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DEVELOPMENT OF FOOD IRRADIATION IN BRAZIL

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ABSTRACT

Ionizing radiation has a long history of successful applications in Brazil. In this paper the history and current status of food irradiation research and commercialization in Brazil are presented. The way in which irradiation of different foods is regulated is also discussed. © 1999 Published by Elsevier Science Ltd. All rights reserved.

1. *Considerations about food irradiation*

Ionizing radiation has a long history of successful worldwide industrial applications such as the sterilization of disposible medical supplies. Nevertheless, the application of this technology to foods is a new challenge with a great potential in contributing to the improved preservation, storage and distribution of a safe food supply.

The use of radiation in food processing has been known as a treatment since antiquity. Meats, fish, fruits and vegetables have always been preserved by the sun's energy. In recent years, infrared and microwave radiation have been added to the list of radiant energies in food processing.

The idea of using ionizing radiation in food preservation almost immediatelly followed Becquerel's discovery of radioactivity in 1895. The suggestion to use ionizing energy to destroy pathogenic and spoilage microorganisms in food was published in a German medical journal the same year. In the early 1900's, patents were issued in the United State and the United Kingdom describing the use of ionizing radiation to destroy microorganisms in food. Interestingly, Madame Curie's Ph.D.Thesis presented in 1929 was about the reduction of colonies of microorganisms by means of ionizing radiation.

The modern era of food irradiation applications research began after the World War II, when more practical ionizing sources became available. Food irradiation became then a technically and commercially feasible process and a more concerted research into the safety and applications started to take place firstly in the United States of America. Reports of successful experiments in the USA stimulated similar efforts in other countries: Belgium, Canada, France, The Netherlands, Poland, Russia, Germany and the United Kingdom.

Irradiation can reduce post-harvest losses by killing insect pests in fruit, grains or spices, reducing food spoilage organisms, inhibiting the sprouting of vegetables and delaying the ripening of fruits [1]. Irradiation, similar to good storage techniques, is one facet of good pest management of grains and can be used as treatment for plant pests of quarantine significance [2].

On the other hand, radiation processing can be used as a public health intervention measure for the control of food-borne diseases. Irradiation can inactivate protozoan or helminth parasites and significantly decrease the probability of viable food-borne bacterial pathogens in fish, poultry, sea foods and red meats [3, 4]. This is extremely important since in the last two decades food-borne diseases of microbial aetiology have become an increasing public health problem all over the world [5].

More research has been focused on the effects of irradiation on foods than has been directed at any other form of food processing or treatment. Free radicals have been implicated as decisive participants in the action of ionizing radiation on biological systems since long time [6, 7]. But free radicals normally occur in plant and animal tissues related to metabolic activity and photochemical processes. So, the estimation of radiolytic products as a basis for evaluating the wholesomeness of irradiated foods has been a great challenge for researchers in the field [8].

Based on available experimental studies and on theoretical estimates, a FAO/IAEA/WHO Joint Expert Committee on Irradiated Foods [9] made in 1981 a recommendation which has, since 1985, been included in the Brazilian legislation, to restrict the radiation sources for irradiation of food to the following :

a) Gamma rays from the radionuclides ^{60}Co (maximum energy 1.33 MeV) or ^{137}Cs (maximum energy 0.66 MeV);

b) X-rays generated from machine sources operated at or below 5 MeV;

c) Electrons generated from machine sources operated at or below 10 MeV.

No measurable induced radioactivity is produced when food is treated with ionizing radiation emitted by these sources.

2. History of Food Irradiation in Brazil

The first papers which were published on food irradiation in Brazil date back to 1968 [10,11]. The section of Entomology of the Center of Nuclear Energy for Agriculture (CENA) from the University of Sao Paulo (CENA), Piracicaba, Sao Paulo, has developed a great deal of research on foods and insects irradiation being Frederico W. Wiendl, the pioneer in the field. The CENA undertook the study of the influence of gamma radiation on pests that infest Brazilian crops, [12,13,14,15], the radiosensitivity of insects fed with irradiated diets [16], the shelf life extension of poultry meat [17], fruit [18] and flowers disinfestation [19, 20, 21]. These last studies were performed in partnership with the IPEN. In the last years, some interesting work on radiation hormesis applied to onions or potatoes [22] was also performed. A summary of the insects able to infest foods studied is presented in Table 1 [23].

Between 1968 and 1970 some studies were carried out at the Federal University of Rio Grande do Sul. The National Commission of Nuclear Energy (CNEN) and the Institute of Military Engineering (IME) in Rio de Janeiro dedicated some research and international review work between 1978 and 1981. Since 1991, research on food irradiation has also taken place at the Institute for Nuclear and Energy Research (IPEN) in Sao Paulo, one of the institutes belonging to the National Commission of Nuclear Energy (CNEN).

2. *Legislation on food irradiation in Brazil*

The decree establishing general regulations for food irradiation, No. 72.718 of 29 August 1973 was published in the *Diario Oficial* on 30 August 1973. It was followed by two Directives from the Ministry of Health: No. 9 of 8 March 1985 and No. 30 of 25 September 1989.

