fruits, most research results demonstrated that the loss was minimum when doses up to 1.0 kGy were used. Exposure to higher doses can cause destruction of this vitamin in direct proportion to dose raise (Ahmed, 1977). Retention of ascorbic acid in oranges, tangerines, tomatoes and papayas varied from 100% to 72% with 0.4 to 3.0 kGy doses (Josephson et al., 1978).

Although most available data refer to irradiation-induced losses, especially of ascorbic acid in the reduced form, losses can actually be lower than reported, given that irradiation can convert ascorbic acid in reduced form into dehydro-ascorbic acid, biologically active form (Snauwart, 1973; Thomas, 1986).

The total of vitamin C in food is calculated by adding up ascorbic acid (AA) and dehydro-ascorbic acid (DHAA) activities. Almost all post-harvest products contain only AA and many studies only determined the content of AA as vitamin C concentration measurement. However, the conversion of AA to DHAA during the storage and processing elicits significant concentration alterations. Therefore, some results reporting the effects of irradiation on vitamin C concentration seem conflicting because some studies only refer to AA concentrations, while others refer to the sum of both, AA and DHAA concentrations (Kilcast, 1994). Folates resistance to irradiation has not been widely studied yet (Diehl et al., 1991). Irradiation of spinach, green cabbage, and Brussels sprouts reduced only 10% of the initial vitamins concentration of these produces. When dehydrated, the vitamin stability in these vegetables is higher than when they are fresh. In studies with fresh vegetables, the application of 10.0 kGy dose was only used to show that folate losses in analyzed foods depend on irradiation dosage (Müller and Diehl, 1996).

Fruit juice

Ascorbic acid is one of the most sensitive vitamins to irradiation (Kilcast, 1994), but there are many fruit in which the level of ascorbic acid is not significantly reduced in tolerable doses (Maxie et al., 1964). Reduction of vitamin C contents with increasing irradiation doses were observed in orange, tangerine, tomato and passion fruit juices, with orange and tangerine being the most sensitive to irradiation (Munhoz-Burgos, 1985). Drastic reductions of ascorbic acid were observed in irradiated tomato juice and black and red currant syrups in comparison to losses resulting from pasteurization by heat (Wilska-Jeska and Skorupinska, 1975). For instance, 70.2 % vitamin C losses were registered for orange juice irradiated with 2.5 to 10 kGy (Hussain and Maxie, 1974). Studies showed that irradiation dose and temperature provoked only a slight reduction of ascorbic acid percentage in orange juice. This percentage was more drastically reduced because of temperature and storage period (Spoto, 1988).

Studies with carrot and kale juices evaluated the modifications in nutritional, microbiological and sensitive characteristics regarding irradiation. Results showed a increased reduction in total ascorbic acid content with increasing irradiation dosage. However, total ascorbic acid concentration, including dehydro-ascorbic acid, remained stable with doses up to 3.0 kGy (Song et al., 2007).

Meat: Fish, Beef, Pork and Poultry

Microorganisms and parasites can contaminate the food in various stages of production, processing, storage and distribution (Loaharanu, 1996). Different treatments have been used to extend the shelf life and eliminate pathogenic microorganisms of the meat products (Kilcast, 1994). Among these treatments, ionizing radiation stands out for its positive effects.

Many studies on meat irradiation used sterilizing doses (20-40 kGy). Others, seeking directed to commercial application, used the doses lower than 10 kGy and showed that nutritive effects were not very different when compared to other preservation methods (Josephson et al., 1978).

Meats are a great source water soluble vitamins from B complex. These vitamins include thiamin (B1), riboflavin (B2), niacin (B5), pyridoxine (B6), biotin (B10), cobalamin (B12), choline, folic acid and pantothenic acid. Water soluble vitamins are less unstable to irradiation than fat soluble vitamins. Vitamin B1 contents of meat products were reduced by 47% after irradiation at 6.0 kGy, 10% with cooking and 54% with the cooking-irradiation combination. Riboflavin and niacin (nicotinic acid) acid were more resistant to irradiation (Fellows, 1998).

