Stewart Postharvest Review 2015, 3:3
www.stewartpostharvest.com
ISSN: 1745-9656

Irradiated food for special diets

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Purpose of the review: It is well-known that ionizing irradiation, as well as other preservation methods, extends food shelf life and controls microbial food-borne diseases. But it is not so evident that due to some peculiar characteristics (eg, high penetration - cold process) it can achieve better results in assuring the safety of ready-to-eat meals formulated for different consumers, ie, the immunocompromised, troops, astronauts, or adventurers.
Main findings: In some countries hospitalized immunocompromised patients have been fed with ready-to-eat meals irradiated at doses according to "clean diet" criteria, and these foods have obtained good sensory acceptability. This has allowed widening of food variety, thereby increasing the nutritional value of their intake. Similar findings were also reported concerning foods used for astronauts, troops and adventurers. Research is still ongoing in the field. However, today, these applications, though promising, seem to be occurring on a small scale.
Directions for future research: Cooperation between food irradiation researchers, nutritionists and physicians is essential to develop and improve new applications. Minimizing radiation doses might be feasible if it is combined with other hurdle technologies. More disclosure is needed mainly directed towards nutritionists, physicians, patients, and the staff of health institutes, catering services, food industry, supermarkets, and the general public. The establishment of national regulations related to this activity, hopefully internationally harmonized, are certainly needed, as well as availability of more food irradiation facilities.

Keywords: food irradiation; special diets; immunocompromise; troops; astronauts; alimentary emergencies

Introduction

Among other uses, ionizing radiation treatment of food, commonly called "food irradiation", can control microorganisms which impair consumer health. It is a physical method that prevents cell reproduction by damaging deoxyribonucleic acid (DNA) without increasing food temperature; for this reason the process is also known as "cold pasteurization". It allows fresh and raw products to be treated, and light polymeric materials to be used as packaging, two valuable options that are not attained by thermal microbicide treatments. Radiation doses are chosen to keep nutritional and sensory qualities minimally changed. Food irradiation wholesomeness is endorsed by many notable institutions, ie, World Health Organization (WHO). As the penetration of these radiations is high, food can be treated inside its closed package, avoiding microbial recontamination on handling. These features favour applications to ready-to-eat meals for special diets.

Microbial foodborne diseases

The prevalence of foodborne diseases takes place in both developing and developed countries. In the USA infectious diseases are the third most common cause of mortality, with 6.5-30 million infections per year, about 9,000 deaths and economic losses of more than US$ 5 billion [1**, 2, 3**]. In Germany there have been about 200,000 annual case reports of "enteritis infectiosa", mostly of domestic origin [4]. Microorganisms are also being incriminated as primary or cofactor agents in several diseases in which their role had not previously been suspected, such as arthritis, inflammatory bowel, neuromuscular disorders [1**].

Lifestyle and foodborne diseases

Factors cited as potential contributors to food-borne illness incidence in the 21st century include food supply globalization, new methods of food production and distribution, and increased reliance on commercial food sources [3**]. Travel, especially by air, has seen a phenomenal increase in recent years, so many human diseases can be spread throughout the world in a matter of hours [1**, 4]. Meals served on flights [5] and particularly on cruise ships have been reported to cause foodborne outbreaks. Population increase, as well as its density through urbanization, creates many environmental problems and human behaviours that impact directly on the spread of infectious diseases. It is also common knowledge that the level of mental stress is proportional to population density [1**]. Social changes such as smaller or single-parent families have important implications in home hygiene due to less time spent in housekeeping , as other pressing matters are prioritised. Shopping takes place less frequently but larger stocks are bought each time. Working parents and the need for many children and old people to feed themselves has led to meals being prepared several days in advance or to the consumption of ready-to-eat meals [1**, 6]. Warming up these meals in microwave ovens for a few minutes does not safely eliminate the potential for secondary contamination from microorganisms which subsequently occur in precooked foods. These microbes can cause infections and, in some cases, intoxications, because some of these toxins are heat stable [1**]. Canned foods do not fulfil the present preference for freshness and nutritional value that consumers demand. Other foods are stored under frozen or refrigerated conditions, most of them being minimally pro-

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doi:10.2212/spr.2015.3.3

cessed, which enhances the probability of conveying food-borne pathogens [7**].The automatic defrosting process of current refrigerators does not imply cleaning should not be done, which is frequently forgotten. The threat of diseases such as listeriosis has only been aided with the increasing use of refrigerators, where *Listeria* not only survives but also grow, because cold storage provides a false sense of security in the minds of many [1**]. Modern times have brought progress in household technology but altered eating behaviours; at home, most foodborne illnesses are the result of lack of proper knowledge and forethought in hygiene and food handling [1**, 3**, 4].