Table 1. List of insects which radiosensitivity was already studied in Brazil

Insect species	Infested food
Acanthoscelides obstectus (Say,1831) (Coleoptera, Bruchidae)	beans (grains)
Anastrepha fraterculus (Wied., 1830) (Diptera, Tephritidae)	fruits
Anastrepha obliqua (Macq., 1835) (Diptera, Tephritidae)	fruits
Araecerus fascicutatus (DeGeer) (Coleoptera, Anthribidae)	coffee (grains)
Callosobruchus analis (Fabr.,1755) (Coleoptera, Bruchidae)	beans
Callosobruchus maculatus (Fabr.,1792) (Coleoptera, Bruchidae)	beans
Callosobruchus phaseoli (F.) (Coleoptera, Bruchidae)	beans, peas
Ceratitis capitata (Wied., 1824) (Diptera, Tephritidae)	citrus
Corcyra cephalonica (Stainton,1865) (Lepidoptera, Pyralidae)	wheat
Gymnandrosoma aurantianum (Lima,1927) (Lepidoptera,Grapholitidae)	oranges
Opogona sacchari (Lepidotera)	banana
Palembus desmestoides (Fairm.,1893) (Coleoptera,Tenebrionidae)	grains
Plodia interpunctella (Hubner,1913) (Lepidoptera, Pyralidae)	bran/wheat
Rhyzopertha dominica (Fabr.,1797) (Coleoptera, Bostrichidae)	grains
Sitophilus granarius (L., 1785) (Coleoptera, Curculionidae)	wheat
Sitophilus oryzae (L.) (Coleoptera, Curculionidae)	rice
Sitophilus zeamais (Motschulsky,1855) (Coleoptera, Curculionidae)	maize
Sitotroga cerealella (Olivier,1819) (Lepidoptera, Gelechiidae)	maize, rice
Tenebrio molitor (L.,1758) (Coleoptera, Tenebrionidae)	grains
Tribolium castaneum (Herbst., 1797) (Coleoptera, Tenebrionidae)	grains
Trogoderma inclusum (LeConte) (Coleoptera, Dermestidae)	grains
Zabrotes subfasciatus (Boh.) (Coleoptera, Bruchidae)	beans

In general, foodstuffs may be exposed to ionizing radiation whose energy is below the threshold for nuclear reactions that could induce radioactivity in the irradiated material. The irradiation of foodstuffs or groups of foodstuffs can only be authorized in those cases where technical and scientific work has been carried out by national or international research institutions duly approved by the National Nuclear Energy Commission, demonstrating that:

a) the irradiated food is safe for consumption;
b) the effect of irradiation on the essential nutrients in the food compares favourably with the losses incurred when the food is treated by conventional processes;
c) the irradiated food is wholesome and the irradiation is effective in achieving the technological purpose intended.

It is responsability of the National Commission for Food of the Ministry of Health to draw up a table of food or groups of foods whose radiation is authorized, indicating in each case: the radiation type and energy level that is permissible, the nominal radiation dose to be applied, the purpose of irradiation, and the treatments to be used before, during or after irradiation in order to achieve the desired purpose.

The Directive of 1985 aproved a general standard for irradiation of food, and the conditions of irradiation for certain food items. The individual authorizations given in 1985 and 1989 are presented in Table 2.

Table 2. Food irradiation authorization in Brazil

Product	Purpose of irradiation	Max. Permitted Dose (kGy)	Year of Approval
Rice	Disinfestation	1	1985
Potatoes	sprout inhibition	0.15	1985
Onions	sprout inhibition	0.15	1985
Beans	Disinfestation	1	1985
Maize	Disinfestation	0.5	1985
Wheat	Disinfestation	1	1985
Wheat flour	Disinfestation	1	1985
Spices	Decontamination, disinfestation	10	1985
Papayas	disinfestation, control of ripening	1	1985
Strawberries	shelf-life extension	3	1985
Fish and fish products	shelf-life extension, decontamination, disinfestation	2.2	1985
Poultry	shelf-life extension, decontamination	7	1985
Avocados Pineapples Persimmons Guavas Oranges Lemons Mangoes Melons Tomatoes	insect disinfestation, control of ripening, shelf-life extension, reduction of microbial load	1	1989

A revision of the legislation about food irradiation is being carry out at present.

4. Commercial food irradiation

Today there are three commercial facilities for industrial irradiation operating in the country, two being exclusively dedicated to their own production of medical disposibles: Johnson & Johnson and IBRAS CPO.
There is only one commercial facility for multipurposes irradiation services, the Empresa Brasileira de Radiações Ltd. (EMBRARAD), located in Cotia, near the city of Sao Paulo. This company operates a Nordion JS-7500 irradiator, with a current activity of about 1,500kCi, designed for the sterilization of medical devices. It also irradiates some food products mainly dried foods like spices. At least three other new multipurpose facilities, now in processing of licensing, are scheduled to initiate their operation in 1999, when it will be possible to start food irradiation on a commercial scale.

5. Present research in food irradiation in Brazil

At present, the following institutes are developing research on food irradiation: Institute of Nuclear and Energy Research (IPEN-CNEN/SP), the Center of Nuclear Energy for Agriculture (CENA), the Biosciences Institute and the School of Pharmacy of the University of Sao Paulo, the Biological Institute in Sao Paulo, the School of Food Technology of the University of Campinas, all in the state of Sao Paulo. Some research is at times performed at the University of Rio de Janeiro and at the University of Pernambuco.
There are few no-medical ionizing radiation sources even for laboratory research installed in the country. The CENA owns an old Gammabeam 650, being the activity about 30kCi in 1974. Now a new ^{60}Co Nordion irradiator of 100kCi is going to be installed in the near future. At the Institute of Military Engineering (IME) in Rio de Janeiro there is an old ^{137}Cs source where some research on food irrdiation are sometimes being performed.
At the Institute for Nuclear and Energy Research (IPEN) there are two small experimental ^{60}Co sources: a Gammacell 220 (AECL) of about 11kCi and a panoramic source of about 1.5kCi and two industrial electron beam accelerators of 1.5MeV.
Using mainly ^{60}Co sources, research works on food irradiation started at the IPEN in 1991 taking as the main subject the development of methods to identify irradiated foods, a new field of study in the country. That choice was based on the following: a Joint Food and Agricultural Organization (FAO)/ International Atomic Energy Agency (IAEA)/ World Health Organization (WHO)expert committee meeting on the wholesomeness off irradiated food, Geneva, 27 October-3 November, 1980, concluded, amongst other things, that "the irradiation of any food commodity up to an overall average dose of 10kGy presents no toxicological hazard; hence toxicological testing of foods so treated is no longer required" [9]. Following this recommendation, the radiation treatment of different foods is now legally accepted in many countries,

although is still prohibited elsewhere. Hence, there is a need for the development of methods which would allow the determination of whether foods have been irradiated. Such methods would serve for both prevention of illegal imports of irradiated foods and the control of labelling regulations.

According to the changes which occur in the food as a result of irradiation, chemical, physical or biological methods can be employed to identify irradiated foods.

