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FOOD IRRADIATION FOR SPACE APPLICATIONS

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Abstract: *As manned space exploration develops and deep space flights become a reality, ensuring the safety and longevity of astronauts on board becomes of paramount importance. One of the important problems is the preservation and safety of food during long flights. Food irradiation is emerging as a promising method to address these issues, offering reliable ways to improve food safety and extend shelf life. This article explores the fascinating world of food irradiation and its significant role in the space industry.*

ОБЛЪЧВАНЕ НА ХРАНИ ЗА КОСМИЧЕСКИ ПРИЛОЖЕНИЯ

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Ключови думи: *радиация, хранително-вкусова промишленост, облъчване на храни, космическа храна, космическа радиация, космическо пространство, космическа среда, материалознание, космически приложения*

Резюме: *С развитието на пилотираната космонавтика и превръщането на мисиите в далечния космос в реалност, осигуряването на безопасността и дълголетието на астронавтите на борда на космическите апарати придобива първостепенно значение. Един от важните въпроси е съхраняването и безопасността на храната по време на дълги полети. Облъчването на храни се очертава като обещаващ метод за решаване на тези проблеми, предлагащ надеждни начини за подобряване на безопасността и срока на годност на храните. Тази статия е посветена на очарователния свят на облъчването на храни и неговата значителна роля в космическата индустрия.*

Introduction

Food quality is a priority and a major issue not only for food professionals. It is of paramount importance for all people and countries of the world, for the survival and progress of mankind and therefore for the aerospace industry.

With advances in space exploration and the increasingly realistic possibility of interplanetary travel, ensuring the health and livelihood of astronauts during extended missions is becoming a critical challenge. One innovative solution that addresses this problem is food irradiation [1–9], a process that is gaining momentum for its ability to preserve and extend the shelf life of foods while protecting them from microbial and other contamination.

Food irradiation and use of radiation in foods

Food irradiation is the process of exposing food and packaging to ionizing radiation, such as gamma rays, X-rays, or electron beams Food irradiation improves food safety and extends the shelf life of products (preservation) by effectively destroying organisms responsible for spoilage and foodborne illness, inhibits germination or ripening, and is a means of controlling insects and invasive pests. The term "food irradiation" can be applied to any process in which food is exposed to either electromagnetic radiation or high energy particles.

Electromagnetic energy can be generated by radioactive isotopes, as in the case of gamma irradiation, or by bombarding thin metal films with high-energy electron beams to produce radiation, as in the case of x-ray irradiation. Alternatively, a high-energy electron beam ("electron beam") can be directed at the food itself.

The mechanism of action of irradiation on the destruction of harmful microorganisms in food is the destruction of the DNA of their cellular structures. The effectiveness of the radiation treatment depends on the type of radiation used, the intensity of the radiation, and the microbe in question. Regardless of the form, food irradiation mainly depends on how much energy is absorbed by the target food. It is useful to measure how much radiation dose will be required, regardless of the amount of food to be irradiated. For this reason, radiation doses are measured in kilogray (kGy) [2].

Food irradiation is now permitted in about 70 countries, and about 600,000 metric tons of food are processed annually worldwide. The regulations for how food is to be irradiated, as well as the foods allowed to be irradiated, vary greatly from country to country. In Austria, Germany and many other countries of the European Union only dried herbs, spices, and seasonings can be processed with irradiation and only at a specific dose, while in Brazil all foods are allowed at any dose.

The main causes of losses of agricultural products (up to 40%) are related to the damage of grain and grain products by insect pests. insect pests, premature sprouting of root crops, bacterial spoilage of flour, meat, fish and other food products during storage. Radiation treatment of foods extends their shelf life without significant qualitative changes in their nutritional performance.

The advantages of food processing with ionizing radiation are:

- easily applicable technology;
- the procedure is carried out in a package;
- no secondary contamination;
- non-toxic;
- not an energy-intensive technology;
- the environment is not polluted.