Aging population

The average life expectancy continuously increases worldwide; the aged in general are more prone to infections because immunological mechanisms slow down [3**]. When persons who are immunologically naïve or debilitated as a result of age, disease, or therapies, are crowded together in day-care centres, which happens for instance with children or the elderly, they are more prone to contracting infectious diseases [1**]. As the elderly population grows, more people are being cared for in nursing homes which are admitting increasingly frail persons with more complex medical and nursing needs [8, 9]. In Germany in 2001 there were 1.8 million patients outside hospitals in need of ambulatory care, of which 0.5 million received home care [4]. In the past older consumers turned to medicine and supplements to fight age-related illnesses; nowadays they, and consequently the food industry, are shifting towards healthier foods [6].

Immunocompromise

Immunocompromised persons have biological defences below those which are considered as "normal limits" due to illness, biological conditions, or situations generating risks. As examples of this, several patient categories can be stated: oncological, transplanted, malnourished, stressed after a high complexity surgical act, under radiotherapy or chemotherapy treatments, suffering from the Acquired Immunodeficiency Syndrome (AIDS) or tuberculosis, etc [7**]. Children, the elderly, pregnant women, persons in institutional settings such as hospitals, nursing homes, schools, correctional facilities, day-care centres, and shelters are also considered at risk [3**]. This enhances the probability of acquiring microbial food-borne diseases caused by pathogens such as *Listeria monocytogenes, Salmonella typhimurium, Escherichia coli O157:H7*, and so on. For most healthy people the distressful vomiting, abdominal cramps and diarrhoea are short lived, but for people with weakened immunity, symptoms are often severe and some infections can be fatal [2]. Some pathogenic bacteria like *L. monocytogenes* have been endemic but in the past decades its incidence has highly increased, not as a result of higher counts in foods, but due to the higher number of immunocompromised persons and the relatively lax food processing and storage methods [1**].

Traditionally, immunosuppressed patients in hospitals were maintained isolated from the environment, with their meals sterilized by different treatments, including irradiation [10**]. Food choices and palatability are severely limited when only canned foods that withstand autoclaving well are served. This sterilizing technology changes the quality of foods like bread, cereals, pastas, condiments such as sugar, powdered nutritional supplements and desserts, regarding their appearance, flavour and texture to such a great extent that patients reject the food. Oven baking does not consistently render sterile goods. Instead, radiation-sterilized foods have normal appearance and taste, two critical features when preparing foods for patients who have received chemotherapy and/or radiotherapy and are experiencing alterations in their taste perception, dry mouths, and oral and oesophageal ulcerations. Almost everything is a good reason for not eating [11**]. At present medical opinion differs from this approach due to the costs and specialized requirements, uncertainties about the clinical benefits, and the psychological convenience of treating these patients in a more natural way [10**]. Studies have shown that total isolation can lead to low morale and poor appetite. Food selection becomes the focal point for patient frustration and also affects their compliance with medical procedures. A wider food selection adds pleasure to patient meals, especially for children [12**].

Consequently, the tendency has been to move from "sterile diets" to " low microbe diets" ("clean diets", or "neutropenic diet"), which have been defined by some authors as containing < 500 bacillus colony-forming units (CFU) per gram of food, or < 1,000 CFU/g of coagulase-negative staphylococci or *Streptococcus viridans* , and < 10,000 CFU/mL Bacillus species, diphteroids or Micrococcus [10**]. However, patients with total immune system suppression will require completely sterile diets. Depending on the cancer type, up to 75% of patients do not die from the disease but from infection. The problem is further complicated because anticancer therapies are highly immunosuppressive, and lead to the breakdown of skin and mucosal lining natural barriers [13**].