Radiation-induced chemical interactions may manifest themselves through changes in physical properties. It is well known that the membranes of living tissues, whether of plant or animal origin, play a vital role for the selective transport of ions [24]. Impedance is a complex quantity depending on the frequency of the measuring alternating current.

Some studies about impedance measurement of irradiated potatoes were performed at the laboratory as a method to identify radiation processing [25]. Some related biochemical gamma radiation effects on potatoes were also studied [26].

On the other hand, the electron spin (or paramagnetic) resonance spectroscopy (ESR) is an established non-destructive method for the analysis of free radicals, used for radiation dosimetry, archaeological dating, analysis of peroxidizing reactions and more recently proposed as a method for identification of irradiated food [24].

In our laboratory, the detection of irradiated chicken by ESR spectrometry of bones was successfully attempted [27, 28]. The same ESR technique was used in order to identify irradiated cereals and flours [29, 30, 31, 32] as well as mollusc shells [33].

Radiosensitivity of seafoods was also studied, as this kind of food may be responsible for many foodborne diseases like *V. cholera* [34, 35]. In our experiments, the radiosensitivity *in vitro* of four strains *of V. cholerae* 01, exposed to different doses of ionizing radiation of ^{60}Co were studied. The D_{10} values of these strains are shown in Table 3.

Table 3. Average values of D_{10} of different strains of *of V. cholerae* 01 obtained for 0.5 and 1.0kGy radiation doses.

V. cholerae 01 strains	D_{10}	
	0.5kGy	1.0kGy
Non-toxigenic	0.10	0.11
El-Tor Inaba 008	0.13	0.12
El-Tor Ogawa 124	0.13	0.11
Classic Ogawa Vc12	0.11	0.11

Some experiments performed in partnership with the Biological Institute of Sao Paulo were able to proved the efficiency of radiation for disinfestation of some Brazilian fruits, mainly guavas [36] and bananas, that are attacked by *Opogona sacchari* as well as the seedlings of *Dracaena fragans* [37].

The viscosity of homogenates and suspensions of comminuted biological materials in solvents like water depends on the extent of the penetration of the solvent into the cells, and thus on cell wall permeability, which is affected by ionizing radiation [24]. Also several macro-molecules are changed, mainly by depolimerization or aggregation, and may contribute to a change in viscosity. Changes in viscosity of spices and other dehydrated vegetables suspensions were studied as a mean of detecting irradiated products [38][39][40][41]. Some results can be seen on Table 4.

Table 4 - Apparent viscosity of spices suspensions as a function of irradiation doses.

	Apparent viscosity (cP)			
Spices	Control	10 kGy	20 kGy	30 kGy
White pepper	154.5+/-9.8	12.0+/-1.9	7.1+/-2.2	4.0+/-0.3
Black pepper	966.6+/-8.5	63.6+/-4.9	9.2+/-0.2	5.4+/-0.7
Cinnamon	402.7+/-	15,5+/-8.6	7.3+/-1.5	6.3+/-0.2
Garlic	528.5+/-23.6	13.5+/-0.6	7.0+/-0.3	6.1+/-0.1
Nutmeg	1991.4+/-58.8	17.1+/-0.3	7.7+/-0.3	6.6+/-0.1

The same methodology was applied to study irradiated industrialized chicken eggs [42]. This is particularly important since irradiation is able to destroy efficiently *Salmonella*, a family of bacteria which occurs in the intestinal tract of humans and other animals that account for important foodborne diseases and contaminate frequently poultry and eggs as well [43]. The apparent viscosity did not significantly change in the irradiated egg white but some changes could be seen in yolk egg and the whole egg. When the temperature of the viscosity reading increased, the viscosity decreased. When a dose of 5kGy was employed, an increase of the viscosity as a consequence of radiation treatment became apparent. This was possible to be seen by using two different methods for evaluation of viscosity: a shear stress fixed at 7 dynes/cm^2, for egg white and yolk, and 10 dynes /cm^2 for whole egg as it can be seen at Figures 1, 2 and 3 for the 3 temperatures assayed. Another approach was based on the Bingham model, as plotted in Figures 4, 5 and 6.