Meat is an important source of dietary thiamin. Thiamin is the most sensitive water soluble vitamin to the processing with ionizing energy (Kilcast, 1994; Giroux and Lacroix, 1998), and its loss occurs through the oxidation (Giroux and Lacroix, 1998). Thiamin is also the most labile vitamin under cooking (Stevenson, 1994). Destruction of thiamin depends on irradiation dosage, and its loss is minimized with temperature reduction (Kilcast,1994). Beef containing 0.24 µg/g of thiamin and submitted to gamma irradiation treatment with 28 and 56 kGy doses presented decrease on thiamin concentration to 0,057 and 0,037 µg, respectively (Ziporin et al., 1957).

The effect of temperature and the applied dose over thiamin and vitamin C content was shown in poultry, in which thiamin losses were up to 43.6% in meat irradiated with 5.0 kGy at 10ºC, and vitamin C losses were up to 18.4%. Reduction of temperature and radiation dose significantly improve vitamin retention (Hanis et al., 1989).

Thiamin is more sensitive to thermal treatment than to irradiation. Beef and pork sterilized by radiation retain more thiamin than thermo-sterilized products (Josephson et al., 1978)46. Thiamin loss rate is not associated to quantity of sulfidrils, protein, humidity, fat, pH or redox potential. Any damage, such as these small losses, can be compensated by the advantages brought by the control of microbiological contamination by irradiation (Mariano, 2004).

The effects of irradiation at frozen or refrigerated state and the effects of cooking such as heating or microwave on thiamin contents in chicken breast were studied. Irradiation reduced the thiamin content. However, temperature condition during the irradiation was much more important factor to the loss of thiamin contents (Chung, et al., 2003).

Nile tilapia (*Oreochromis niloticus*) and cavala-moira (*Scomberomorus commersoni*), either irradiated with 1.5 to 10.0 kGy doses and stored for 20 days at refrigeration temperature or non-irradiated, were analyzed in regard to vitamins such as thiamin, riboflavin and tocopherol contents. Irradiation did not affect riboflavin content whilst alterations in thiamin contents were only observed in doses higher than 4.5 kGy. Filets submitted to 3.0 kGy doses (Al-Kahtani et al., 1996) presented larger retention of tocopherol.

Smaller loss of thiamin and retinol was registered for the irradiated foods which were also vacuum-packed and processed at low temperature. *Scyliorhinus retifer* irradiated at 0°C and irradiated with 3.0 kGy dose did not present reduced thiamin content; however, when irradiated with 30.0 kGy dose, there was a loss of 45% thiamin (Diehl, 1992).

A study was made on the loss of thiamin and riboflavin due to gamma irradiation of beef, lamb and pork longissimus dorsi, turkey breast and leg muscles. Thiamin losses averaged 11%/kiloGray (kGy) and riboflavin losses 2.5%/kGy above 3.0 kGy. The rate of loss of thiamin in beef was higher than that in lamb, pork and turkey leg, but not turkey breast, with losses of 16%/kGy in beef and 8%/kGy in lamb. The rate of thiamin loss was not related to sulfhydryl, protein, moisture, fat or water content, pH or reducing capacity by redox titrn. Loss of riboflavin was not different among the species. Any detriment from such slight losses would seem to be more than compensated by the advantage of controlling bacteriol. contamination by irradiation processing (Fox et al., 1995).

The effect of low dose ionizing radiation on free α-tocopherol levels in beef, pork and lamb longissimus dorsi muscle and on turkey leg and breast muscle were detected. The samples were irradiated in air with a ^{137}Cs source at eight dose levels between 0 and 9.4 kGy at 5°C. Irradiation resulted in a significant decrease in γ-tocopherol levels in all of the meats studied. There were no statistically significant differences in the rate of loss of tocopherol due to species, with the exception of turkey breast. The rate of loss of tocopherol in turkey breast tissue was greater than the other meats (Lacritz, 1995).