In a study performed in the UK involving 43 hospitals where both adult and paediatric patients were undergoing bone marrow transplant [12**], results indicated that completely sterile diets, achieved by autoclaving or irradiation, were no longer indicated. Standards of acceptable microbial content needed to be established; until then each unit should agree on a written, low microbial protocol. Ready made cook-chill meals, as well as ice-creams [12**, 14], were totally restricted in 50% of the units; salads, in 92% of them. In many hospitals, meals are manufactured and cooked in their own kitchens; increasingly, however, they are prepared in advance by cook-chill and cook-freeze systems [8, 15], which do not assure microbial safety, and catering systems are outsourced. Between 1999 and 2004, four outbreaks of *L. monocytogenes* infection associated with sandwiches purchased from, or provided in, hospitals occurred in the UK [8]. Sandwiches were found to contain *Listeria sp.* more frequently than their component foods [16].

In another study, dietitians at 20 centres in the UK carrying out bone marrow transplant in children were asked for information on their current practice in "clean" diets [17]. The level of restrictions greatly varied among centres, in agreement with other reports [12**, 14,18]. The use of microwave ovens to cook food for these patients remains controversial [14]. High risk foods were listed as cooked meat and poultry, dairy products, cooked eggs and egg products, shellfish and cooked rice, raw vegetables and fruits, in coincidence with many other authors [12**, 14, 18–20] . Bread was toasted to kill surface yeasts; spices were cooked to destroy bacterial spores. However, the value of a low bacterial diet has not been demonstrable due to the difficulty of performing comparative studies that exclude the influence of other protective isolation components: limited physical contact, air filtration, and prophylactic antibiotics [15, 19, 21, 22]. In addition, the restriction of fruits and vegetables may disrupt the delicate balance of the gut flora and increase the risk of bacterial overgrowth and translocation. As it limits food choices, the neutropenic diet may compromise the overall nutritional status and increase morbidity [18, 20].

Food irradiation

Ionizing irradiation is probably the most studied food preservation method in history [23**, 24]. This technology has been tested for safety and efficacy for decades, and its use is endorsed by numerous health organizations [3**, 25, 26]. The American Dietetic Association supports the use of food irradiation to help those populations most at risk of food-borne illness [3**]. Radiation pasteurization may well become as important for improving the hygienic quality of solid foods as heat pasteurization was for liquid foods such as milk. This technology is being progressively adopted in an increasing number of countries, and more and more clearances on radiation decontaminated foods are issued or expected to be granted in the near future [27].

The Food and Environmental Preservation Section of the International Atomic Energy Agency has encouraged and supported much research on the subject by means of coordinated projects [28–31]. However, food irradiation has always generated an unusually intense level of public debate, particularly within the European Community, which has frequently been centred around unscientific and unsupportable statements that have nonetheless received extensive publicity. A realistic evaluation of the effects of irradiation on the nutritional quality of foods should be based on experiments carried out at doses used in practice or proposed for practical applications [24, 32**, 33**]. In contrast, 8,000 tons of meat products are annually treated in the USA [34], and increasing volumes of fresh fruits irradiated as phytosanitary treatment are being imported (13,000 tons in 2013) [35].

Irradiated food for the immunocompromised

Irradiation at non-sterilizing doses could widen the variety of "low microbe" meals used for the immunocompromised, either in hospitals or at home. The benefit would be not only nutritional but also psychological, supplying patients with a titbit to raise spirit, enhance appetite and make them fit in family and society [36]. At sterilizing radiation doses, nutritional losses will be greater and patients may require vitamin supplements, as happens with other food sterilising methods [37**].