Figura 1: Shear Stress Fixo - 5°C

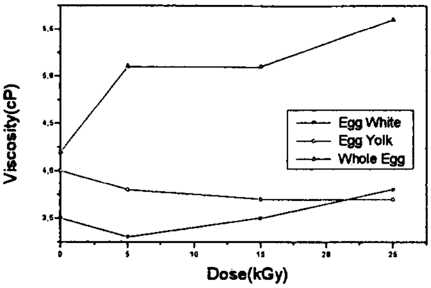


Figura 2: Modelo de Bingham - 5°C

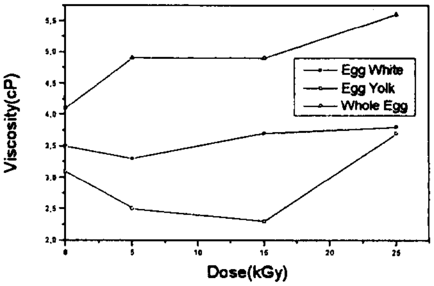


Figura 3: Shear stress Fixo - 15°C

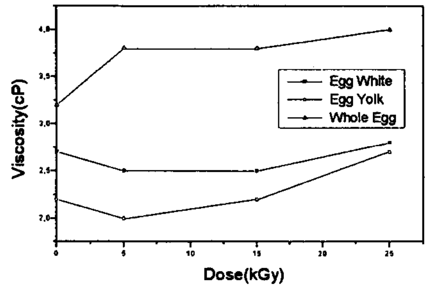


Figura 4: Modelo de Bingham - 15°C

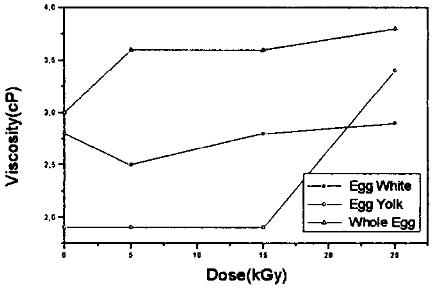


Figura 5: Shear Stress Fixo - 25°C

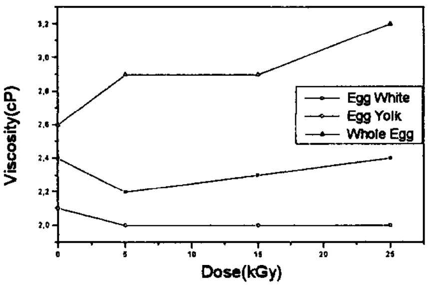
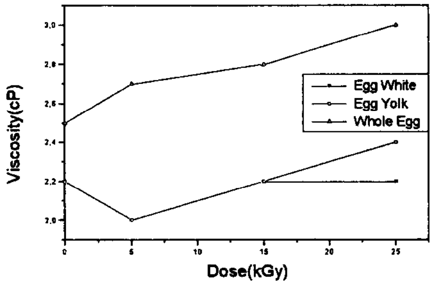


Figura 6: Modelo de Bingham - 25°C



Figures 7-14 display the results of our assays on viscosimetry of different fractions of industrialized egg. The egg white viscosity remained almost constant when irradiated with doses from 0 to 25kGy, being the maximum difference less than 10% at 5.0 °C and 15°C, and no differences at all at 25°C for any dose value, no matter the method employed to calculate the viscosity. On the other hand, egg yolk showed some differences in the rheological properties depending on the dose level. At 5.0 °C and 15.0 °C for the dose of 25kGy there is a significant increase (about 20 and 40%) in the viscosity only when the Bingham model was used.

Whole egg rheological behavior was not the sum of the respective behavior of white and yolk egg. The viscosity varied from 20 to 37% among the irradiated and the unirradiated samples for all the temperatures assayed.

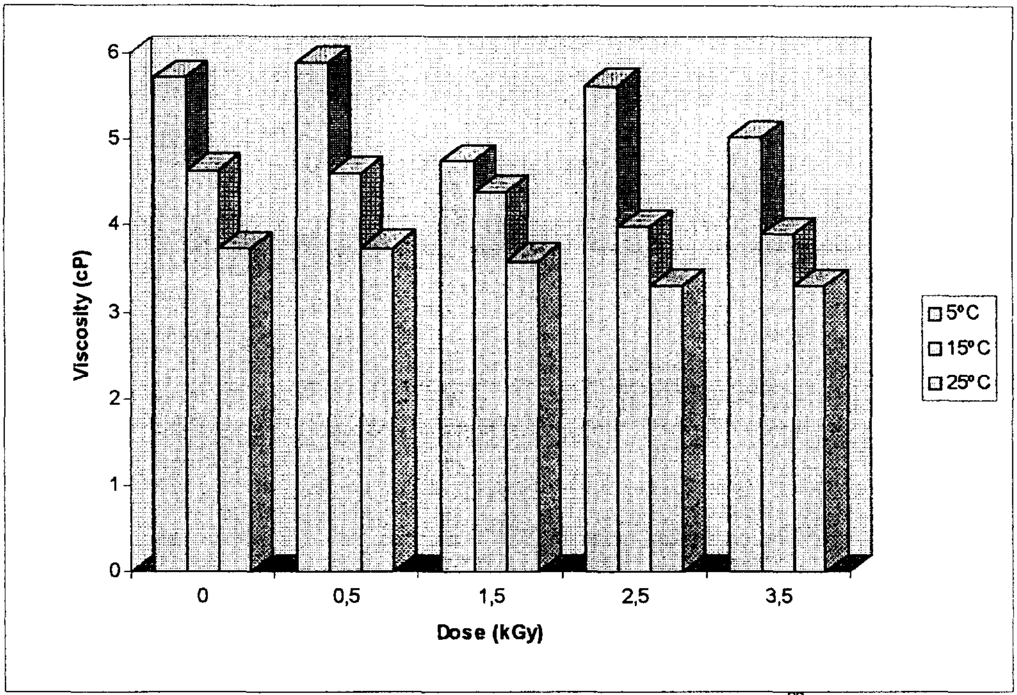


Figure 7. Variation of apparent viscosity of powder white egg treated by ^{60}Co gamma radiation, shear stress 10dy/cm^2.

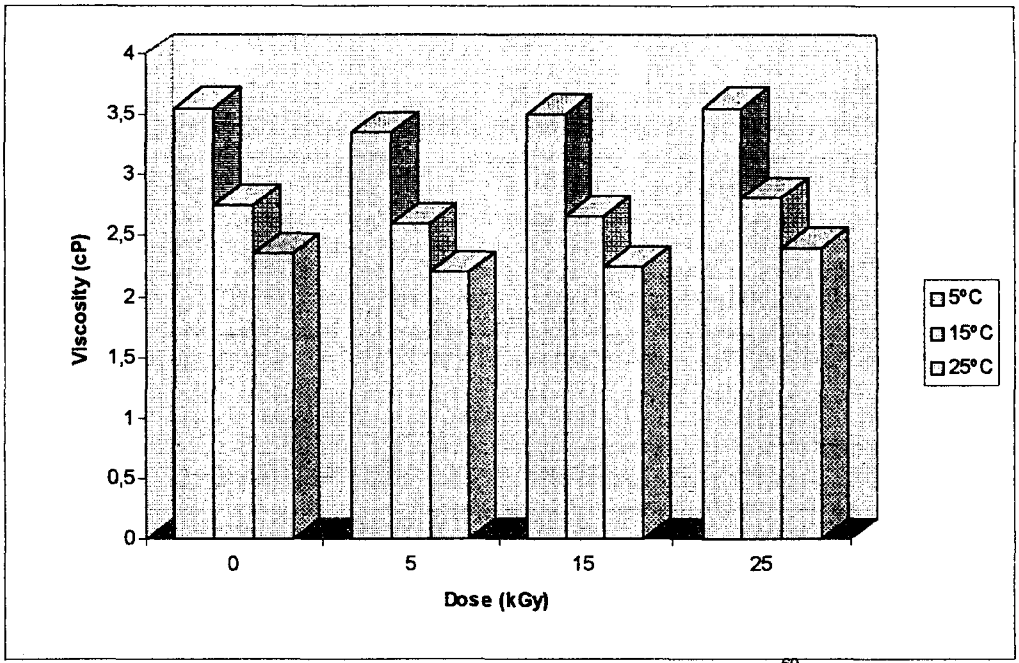


Figure 8. Variation of apparent viscosity of powder white egg treated by ^{60}Co radiation, shear stress 7 dy/cm^2.