By irradiation of 5 and 10 kGy, riboflavin contents of egg powder were responsable for reduction to 80.18 and 84.80% of non-irradiated sample, and niacin contents in chicken breast were reduced to 85.30 and 92.60%, respectively. These results suggested that the reducing rate by gamma irradiation seemed to be lower in niacin content than in riboflavin, and the losses of riboflavin and niacin occured within the range of 20% by irradiation of up to 10 kGy (Kim et al., 2005).

The effect of ionizing radiation on free tocopherols in chicken was detected. Raw chicken breast muscle with skin and adipose tissue removed was subjected to gamma radiation from a 137Cs source at 1, 2.25, 5.0, and 10.0 kGy. The chicken was packaged aerobically, and irradiated at 4°C. Irradiation resulted in a significant linear decrease in α and γ-tocopherol with increasing dose levels. At 3 kGy, the maximum level approved by the FDA for poultry, a 15% redution of free γ-tocopherol and a 30% redution for free α-tocopherol were observed (Lakritz and Thayer, 1992).

Effects of gamma radiation in thiamin, riboflavin and niacin contents were studied in shrimp (*Penaeus monodon*) irradiated at different temperatures. Thiamin loss increased with increasing irradiation doses and temperature, but non-significant changes were observed in regard to riboflavin and niacin. In samples irradiated with 7.0 kGy and 4.0 kGy doses (-20°C), thiamin losses were 31 and 23%, respectively. Vitamin destruction was significantly smaller at -20 ºC, in comparison to 4 ºC (Lee and Hau, 1996).

Thiamin loss (35.5%) in irradiated, dried shrimp was observed in 3.2 kGy doses. Losses of complex B vitamins varied from 8 to 18% (Srinivas et al., 1974). Non-significant alterations in pyridoxine (B6) and cianocobalamin (B12) contents were

observed in shrimp irradiated with doses between 4.0 kGy and 7.0 kGy, at -20°C (Hau and Liew, 1993).
Changes in thiamin, riboflavin, and α-tocopherol concentrations due to gamma irradiation were followed in alligator, caiman, bison, and ostrich (exotic) meats. The proximate components showed that the exotic meats generally had lower fat content than domestic animal meats and that the thiamin content of the reptiles was lower. The changes in the vitamins due to irradiation were similar to those previously observed for domestic species (Lacritz et al., 1998).

Cereals and grains

The main purpose of cereal irradiation is decontamination and elimination of pathogenic microorganisms. The 10 kGy dose, accepted by Codex Alimentarius Committee (WHO, 1994) is very effective for the microbiological decontamination of wheat (*Triticum vilgare*), barley (*Hourdeum vulgare*), corn (*Zea mays*) and sorghum (*Sorghum biocoler*), and does not provoke unfavorable nutritive effects to them. The small loss of some nutrients (thiamin 22-33%, and riboflavin 10-16%) could be compensated by beneficial effects of processing (Aziz et al., 2006).
Researches with white rice fortified with folic acid, packed and later irradiated with necessary doses for insect disinfestations, showed vitamin retention in the food, with minimum nutrient losses (Dionísio et al., 2005). Losses in products based on crushed grains was bigger than in whole grains. However, this loss could be minimized by oxygen exclusion during the irradiation and storage (Kilcast, 1994).
The effects of cooking followed by irradiation (10 kGy) on vitamins B1 and C, and the antinutritional factors, phytic acid and nitrates, in a ready-to-eat meal of sorghum porridge and spinach-based relish were investigated. Cooking reduced vitamin B1 and C contents of the spinach relish, and irradiation caused further losses. Cooking did not alter vitamin B1 content of the sorghum porridge but irradiation decreased it drastically. Cooking did not decrease phytic acid in the sorghum porridge, but irradiation caused a significant decrease. The reduction of antinutritional factors by cooking, followed by irradiation, could be promising for the application of this technology to traditional African cereal and leafy vegetable foods. However, ways need to be found to minimise the vitamin loss, such as blanching and cooking in minimum water and irradiation at cryogenic temperatures in an oxygen-free atmosphere (Duodu et al., 1999).
The sensitivity of *Tribolium confusum* - a small flour beetle - to radiation was studied in a dose range of 0–0.8 kGy. The vitamin E content and the rate of lipid-oxidation of wheat germ were determined. The vitamin E content decreased after radiation treatment. However, during the storage for at least six months, it remained at a level specified by the food quality standards (higher than 10 mg%)) (Kovács et al, 1996).
The effect of ^{60}Co gamma rays on the content of several B-vitamins in two varieties of Brazilian beans has been studied. Carioca (*Phaseolus* vulgaris *L.* var. *Carioca*) and Macaçar beans (*Vigna unguiculata L. Walp*, var. *Macaçar*) were irradiated at doses of 0, 0.5, 1.0, 2.5, 5.0 and 10 kGy, and subsequently stored at ambient temperature for six months. The content of vitamin B1, B2 and B6 was analysed by HPLC. Only slight changes were observed for thiamine and riboflavin, whereas a dose-dependent decrease was noted for pyridoxine, which, however, was significant only at the highest doses of 5 and 10 kGy. However, at the disinfestation dose up to 1 kGy, acceptable ratings were obtained for the sensory evaluation. In conclusion, for insect disinfestation of Brazilian beans, radiation processing could be a promising technology (Villavicencio et al., 2000)