Requirements for radiation technologies are the subject of a number of international documents, but the main standards are those of the Codex Alimentarius:

- General Standard for Irradiated Foods and
- International Recommended Guide for the Radiological Treatment of Foods.

Technological objectives in food irradiation are:

- prolongation of storage life;
- sterilization - they are good for years without refrigeration;
- slowing the vision of fruits and vegetables;
- retarding the sprouting of root vegetables;
- control of disease-causing microorganisms.

Since 1943, experiments have begun on the use of ionizing radiation for sterilizing and preserving food products. Treating foods with ionizing radiation preserves them and destroys or inhibits the growth of microorganisms, such as bacteria and parasites, which might otherwise cause foodborne illness. Microorganisms are distinguished by extremely high radiation resistance.

Food irradiation has been approved by many countries and is supported by the World Health Organization. For example, in the U.S. and Canada, food irradiation has existed for decades.

Food irradiation is used commercially and overall volumes are increasing slowly, even in the European Union where all member states allow the irradiation of dried herbs, spices and vegetable flavourings but only some allow other foods to be sold as irradiated.

Although some consumers choose not to purchase irradiated products, there is a sufficient market for retailers to stock irradiated products permanently for many years. When labeled irradiated products are made available for retail sale, consumers purchase and re-purchase them, indicating that there is a market for irradiated products, although the need for consumer education remains.

Food scientists have concluded that any fresh or frozen food subjected to irradiation in certain doses is safe to eat, with over 60 countries using irradiation to maintain the quality of their food supply.

Irradiation leaves a product with qualities (sensory and chemical) that are more similar to unprocessed food than any preservation method that can achieve a similar degree of preservation.

Irradiated food does not become radioactive; only power levels that are incapable of causing significant induced radioactivity are used for food irradiation.

The provisions of the Codex Alimentarius are that any "first generation" product must be labeled "irradiated" as any product derived directly from an irradiated raw material; for ingredients the provision is that even the last molecule of an irradiated ingredient must be listed with the ingredients even in cases where the unirradiated ingredient does not appear on the label. The RADURA-logo is optional; several countries use a graphical version that differs from the Codex-version. The proposed published labelling rules (from Codex Alimentarius) include the use of the Radura symbol for all products that contain irradiated food. This is necessary because irradiated food cannot be determined by smell, sight or taste.

In the USA all irradiated foods must include a visible Radura symbol followed in addition by the statement "treated with irradiation" or "treated by irradiation". Bulk foods must be individually labeled with the symbol and statement or, alternatively, the Radura and statement should be located next to the sale container.

The European Union does not provide for the use of the Radura logo and relies exclusively on labeling by the appropriate phrases in the respective languages of the Member States.

The "Radura" symbol (recommended by Codex Alimentarius), which is required by U.S. Food and Drug Administration regulations to indicate that food has been treated with ionizing radiation, is shown in Fig. 1.

Fig. 1. The logo is the symbol “Radura”. This is the international symbol indicating a food product has been irradiated. The logo is usually green and resembles a plant in circle. The top half of the circle is dashed. Graphical details and colors vary between countries.

Advantages and benefits of using irradiated foods for space applications

The US Food and Drug Administration has approved irradiation of food for limited purposes since 1963, and NASA has used irradiated food on its space missions for decades as a precaution against foodborne pathogens. However, it is only in the last 20 years that irradiation has been approved for uses that could have a significant impact on the presence of pathogens in food.

Developing food for space missions is a complex process. These products must be extremely durable, high energy density, incredibly nutritious and portable. In addition, different types of food for different types of consumers should be considered. Although modern technology has increased the shelf life of some foods to 3-5 years, this still does not meet some stringent requirements. The creation of new technologies or the combined use of several existing technologies is necessary to achieve a longer shelf life. This combination provides not only an extremely long shelf life, but also specific functional characteristics of specialized food products. To support long-term space missions, food scientists and researchers are focusing primarily on the shelf life of food products.