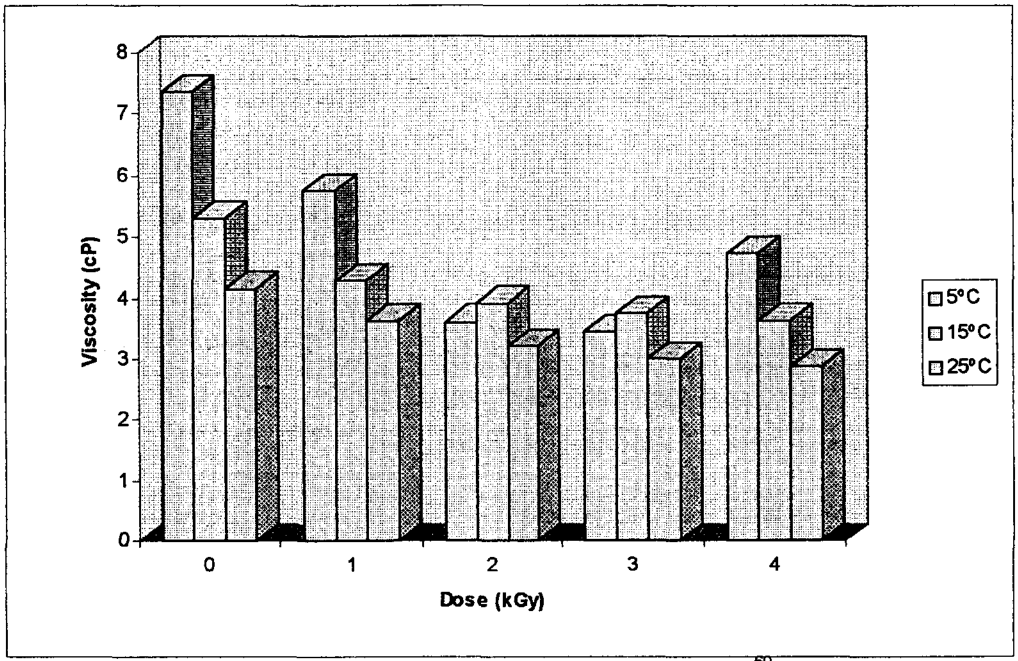


Figure 9. Variation of apparent viscosity of liquid white egg treated by ^{60}Co radiation, shear stress 11.5 dy/cm^2.

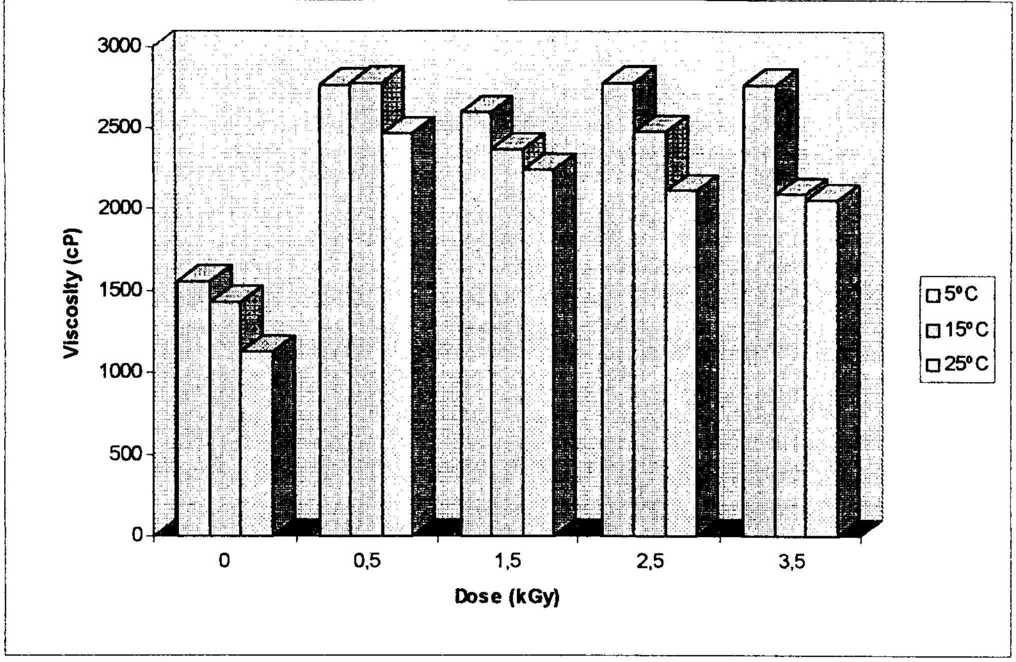


Figure 10. Variation of apparent viscosity of yolk powder treated by ^{60}Co radiation, shear stress 200 dy/cm^2.