CONSIDERATIONS

Same as for other processing treatments, irradiation induces certain alterations that can modify the chemical composition and nutritive value of the foods. Vitamins presented different sensitivities regarding the treatment with ionizing energy. Vitamin C is one of the most sensitive to radiation. However, its sensitivity is also high in relation to several factors (exposure to oxygen, temperature elevation, pH modifications). In general, low dose irradiation treatments do not cause significant alterations in vitamin contents of the foods. This method should be used because of its efficiency and low cost compared to other traditional methods.

ACKNOWLEDGEMENTS

The authors wish to thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the posgraduate fellowship given to them.

RESUMO

Assim como outras técnicas de processamento de alimentos, a irradiação induz certas alterações, que podem modificar a composição química e o valor nutritivo dos alimentos. A natureza e extensão destas mudanças dependem essencialmente da composição do alimento, da dose de irradiação e de fatores tais como a temperatura e a presença ou ausência do oxigênio do ar. Enquanto que algumas vitaminas, como a riboflavina, niacina e vitamina D são bastante estáveis, outras, como a tiamina e vitaminas A e E, são relativamente lábeis. O objetivo da presente revisão foi discutir as prováveis perdas de vitaminas de diversos produtos submetidos ao processo de irradiação.

REFERENCES

Ahmed, E. S. (1977), Biochemical responses of skin-coated citrus fruits irradiated for preservation, *Arab. J. Nuel. Soi. Appl.*, Cairo, **10**, 155.

Al-Kahtani, H. A.; Abu-Tarboush, H. M.; Bajaber, A. S.; Atia, M.; Abou-Arab, A.A.; El-Mojaddidi, Mohamed, A. (1996), Chemical changes after irradiation and post-irradiation storage in tilapia and spanish mackerel. *J. Food Sci.*, **61**, 729-733.

Anvisa. Agência Nacional de Vigilância Sanitária. *Sistema de legislação em vigilância sanitária.* Disponível em: <http//www.anvisa.com.br>. Acesso em: jun. 2005.

Aziz, N. H.; Souzan, R. M.; Azza, S. (2006), Effect of γ-irradiation on the occurrence of pathogenic microorganisms and nutritive value of four principal cereal grains. *Appl. Radiat. Isot.*, **64**, 1555-1562.

Beyers, M.; Thomas, A. C. (1979), Gamma irradiation of subtropical fruits.4. Changes in certain nutrients present in mangoes, papayas and litchis during canning, freezing and gamma irradiation. *J. Agric. Food Chem.*, **27**, 48-51.