Below are 20 reasons to use irradiated food on aerospace missions:

1. Improving food safety. Irradiation effectively kills or reduces harmful bacteria, viruses and parasites, minimizing the risk of foodborne illness in space;

2. Increased shelf life. Irradiation helps maintain the quality and freshness of food for a longer period, making it suitable for long space missions where resupply is limited;

3. Nutrition conservation. Irradiating food does not significantly change the nutritional value of the food, ensuring that astronauts receive essential nutrients during space travel;

4. Reduce food waste. By extending the shelf life of food, irradiation helps minimize spoilage and waste, maximizing the use of available resources in space;

5. Improving the quality of food. Irradiation helps preserve the taste, texture and appearance of food, ensuring that astronauts can enjoy a varied and enjoyable diet during their missions;

6. Increasing food availability. Irradiation allows a wider range of food products to be used in space by reducing potential contamination risks and allowing perishable foods to be stored for longer periods of time;

7. Ensuring sterility. Food irradiation can effectively sterilize food, destroying harmful microorganisms and keeping food safe for consumption, especially in sensitive environments such as space;

8. Reduced chemical dependency. Irradiation can replace or reduce the need for chemical additives, preservatives and pesticides in foods, providing a cleaner and more sustainable solution;

9. Pathogen control. Food irradiation can target specific pathogens present in foods, reducing the risk of outbreaks and increasing the overall safety of the food supply in space;

10. Support off-planet agriculture: Irradiation can be used to treat seeds and plant material for space agriculture, ensuring the production of safe and disease-free crops for sustainable food production in space habitats;

11. Adaptability to different types of food. Food irradiation is applicable to a wide range of food products, including fruits, vegetables, meats and ready-to-eat meals, allowing for a varied and nutritious diet in space;

12. Convenience and storage. Irradiated foods do not require long-term refrigeration or complex storage conditions, making them easy to transport and handle in confined spaces;

13. Reducing the content of allergens. Irradiation can reduce allergenic proteins in some foods, providing safer dining options for people with allergies or sensitivities;

14. Control of invasive species. Irradiation can be used to treat foods that may carry invasive species or pests, preventing them from establishing and spreading into space habitats'

15. Saving time and resources. Irradiation dramatically reduces the need to manually inspect and sort food, saving valuable time and resources during space missions;

16. International recognition. Food irradiation is recognized and approved by international organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), making it a globally accepted method of ensuring food safety;

17. Increased emergency capacity. In emergency situations or unforeseen circumstances, irradiated food can be quickly used as a safe and reliable food source for astronauts in space;

18. Support for long missions. The use of irradiated food could support long-duration missions by providing astronauts with a sustainable and varied diet that promotes their physical and mental well-being during long periods in space'

19. Mitigate supply chain problems. Irradiation could help overcome problems associated with inconsistent supply chains in space exploration by extending the shelf life of food and reducing the need for frequent restocking;

20. Future Potential: Further advances in food irradiation technology may unlock additional benefits such as improved nutrient retention and improved food quality, thereby continually improving the nutritional options available to astronauts in space.

The future of food production will be shaped by technological advances such as 3D food printing and space gardening. Additionally, a number of experiments are being carried out by space agencies to enable future space travel. Research on environmentally friendly packaging materials is being conducted to reduce the weight of space flights. Biofilms that prevent microbial growth and increase the shelf life of the product is currently at least five years are being developed by researchers. In addition, the development of food products for space will be achieved through the cooperation of several space agencies.

The situation in Bulgaria

In 2008 for the first time in Bulgaria, a device for irradiating food was registered: gamma-sterilizer BULGAMMA of SOPHARMA AD, manufactured by NORDION, Canada [3]. The irradiator is a panel type loaded with ^{60}Co sources with a total source activity of 100,000 Ci. The products are irradiated in aluminium containers with a volume of 0.25 m^3. The containers are moved by a conveyor system into the irradiation chamber.

For radiation treatment of food in European Union (EU) it is allowed to use:

- gamma radiation from radioisotopes cobalt and cesium;
- X-rays with electron energy below 5 MeV;
- accelerated electrons, with electron energy up to 10 MeV.