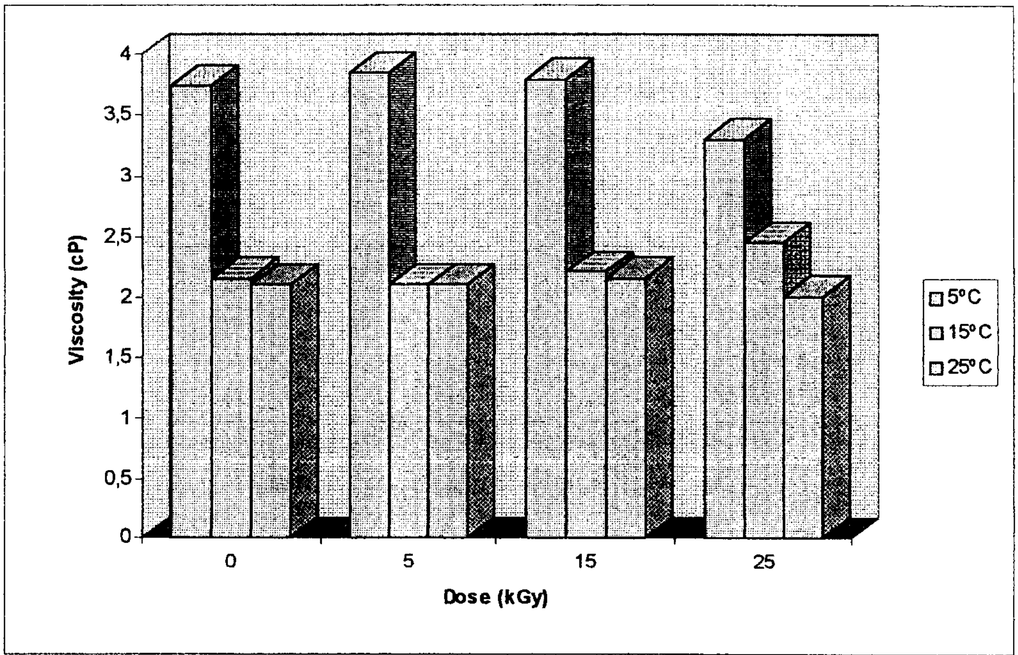


Figure 11. Variation of apparent viscosity yolk powder treated by ^{60}Co, shear stress 7 dy/cm^2.

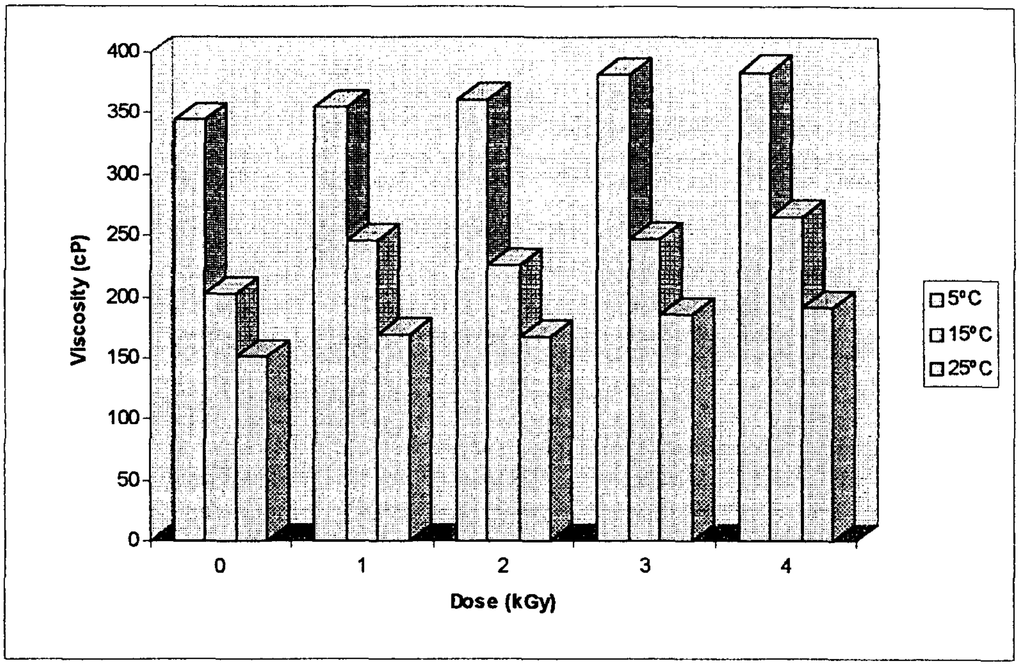


Figure 12. Variation of apparent viscosity of liquid yolk treated by ^{60}Co radiation.

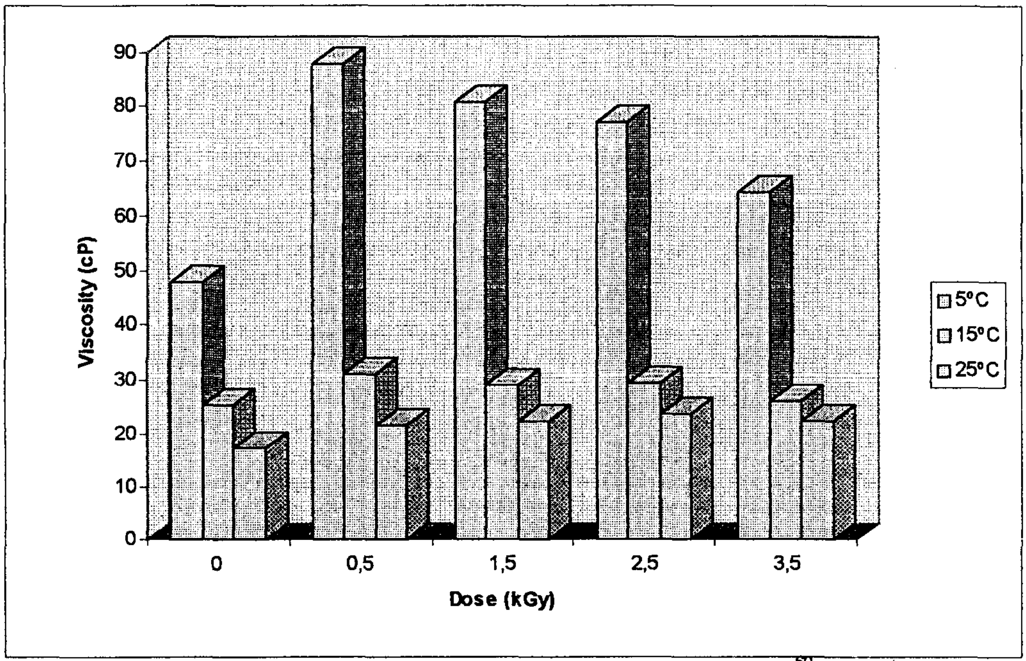


Figure 13. Variation of apparent viscosity of whole egg powder treated by ^{60}Co radiation.