Food scientists and technologists keep their interest on this subject worldwide. Certain refrigerated ready meals: roast pork and gravy, boiled potatoes and mixed vegetables, pureed portions of chicken and gravy, boiled potatoes and garden peas, which were consumed at some Belfast hospitals or used as "meals-on-wheels" for elderly people, when irradiated at 2 kGy attained "clean diet" microbiological conditions for 14 days, with thiamin and vitamin C losses comparable to those resulting from cooking [38]. Cooked frozen cheese hamburgers irradiated at 4 kGy, and minimally processed, refrigerated salad composed of lettuce, grated carrot, onion and "Cherry" tomatoes , irradiated at 2 kGy attained neutropenic diet conditions. Salad shelf life was extended until the 18^{th} storage day [39]. Other meals proposed for immunocompromised patients, eg, duck with orange sauce, chicken, salmon, white fish, fried potatoes, stuffed pancakes, rice with currants, and mashed potatoes and carrots, were vacuum packaged and irradiated between 12 and 40 kGy; these remained sterile for 11 months under refrigeration. Off-odour and off-flavour were detected only in the irradiated fried potatoes, which were rejected because of their softness [40]. A typical Philippine chicken meal called "Adobo", irradiated with 25 kGy, maintained good nutritional and sensory quality [41]. A ready-to-eat refrigerated meal composed of steak, gravy and mashed potatoes, irradiated at 5.7 kGy, reduced more than 6 log cycles of *L. monocytogenes* for at least 3 weeks, retaining good sensory quality [42]. Some typical Argentine meals, eg, cannelloni with tomato sauce, ham and cheese sandwiches, custard, and bread pudding, were irradiated for immunocompromised patients and were found to attain microbiological safety and very good sensory quality for at least 8 days of storage at refrigeration temperatures, which would allow a convenient week-long provision to hospitals [7**].

Fresh fruits and vegetables provide phytochemicals and other bioactive compounds that protect against degenerative diseases. Irradiation has minor effects on the antioxidants in plant produce, with some limited exceptions such as vitamin C [43]. Some ready-to-eat salads were inoculated with different non-sporulated pathogens and irradiated to assure hygienic quality, which was achieved at 1.2 kGy for chicory and mixed salad, 1.4 kGy for organic rucula, and 2.0 kGy for soy and alfalfa sprouts. The disinfection doses were effective even during storage without impairing sensory quality [44]. A 12D inactivation of *L. monocytogenes* was achieved by irradiating at -78°C mozzarella cheese with 16.8 kGy and ice-cream with 24.4 kGy [45]. Other authors found that total bacterial counts of creamy or water ice-creams irradiated at -20°C with 3 kGy were reduced by three log cycles, and natural *Staphylococcus spp.* and coliform contaminations were eliminated; sensory acceptability was good even at 6 kGy during 45 days of storage [36].

Honey consumption is not recommended for infants below one year and adults with weak immunity because it can contain microbial spores such as those causing botulism. When irradiated at 15 kGy it attained full microbial decontamination, retaining physical and biochemical properties regarding anti-mutagenic action, *in vitro* DNA protective ability, and anti-cancer activity [46]. Other authors reported a 2.3 fold log reduction of inoculated *Clostridium botulinum* spores in honey irradiated with 20 kGy; chemical parameters established by regulations to check quality and good manufacturing practices were not modified by this treatment [47].

Bread microorganisms are usually bacterial spores that survive the baking process, and yeasts and moulds from environmental contamination before packing. An Arabic bread irradiated with 6 kGy attained a 4-log-cycle reduction of sporulated bacteria, rendering it safe to be used as food for immunocompromised patients. The authors focused on ethnic foods such as Arabic bread, dates and spices, which might improve the comfort of these patients [13**]. Similar results were found with a traditional Indian bread irradiated at 25 kGy, which remained sterile for 6 months and had good sensory acceptability [48]. Irradiation has also proved useful in decontaminating sandwiches according to clean diet criteria [7**, 49, 50].