Beyers, M.; Thomas, A.C.; Van Tonder, A. (1979), Gamma irradiation of subtropical fruits. I. Compositional tables of mango, papaya, strawberry, and litchi fruits at the edible-ripe stage. *J. Agric. Food Chem.*, **27**, 37-42.

Cena. Centro de Energia Nuclear na Agricultura. Disponível em: <http://www.cena.esalq.usp.br>. Acesso em: maio 2006.

Clark, I. D. (1959), Possible applications of ionizing radiations in the fruit, vegetable and related industries. *Int. J. Appl. Radiat. Isot.*, **6,** 175-181.

Crawford, L.M.; Ruff, E.H. (1996), A review of the safety of cold pasteurization through irradiation. *Food Control*, **7**, 87-97.

Croci, C. A.; Banek, S. A.; Curzio, O. A. (1995), Effect of gamma-irradiation and extended storage on chemical quality in onion (*Allium cepa* L.). *Food Chem.*, 5**4**, 151-154.

Chung, Y-J.; Yook, H-S. (2003), Effects of gamma irradiation and cooking methods on the content of thiamin in chicken breast and vitamin C in strawberry and mandarin orange. *Han'guk Sikp'um Yongyang Kwahak Hoechi*, **32**, 864-869.

Chunyao, W; Mengyue, J., Meixu, G.; Xiuye, M.; Shufen, Z; Shucheng, L. (1993), A study of the physiological changes and nutritional qualities of irradiated apples and the effect of irradiation on apples stored at room temperature. *Radiat. Phys. Chem.*, **42**, 347-350.

Curzio, O. A.; Croci, C. A.; Ceci, L. N. (1986), The effects of radiation and extended storage on the chemical quality of garlic bulbs. *Food Chem.*, **21**, 153-159.

Diehl, J. F. (1992a). *Safety of irradiated foods*. 2th ed. New York: Marcel Dekker.

Diehl, J. F. (1992b), Nutritional effects of combining irradiation with other treatments. *Food. Control*, **2**, 20-25.

Diehl, J. F., Hasselmann, C.; Kilcast, D. (1991), Regulation of food irradiation in the European Community: is nutrition an issue? *Food Control*, **2**, 212-219.

Dionísio, A. P.; Crepaldi, P. F.; Walder, J. M. M.; Godoy, H.T. (2005), Efeito da radiação ionizante do Co-60 em arroz enriquecido com ácido fólico. Paper presented at 6th Latino-American of Food Science Symposium, Campinas, São Paulo, Brazil.

Dionísio, A. P.; Domarco, R. E.; Walder, J. M. M. (2004), Efeitos da radição gama do Cobalto-60 em maçãs (*Malus domestica).* Paper presented at 10th Encontro Científico dos Pós-Graduandos no *CENA/USP*, Piracicaba, São Paulo, Brazil.

Duodu, K. G.; Minnaar, A.; Taylor, J. R. N. (1999), Effect of cooking and irradiation on the labile vitamins and antinutrient content of a traditional African sorghum porridge and spinach relish. *Food Chem.*, **66**, 21-27.

Evangelista, J. (2000), Alimentos Irradiados. In: Alimentos - um estudo abrangente. São Paulo: Editora Atheneu, pp.135 - 169.

Fan, X.; Mattheis, J. P. (2001), 1-Methylcyclopropene and storage temperature influence responses of

"Gala" apple fruit to gamma irradiation. *Postharvest Biol. Technol*., **23**, 143-151.

Farkas, J. (2006), Irradiation for better foods. *Trends Food Sci. Technol*., **17**, 148-152.

Fellows, P. (1988), *Food processing technology: principles and practice*. Chichester: Horwood, pp.186-195.

Fox Jr., J. B.; Lakritz, L.; Hampson, J.; Richardson, R.; Ward, K.; Thayer, D. W. (1995), Gamma irradiation effects on thiamin and riboflavin in beef, lamb, pork, and turkey. *J. Food Sci*, **60**, 596-598.