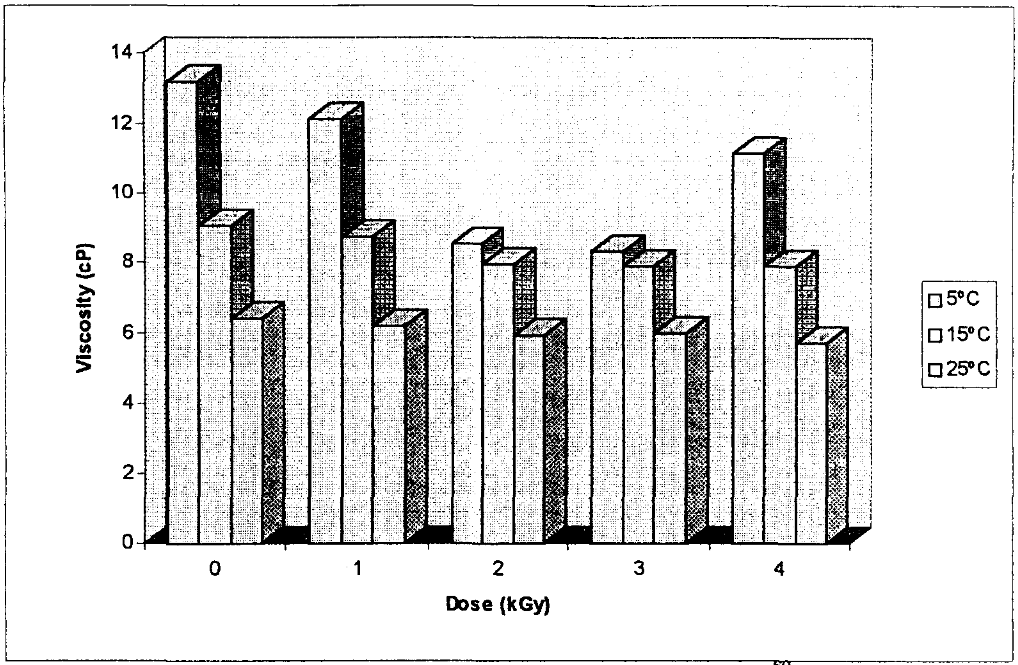


Figure 14. Variation of apparent viscosity of liquid whole egg treated by ^{60}Co radiation.

Irradiation reduced yolk color as a function of the radiation exposure (see Figure 7). The color of yolk extracted in light petroleum faded as a function of the dose, being the peak at 445nm completely absent when the dose went up to 1.5kGy. This is in agreement with the results from other authors who described that egg carotenoids are very susceptible to irradiation, as compared to carotenoids of some dry plant materials [44].

Yolk proteins seem to be more susceptible to radiation-induced breakdown than egg white proteins do. Also, dehydrated egg products are more susceptible to peroxidation due to an unfavorable high surface to volume ratio [45]. The dominant radiation-induced chemical changes in whole egg powder and egg yolk powder irradiated in air are degradative changes of lipidic components: the accumulation of lipid hydroperoxides and the destruction of carotenoids. For the food industry, it is also important the deterioration of protein functionality such as the foaming power of the egg white and the emulsifying capacity of the egg yolk.

The influence of Co-60 gamma radiation on the chemical and organoleptic properties of solid whole egg and solid egg yolk and egg white was studied by others to provide a basis for assessing the feasibility of the radicidation of *Salmonella* in egg powder [44]. The dose of 2.4kGy was described as adequate for a *Salmonella* inactivation factor of 10^3, being at the same time below both the induction dose to produce extensive degradation and the threshold dose of 3kGy to produce noticeable sensorial changes.

The results of our work showed that there were some changes in viscosity for whole egg powder but only slight changes for egg white powder or yolk and there was a color disappearance in the yolk as a function of dose. It seems that the sort of changes caused by radiation on chicken eggs will not impair its technological use providing at the same time a safer food product.

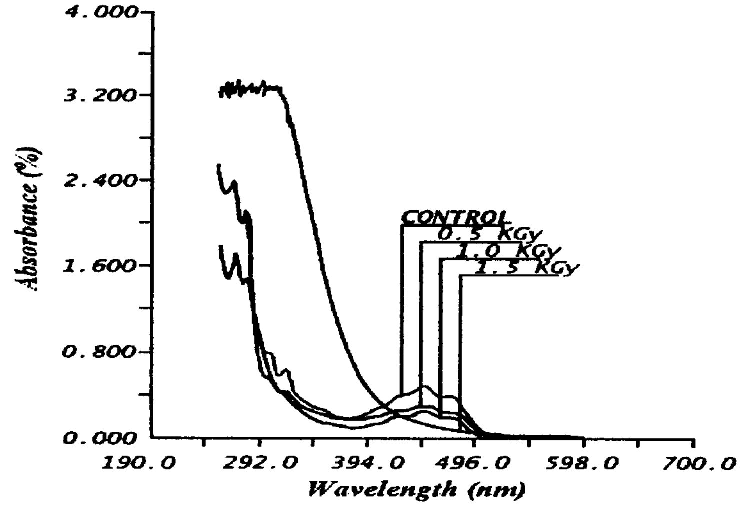


Figure 15. Absorbance (%) versus wavelength (nm) of extracted irradiated yolk.

Thermoluminescence (TL) is the emission of light upon release of trapped charge carriers by heating. As the result of irradiation part of the absorbed energy is stored by trapping charge carriers at impurity or defect sites in crystalline lattices. It is an established method in radiation dosimetry and has been introduced in the heighties for the identification of irradiated foods [24]. Viscosimetry, ESR and thermoluminescence (Table 5) was used to detect irradiated spices in our laboratory [45, 46, 47, 48, 49]. Table 6 describes the differentiation factors found esperimentally using the different physical methods. The application of a combination of analytical methods seems the most reliable way to identify irradiated foods.