Feeding the immunocompromised with irradiated food

Time- sustained activities

In the UK, radiation sterilized diets have been offered to immunosuppressed patients since the early 1960s at the Hammersmith Hospital, London. From 1970 to 1988 a service was offered by Irradiated Products Limited (then Isotron) firstly at Wantage and then at Swindon. Some irradiated spices and tea were provided to patients at the Charring Cross Children´s Hospital, London, until its closure in 1993. A number of hospitals in Scotland also used radiations for the same purpose; the process was carried out at the Scottish Universities Research and Reactor Centre, East Kilbride [10**, 17]. The USA also applied this technology at the Fred Hutchinson Cancer Research Centre in Seattle; a broad group of foods: breads, noodles, pastry products, cereals, dry beverages, snacks, candies, condiments, and nutritional supplements, were sterilized by irradiation for bone marrow transplant patients between 1974 and 1988 with very good acceptability regarding aspect and taste. In 1978 they tested irradiated meats from a commercial firm; patients found them moist and tender, with normal and appealing appearance. Similar meats that were sterilized by autoclaving were dry and overcooked, and patients who suffered oral lesions and dry mouth were unable to chew and swallow them. The authors recognized that their bone marrow transplant program had been fortunate for having access to a local food irradiation facility at the Department of Fisheries [11**]. However, since then there has been a scarcity of references on the steady use of the irradiation technology for providing meals to the immunocompromised. A survey published in 2008 reported that few long term care facilities used irradiated ground beef or irradiated poultry products, and many of them were not adhering to national recommendations on the avoidance of certain foods considered high risk for elderly patients [9].

Research trials

Sterile ice cream and frozen yogurt which had been irradiated at 40 kGy were offered to 17 immunosuppressed patients recovering from bone marrow transplant, with good acceptability. However, higher ratings were obtained from a sensory panel of healthy individuals than from the patient panel, confirming that new foods for the low-microbial diet should be "market-tested" by the targeted patient population before inclusion in the menu [51]. Commercial freeze dried apples, pears, strawberries and pineapples were radiation-sterilized with 5 kGy, except grapes which needed 12 kGy for that purpose, without impairment of their sensory quality as tested by immunocompromised patients [52]. Between 2003 and 2004 a whole lunch composed of grated carrot, "Cherry" tomato and hard boiled egg salad; chicken and vegetable pasties; and fresh apple and pear pieces in strawberry jelly with soft cheese was irradiated, at different doses each dish, to attain safe microbial counts according to clean diets. It was tasted by 44 immunocompromised patients at the Clinical Hospital "Jose de San Martin", Buenos Aires, Argentina, with very good sensory acceptability. Colour was highly appreciated as they usually tasted cooked, brownish foods [7** 37]. In Pakistan in 2011, ethnic meals containing sprouted legumes, chicken, liver, pea, gourd and oil, vacuum sealed in multilayer pouches and nutritionally enriched according to recommended dietary allowances, were irradiated at 8 kGy to achieve microbial counts within neutropenic diet limits. These meals were offered to both breast and brain cancer patients during 3 weeks. During that time usual blood biochemical analyses were performed, which turned out normal, but most outstandingly: patients gained weight, which is very important for physical and psychological recoveries [53**].

Shelf-stable irradiated food for alimentary emergencies

Wars, natural disasters, poverty, migrations, drug-abuse, unsafe sex, malnutrition, chemical pollution, deforestation, climatic changes, and homelessness can also cause immunocompromise [1**]. In some of these situations, agriculture and food production are quickly and seriously impaired [54]. Food safety is at risk when storage and handling are improperly performed; in many cases cooking is not possible due to lack of fuel and facilities. Ineffective sanitation, including scarce drinking water and toilets, can multiply the risk [55]. Irradiation can help by providing shelf stable packaged foods which could have been manufactured and stored in advance as a precautionary measure. For example, a packed, highly nutritive, preservative-free bread, formulated to fulfil the requirements of people under alimentary emergencies, attained at least a 9-fold shelf life extension (43 days) at room temperature when irradiated at 6 kGy, maintaining its sensory characteristics and improving sanitary quality. It remained sterile for 9 months [56].

Irradiated food for troops

Napoleon is often credited with the axiom: "*An army travels on its stomach*". Because of military interest in food irradiation, which was hoped to eventually replace both canned and dried ration components [57], much of the early research (1950s – 1970s) was done to sterilize food by the Quartermaster Corps of the USA Army at the Food and Container Institute in Chicago, Illinois. Something similar happened in the Soviet Union. It was concluded that suitable, wholesome and economical rations could be obtained by irradiation [58]. In addition, the stability of rations is crucial to keep minimum inventory levels that can be quickly available on the initial phases of a military operation. The ideal military diet should have nutritional adequacy for arduous physical duties, a prolonged shelf life, increased packaging protection, and universal palatability to satisfy diversity of tastes and cultures. Nutritionists realised that no matter how balanced the ration was, it would only benefit the soldiers who consumed all of the components. Monotony seemed to be one of the biggest problems [57]. However, neophobia is of intrinsic interest in military rations because the food often does not have its familiar shape, colour and other sensory attributes [59].