Fox Jr., J. B..; Ackerman, S.; Thayer, D. W. (1989), The effect of irradiation on the B vitamins on pork chops nad chicken breasts *Int. J. Radiat. Biol.,* **55**, 689-703.

Gava, A.J. (1983), *Princípios de tecnologia de Alimentos*, 5th ed., Nobel: São Paulo, cap.6.

Giroux, M.; Lacroix, M. (1998), Nutritional adequecy of irradiated meat – a review. *F. Res. Int.*, 31, 257-264.

Hallman, G. J (1999), Ionising radiation quarantine treatments against tephritid. fruit flies. *Postharvest Biol. Technol.*, **16**, 93-106.

Hanis, T.; Jelen, P.; Klir, P.; Mnukova, J.; Perez, B.; Pesek, M. (1989), Poultry meat irradiation – effect of temperature on chemical changes and inactivation of microorganisms. *J. Food Prot*., 52, 26-29.

Hau, L. B.; Liew, M. S. (1993), Effects of γ-irradiation and cooking on vitamins B6 and B12 in grass praws (*Penaeus monodon*). *Radiat. Phys. Chem*., **42**, 297-300.

Hsu, H. Y.; Peacher, W. G. (eds) (1994), *Chinese Herb Medicine and Therapy*. Keats Publishing, New Canaan.

Hussain, A.; Maxie, E. C. (1974), Effect of gamma rays on shelf life and quality or orange juice. *Int. Biodet. Bull.*, California, **10**, 81-86.

IPEN, Centro de Tecnologia das Radiações. *Instituto de Pesquisas Energéticas e Nucleares*. Disponível em <http://ipen.br/ > Acesso em 18 jun. 2005.

Janave, M. T.; Thomas, P. (1979), Influence of post-harvest storage temperature and gamma irradiation on potato carotenoids. *Potato Res*., **22**, 365-369.

Josephson, E.S., Thomas, M.H., Calhoun, W.K. (1978), Nutritional aspects of food irradiation: an overview. *J. Food Proc.Pres.,* **2**, 299-313.

Joshi, M.R.; Srirangarajan, A.N.; Thomas, P. (1990), Effects of gamma irradiation and temperature on sugar and vitamin C changes in five Indian potato cultivars during storage. *Food Chem.*, **35**, 209-216.

Kilcast, D. (1994), Effect of irradiation on vitamins. *Food Chem.*, **49**, 157-164.

Kim, S-H.; Yook, H-S.; Byun, M-W.; Chung, Y-J. (2005), Effects of gamma irradiation on the content of riboflavin in egg powder and niacin in chicken breast. *Han'guk Sikp'um Yongyang Kwahak Hoechi*, **34**, 1459-1463.

Kovács, E.; Kiss, I.; Boros, A.; Horváth, N.; Tóth, J.; Gyulai, P. and Szalma, A. (1986), Disinfestation of different cereal products by irradiation. *International Journal of Radiation Applications and Instrumentation. Part C. Radiation Physics and Chemistry*, **28**, 545-548.

Lakritz, L.; Thayer, D. W. (1992), Effect of ionizing radiation on unesterified tocopherols in fresh chicken breast muscle. *Meat Sci.*, **32**, 257-265.

Lakritz, L.; Fox, J. B.; Hampson, J.; Richardson, R.; Kohout, K.; Thayer, D. W. (1995) Effect of gamma radiation on levels of α-tocopherol in red meats and turkey. *Meat Sci.*, **41**, 261-271.

Lakritz, L.; Fox, J. B.; Thayer, D. W. (1998), Thiamin, riboflavin, and α-tocopherol content of exotic meats and loss due to gamma radiation. *J. Food Prot.*, **61**, 1681-1683.

Lacroix, M.; Bernard, L.; Jobin, M.; Milot, S.; Gagnon, M. (1990), Effect of irradiation on the biochemical and organoleptic changes during the ripening of papaya and mango fruits. *International Journal of Radiation Applications and Instrumentation. Part C. Radiation Physics and Chemistry*, **35**, 296-300.