Table 5 - TL signal intensities from irradiated spices.

Thermoluminscence (nC)				
Spice	Control	10 kGy	20kGy	30 kGy
Celery	0.45+/-0.03	6.5+/-0.1	7.2+/-0.1	8.0+/-0.3
Cinnamon	0.07+/-0.01	3.7+/-0.5	4.5+/-0.2	5.9+/-0.1
Cumin	0.35+/-0.04	12.1+/-2.6	13.5+/-1.5	15.7+/-1.0
Garlic	0.07+/-0.01	0.7+/-0.1	0.8+/-0.1	0.9+/-0.1
Paprika	0.06+/-0.02	7.0+/-2.0	7.6+/-0.1	8.7+/-0.1
Black Pepper	0.07+/-0.01	1.8+/-0.5	2.5+/-0.3	3.9+/-0.1
White Pepper	0.25+/-0.01	1.5+/-0.1	2.1+/-0.2	3.2+/-0.1
Coriander	0.45+/-0.03	6.5+/-0.3	7.0+/-0.3	7.9+/-0.1

Table 6 - Differentiation factors for spices anlyses.

Identification	Viscosity	TL	ESR
Very Good (factor >50)	Nutmeg	Cinnamom, paprika	
Good (factor 10-50)	white pepper, black pepper, cinnamom, garlic	celery, cumin, garlic, black pepper, coriander	
Limited (factor 2-10)		white pepper	white pepper, cinnamom, nutmeg, garlic
Bad (factor <2)	Cumin		black pepper

Some experiments on sensory analysis of irradiated foods were performed. Figure 16 and 17 present the results of 30 consumer opinion on the sensory evaluation of two varieties (Dower and Campineiro) of Brazilian irradiated strawberries. No significant differences were found on appearance, texture, colour, flavour and aroma among unirradiated and irradiated fruits.

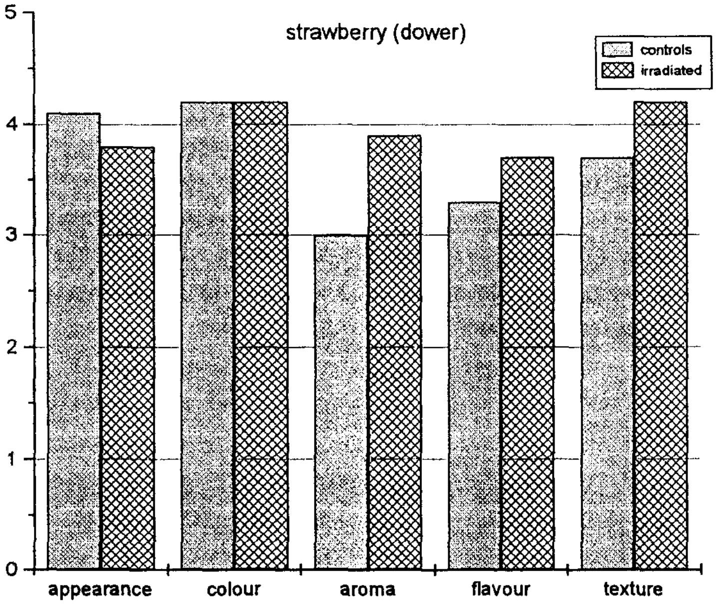


Figure 16. Sensory comparison among unirradiated and 2kGy irradiated strawberries, variety Dower.

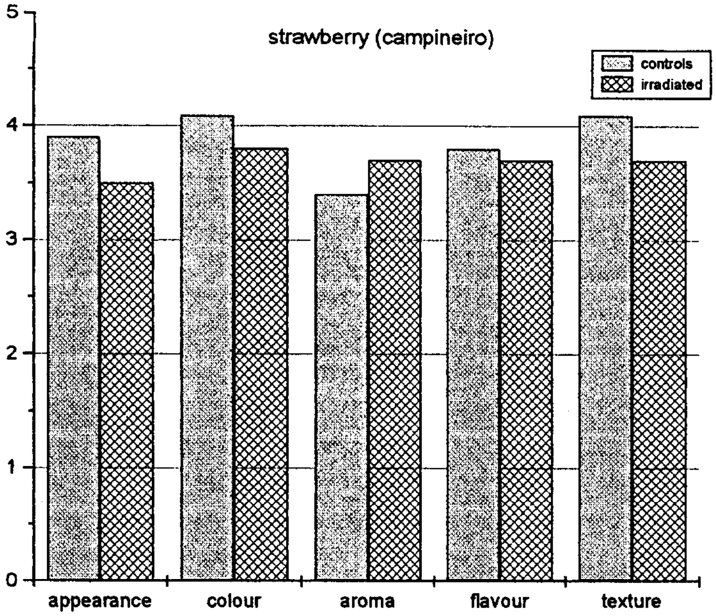


Figure 17. Sensory comparison among unirradiated and 2kGy irradiated strawberries, variety Campineiro.

New lines of research are at present being introduced. One is related to rheological properties of irradiated additives commonly used in food industry. Food hydrocolloids both from vegetal or animal origin are becoming extremely important in food technology. Another line is about the development of edible films or coatings. One of the most useful functions of edible films is their ability to act as barriers, either to gas, oil, or, more often, water. Moisture levels in foods are critical for maintaining freshness, controlling microbial growth, and providing mouthfeel and texture. Edible films can control water activity preventing either moisture loss or uptake. Radiation processing can contribute to this development bringing some advantages. As there is substantial evidence that radiation can improve the quality of alcoholic beverages a study on the irradiation of Brazilian "cachaça", a sugarcane spirit is being initiated.

CONCLUSIONS

The use of ionizing radiation on foods in Brazil offers a practical choice to industry to maintain quality and extend shelf life bringing benefits to those engaged in protecting the public health. International standards for irradiated foods will serve to strengthen national regulations, assure consumers and the food industry that the technology is being properly controlled, and facilite trade. The development of new lines of research seems to be very important for local economy and need. It is expected that the Brazilian experience in food irradiation will be helpful for the promotion of the commercialization of irradiated foods in Latin America.

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