In 1991 food distribution problems associated with operations Desert Shield and Desert Storm renewed the interest in irradiation to extend the shelf life of refrigerated foods for field use, and to produce shelf stable ration entrees. Field feeding is a crucial component of life quality and irradiation is a technology that can help simplify, resupply and reduce dependence on frozen storage, control foodborne pathogens in fresh foods and at the same time enhance soldier morale. The Army´s program was limited to selection and economic evaluation of candidate items for field feeding and support for expansion of commercial applications of food irradiation [58]. Though scientifically proven to be effective and superior to existing processes, irradiation was not used for USA military rations due to lack of public acceptance. Nowadays this technology is beginning to be considered a safe alternative process, so the army position could eventually change [57].

In South Africa in 1989, general clearance was obtained from the Department of Health to supply shelf stable irradiated food to the Defense Force (SADF); from then to 1995 about 1.8 million portions were sold to the SADF. The applied radiation dose was 45 kGy, equivalent to a 12 D dose for products without preservatives or nitrates. Many of the special forces used irradiated meat products like roast beef and pork with gravy, bacon, beef and chicken curry, which kept shelf stable for three years at room temperature, for long periods as their sole protein intake, without negative health issues on record. Starches and vegetables could not be successfully irradiated at high dose [60].

Irradiated food for outdoor activities

In 1992 the Atomic Energy Corporation of South Africa obtained approval from the Department of Health to sell to outdoor enthusiasts through selected hiking/outdoors shops acting as agents for irradiated shelf stable meat products, which have been used in Mount Everest expeditions, Cape to Rio international yachtsmen, and outdoor adventures such as hiking and river rafting. These products, packed with multilayer films lighter than metallic cans, have also been used by exploration teams and as emergency rations by mining companies, The outdoor market exists although it is limited in size (22, 000 portions in 1999) [60].

Irradiated food for space

Since the beginning of space exploration, animals have been an integral part of flight programs. In conducting animal studies, diet is important because nutrition affects physiological systems. The space environment has numerous conditions that can alter nutrient requirements such as stress, increased radiation exposure, group housing, and gravitational changes. Irradiation is useful in this case; for eg, NASA's short term (18- 20 days) animal feeding studies indicated that food bars treated with potassium sorbate and irradiated between 15 and 25 kGy were palatable, supported growth and maintained health in rats [61].

Several sterile irradiated products that have been developed by the USA Natick facility have been used for astronaut feeding in the NASA space programme and found to be highly acceptable [57]. Food shelf life should be one year, mostly without refrigeration. Palatable, enjoyable foods were considered an important factor in enduring nausea, weightlessness, isolation and eventual unknown dangers. Some people experienced a dislike for certain foods which they had not experienced on the ground. Some meals were hydratable such as casseroles, soups, vegetables and drinks; others were from the military, ie, ready–to-eat irradiated meats [58, 62]; natural-form foods like dried fruits, fresh fruits and vegetables (for early in the flight), pudding and candy. Ice-cream was greatly appreciated for the associated good memories [62**]. Fresh bread spoilage due to moulds even in the presence of chemical inhibitors was noted in early missions. All NASA flights from Apollo 12 to 17 carried fresh irradiated bread [63], and in Apollo 17, a sandwich composed of irradiated bread and irradiation sterilized ham was included in the diet. The combination of applying 0.5 kGy to the flour [64], a mould inhibitor and 2 kGy to the bread rendered an acceptable product for one month [65]. Bread that had been vacuum packed and then stored for months looked and tasted like paste. Some odd technological issues should be also considered, ie, crumbs are problematic because debris drift about the cabin and into eyes and noses before being pulled into air filters. On early Shuttle flights, irradiated bread slices, individually packaged, had a long shelf life and were guaranteed to be free of any bacteria or fungi, but they did no taste good. There was a relative monotony of the diet and the urge for a little variety. For astronauts, sharing food is a source of relaxation, entertainment and fun in addition to the nutrient consumption [62]. In 1995 the FDA approved the irradiation of frozen meals at a minimum dose of 44 kGy for use by NASA astronauts [60].