Lastarria-Tapia, H. J.; Sequeiros, N. (1985), Efecto de la radiacion gamma em manzanas "delicias" almacenadas al médio ambiente y em refrigeracion. In: INTERNATIONAL ATOMIC ENERGY AGENCY. *Food Irradiation Processing. Vienna*, 55-60.

Lee, K. F.; Hau, L. B. (1996), Effect of γ-irradiation and post-irradiation cooking on thiamine, riboflavin and niacin contents of grass praws (*Penaeus monodon*). *Food Chem.*, **55**, 379-382.

Loaharanu, P. (1996), Irradiation as a cold pasteurization process of food. *Vet. Parasitol.*, **64**, 71-82.

Lopez, G. M. Rivas, G. A., Ortin, S. N. del Val Cob, M. (1967), Preservation of food by irradiation. VI. Preliminary investigation on strawberries, in *Symp. Application of Radioisotopes*, Madrid, **21**.

Mariano, C. O. (2004), Efeitos da radiação gama na conservação da carne bovina refrigerada. PhD Thesis, Center of Nuclear Energy in Agricultural, CENA/USP. Piracicaba, São Paulo, Brazil.

Marin-Huachaca, N. S.; Lamy-Freund, M. T.; Mancini-Filho, J.; Delincée, H.; Villacencio, A. L. C. H.(2002), Detection of irradiated fresh fruits treatd by e-beam or gamma rays. *Radiat. Phys. Chem.*, **63**, 419-422.

Maxie, E. C., Eaks, I. L., Sommer, N. F. (1964), Some physiological effects of gamma irradiation on lemon fruit. *Radiat. Bot.*, California, **4**, 405-411**.**

Maxie, E. C.; Sommer, N. F. (1968), Changes in some chemical constituints in irradiated fruits and vegetables. In: INTERNATIONAL ATOMIC ENERGY AGENCY. *Preservation of fruit and vegetables by radiation*. Vienna, 39-44.

Mitchell, G. E.; McLauchlan, R. L.; Isaacs, A. R., Williams, D. J., Nottingham, S. M. (1992), Effect of low dose irradiation on composition of tropical fruits and vegetables. *J. Food Comp. Anal.*, 5, 291-311.

Moy, J. H.; Wong, L. (2002), The efficacy and progress in using radiation as a quarantine treatment of tropical fruits – a case study in Hawaii. *Radiat. Phys. Chem.*, **63**, 397-401.

Müller, H. ; Diehl, J. F. (1996), Effect of Ionizing Radiation on Folates in Food. Lebens-Wiss. *U.-Technol*., **29**, 187-199.

Munhoz-Burgos, R. A. (1985), Uso de la radiación gama para extender el tiempo de conservación del jugos de algumas frutas exóticas, In: SEMINÁRIO SOBRE IRRADIACIÓN DE ALIMENTOS PARA PAÍSES DA AMÉRICA LATINA, 1., Quito, 1985. Actas. Vienna: IAEA, 1-25.

Patil, B. S.; Vanamala, J.; Hallman, G. (2004), Irradiation and storage influence on bioactive components and quality of early and late season "Rio Red" grapefruit (*Citrus paradisi* Macf.). *Postharvest Biol. Technol*., **34**, 53-64.

Pellegrini, C. N.; Croci, C. A.; Orioli, G. A. (2000), Morphological changes induced by different doses of gamma irradiation in garlic sprouts. *Radiat. Phys. Chem*., **57**, 315-318.

Pezzutti, A.; Marucci, P. L.; Sica, M. G.; Matzkin, M. R.; Croci, C. A. (2005), Gamma-ray sanitization of Argentinean dehydrated garlic (*Allium sativum* L.) and onion (*Allium cepa* L.) products. *Food Res. Int.*, **38**, 797-802.

Rios, M. D. G.; Penteado, M. D. V. C. (2003), Determinação de α-tocoferol em alho irradiado utilizando cromatografia líquida de alta eficiência (CLAE). *Quim. Nova*, **26**, 10-12.