To date, only these foods are allowed to be treated with ionizing radiation in our country [2, 4]:

- dried aromatic herbs;
- dried spices;
- dried vegetable spices.

Although certain exposures are permitted in the EU, they also require authorization from the relevant national authority of the Member State.

Ethical Considerations

There may be ethical concerns regarding the acceptance of irradiated food by astronauts and the general public. However, it is important to note that food irradiation has been researched extensively, and numerous international health organizations, including the World Health Organization (WHO), the United Nations Food and Agriculture Organization (FAO), and the U.S. Food and Drug Administration (FDA), have approved its use as a safe and effective food preservation technique.

Irradiated products do not become radioactive. A radioactively contaminated product is a product that, for some reason, contains radionuclides and it (or its components) has radioactivity.

The product treated with radiation cannot acquire radioactivity, because during the radiation treatment there is no direct contact of the radioactive substance with the product, and the dose rate of gamma radiation or electron radiation is allowed in the processing of food products according to international standards completely eliminates the possibility of induced radioactivity.

Key advantages of food processing technology using irradiation: The most studied preservation method to date; Accelerated electrons penetrate the packaging, which protects the product from subsequent bacterial contamination; Processing does not change the taste and smell; The temperature increase during processing does not exceed several degrees; The technology does not restore the quality of spoiled food and cannot replace quality food production methods.

In the USA and other countries, systematic educational advertising is carried out about the safety of food products after their radiation treatment. Legislative acts, international agreements are indicated, and the quality of processed and unprocessed products is compared.

All this contributes to the promotion of products in the markets. More than 600 radiation centers have been created around the world; the leaders are the USA and China. Food and agriculture is the third largest segment of the global radiation technology market. In China, more than 80 centers irradiate food.

Challenges and future directions

- There are potential limitations and challenges in applying food irradiation in space, such as energy requirements and equipment considerations.
- Research is forthcoming on advances in food irradiation techniques for space applications, including the development of compact and efficient irradiation systems.
- The important collaboration between space agencies, food scientists and engineers to further improve food irradiation for space exploration should be strongly developed.

There are other alternatives regarding the delivery of food for a long-term mission [5]. Instead of bringing food to Mars, visionaries and explorers focused on growing and processing food on the planet Mars. This issue provides much research on food production and food processing related to the Mars project.

Conclusion

We have reviewed only a small part of the vast topic of aerospace applications of irradiated foods. Food irradiation effectively improves food safety/security and extends food shelf life. The use of radiation is one of the most promising and rapidly developing technologies to solve these problems.

The planned landing of man on Mars will take place as an international project, but not before methods and materials are invented to protect people and equipment from space radiation, and not before the problem of feeding astronauts is solved.

Food packaged for future deep space exploration missions will be exposed to galactic cosmic rays (GCRs) and solar radiation in deep space at higher levels and in different spectra than in low Earth orbit (LEO) [6]. This is where the use of radiation will certainly help in the production of space food. The study [6] evaluated the effects of simulated GCR (approximately 0.5 and 5 Gy doses) at the NASA Space Radiation Laboratory (NSRL) on two retort heat-stabilized food products that are good sources of radiation-labile nutrients (thiamine, vitamin E, or unsaturated fats). No trends or differences in nutrition were found between radiation-treated samples and controls immediately after treatment or one year after treatment. Small changes in several nutrients were measured after one year of storage. Further studies may be needed to confirm these results, as the foods in this study were heterogeneous and this may have masked significant changes due to bag-to-bag variation. Therefore, future studies should focus on homogenous, high-moisture foods for spaceflight, which are good sources of radiation-labile nutrients, such as thiamin and vitamin E.

Food irradiation stands as a promising solution for enhancing food safety and preservation in space applications. As space exploration progresses and humanity ventures into deep space missions, ensuring astronauts have access to safe, nutritious, and long-lasting food supplies becomes increasingly crucial. Food irradiation not only eliminates harmful pathogens and extends shelf life but also retains the nutritional value of food. By embracing this technology, we pave the way for successful long-duration space missions, pushing the limits of human exploration and discovery.

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