The Korean Atomic Energy Research Institute has also used irradiation technology, sometimes in combination with freeze drying, to develop traditional meals for use as space food. Microbiological requirements were followed according to the Russian Institute of Biomedical Problems which certifies products for use in the International Space Station. Sensory quality of space food is important to prevent malnutrition, as astronauts tend to avoid consuming unappetizing meals. A traditional Korean meal called "miyeokguk", composed of cooked beef, sea tangle, garlic, salt and water, when freeze-dried, packaged and irradiated at 10 kGy, fulfilled microbiological requirements as space food [66].

Consumer perceptions about irradiated food

Widespread use of irradiation remains controversial because of public concern regarding the safety of the technology and the wholesomeness of irradiated foods [67]. In the USA, a survey on foods processed by emerging technologies was administered in 2007 to 225 potential consumers belonging to three groups: mall shoppers, military troops, and laboratory employees. Results showed that lack of knowledge regarding food technologies impaired acceptance, while product tasting reduced reluctance [68, 69]. Among the processes that consumers were most concerned about were genetic engineering, bacteriocin addition and irradiation in successive order. The potential risk associated with the product had the greatest importance in determining consumer interest for the three respondent groups, followed by the processing method, the endorsing agency, and the product type. Animal-based (versus plant-based) products were perceived as more risky with respect to novel processing technologies. Better taste and better nutrition were highly appreciated by all the groups; the military respondents, being young and male, attached the lowest importance to risks associated with the products [69]. In a German survey addressed to the general public in 2001, to the question "which of the following foodstuffs represent a risk to your health?", the order of responses was: irradiated food; meat from animals treated with hormones; food with chemical additives; food with preservatives. The risk from food infections appeared not to be recognized [4].

A survey carried out in a health care service in the UK in 2008 showed that lack of product information and availability were the most frequently reported reasons why facilities did not use irradiation or thermal pasteurization; safety, nutritional and organoleptic quality concerns about these processes were less frequently reported. [9]. In Argentina from 2003-2004, 44 hospitalized immunocompromised patients who tasted a whole irradiated lunch not only afforded the highest sensory qualifications to the meals, but also were amazingly receptive to food irradiation considering that the method had been unknown to them until then. They expressed their gratitude for caring about their health and joy, and hoped such meals could be commercially available [7].

Conclusions

Ionizing radiation treatment, associated with good manufacturing practices, has been proven to be effective in controlling pathogenic microorganisms in ready-to-eat foods, affording a diet diversification for the immunocompromised with nutritional and psychological benefits, as well as safer products for the general public. However, since knowledge about food irradiation capacities and wholesomeness is still scarce to many, more disclosure is needed mainly directed at nutritionists, physicians, patients, and the staff of health institutes, catering services, food industry, supermarkets, and general public. Many immunocompromised persons lead a fairly "normal" life out of hospitals, so commercial availability of safe, varied, nutritious and appealing ready-to-eat irradiated meals would contribute to their health and well-being.

Collaboration between food irradiation researchers, nutritionists and physicians is considered essential to go further on new applications. Finding the best conditions, doses, and combination treatments [70, 71] is another challenge that food irradiation face in order to minimize nutritional and sensory losses, for the benefit of the immunocompromised or any other "target" group in need of special diets. Infectivity capacity and statistical estimations about regular microbial contamination in foods should be evaluated and taken into account when choosing radiation doses, in order to use the lowest one which guarantees safety. The establishment of national regulations related to this activity, hopefully internationally harmonized, are certainly needed, as well as the availability of more food irradiation facilities.

Acknowledgements

Librarian Silvana Semino, Head, Documentary and Information Centre, Ezeiza Atomic Centre, National Atomic Energy Commission- Argentina, is gratefully acknowledged for the prompt and efficient provision of literature .

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