Saito, Z.; Igarashi, Y. (1970), Effects of gamma irradation on changes in acidity, vitamin C, and non-protein nitrogen in apples, *Hirosaki Daigaku Nogakubu Gakujutsu Hokoku*, **16**, 1-9.

Siqueira, A. A. Z. C.de (2001), Efeitos da irradiação e refrigeração na qualidade e no valor nutritivo da tilápia (*Oreochromis niloticus*). MsC Thesis, University of São Paulo. ESALQ/USP. Piracicaba, São Paulo, Brazil.

Snauwart, F. (1973), Influence of gamma irradiation on the provitamin A (β-carotene) in solution. *Radiation Preservation of Food* (Proc. Symp. Bombay, 1972), IAEA, Vienna, 29.

Sommers, C.; Xuetong, G.; Niemira, B. (2004), Irradiation of ready-to-eat foods at USDA'S Eastern Regional Reasearch Center-2003 update. *Radiat. Phys. Chem*, **71**, 509-512.

Song, H. P.; Byun, M. W.; Jo, C.; Lee, C-H; Kim, K-S; Kim, D-H. (2007), Effects of gamma irradiation on the microbiological, nutritional, and sensory properties of fresh vegetable juice. *Food Control*, **18**, 5-10.

Spoto, M. H. F.(1988), Radiação gama na conservação do suco concentrado de laranja. MsC Thesis. University of São Paulo. ESALQ/USP. Piracicaba, São Paulo. Brazil.

Srinivas, H.; Vakil, V.K.; Sreenivasan, A. (1974), Nutritional and compositional changes in dehydro-irradiated shrimp. *J. Food Sci*., **39**, 907-911.

Stevenson, M.H. (1994), Nutritional and other implications of irradiating meat. *Proc. Nutr. Soc.*, **53**, 317-325.

Thomas, P. (1986), Radiation preservation of feed of plant origin. Tropical fruits bananas, mangoes and papayas, *CRC Crit. Rev. Food Sci. Nutr.*, Bombay, **23**, 147-204.

Villavicencio, A. L. C. H.; Mancini-Filho, J.; Delincée, H.; Bognár, A. (2000), Effect of gamma irradiation on the thiamine, riboflavin and vitamin B6 content in two varieties of Brazilian beans. *Radiat. Phys. Chem.*, **57**, 299-303.

Wang, J.; Chao, Y. (2003), Effect of ^{60}Co irradiation on drying characteristics of apple. *J. Food Eng.*, **56**, 347-351.

Wang, J.; Chao, Y. (2003), Effect of gamma irradiation on quality of dried potato. *Radiat. Phys. Chem*., **66**, 293-297.

Wen, H. W; Chung, H. P.; Chou, F. I.; Lin, I. H; Hsieh, P.C. (2006), Effect of gamma irradiation on microbial descontamination and chemical and sensory characteristic of lycium fruit. *Radiat. Phys. Chem.*, **75**, 596-603.

Wiendl, F. M. (1984), A salubridade dos alimentos irradiados. *Bol. SBCTA*. **18**, 48-56.

Wilska-Jeszka, J.; Skorupinska, A. (1975), Evaluation of radiated and pasteurized fruit juices during 12 months of storage. *Seszyty Naukowe Politechniki Lodzka Spozywcza*, **23**, 243-259.

WHO - World Health Organization (1994). Safety and nutricional adequacy of irradiated food. Geneva.

Ziporin, Z. Z.; Kraybill, H. F.; Thach, H. J. (1957), Vitamin content of foods exposed to ionizing radiation. *J. Nutrient*, **63**, 201-209.

Zhang, L.; Lu, Z.; Lu, F., Bie, X. (2006), Effect of γ-irradiation on quality-maintaining of fresh-cut lettuce. *Food Control*, **17**, 225-228.

Received: February 27, 2007;
Revised: July 20, 2007;
Accepted: June 25, 2008.