FOOD IRRADIATION: HISTORICAL PERSPECTIVE AND STATUS IN INDIA

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ABSTRACT

Food irradiation has emerged as a pivotal technology in the realm of food preservation and is gaining increased importance in food and agricultural sectors. The technology uses ionizing radiations emanating from either radioactive or machine sources in facilities designed for this purpose. It can be effectively utilized for the extension of the storage life of agricultural commodities, and elimination of harmful microorganisms, insects, and parasites for mitigating risk of foodborne illnesses. It is also used to destroy quarantine pests to overcome barriers in international trade. The technology is well entrenched in the historical developments and understanding of the sources of ionizing radiation, and their biological effects including those on agricultural commodities and foods. Its commercial application for large scale public use was approved by the national and international health regulatory authorities only after carefully examining a large volume of scientific evidence vouching for the overall safety of the radiation processed food for the consumption by human being. India being one of the world's largest producers of agricultural and horticultural commodities incurs significant post-harvest related economic losses annually. Food borne illnesses also cause huge burden on Indian economy. For preventing these losses, the country needs to integrate food irradiation technology with its vast food supply chains for improving food safety and security.

1. Introduction

Radiation processing of food, also called food irradiation, is an important emerging technology for integration in country's food supply chains, for extending shelf life and improving its safety. Ionizing radiations are the most effective means to destroy harmful insect pests, parasites and microbes in food and agricultural commodities. Ionizing radiation can also be used to control certain physiological changes including ripening as well as senescence in various fruits, vegetables, and sprouting in bulb and tuber crops. The dose dependent beneficial effects of ionizing radiation do not compromise the nutritional and sensory attributes of food commodities. The commercial adoption of the technology by the industry started only after decades of scientific research, safety assessment of irradiated food, and stringent global regulatory oversight approved its use for ensuring food security, food safety, and facilitating international trade. India, being one of the world's largest producers of a diverse variety of agricultural and horticultural crops incurs significant post-harvest related economic losses annually. For preventing these losses, the country needs to integrate food irradiation technology with its food supply chains, making it an important component of its food safety and security strategies. Thus, food irradiation technology will not only help reduce post-harvest losses in agricultural and horticultural commodities, but also help their export to countries meeting stringent quality as well as quarantine standards in international trade. The active role that the government has played in promoting research and development in food irradiation, establishing regulatory framework, setting up of commercial technology demonstration units, and promoting entrepreneur development, underscores its commitment for leveraging this technology for the benefit of farmers as well as entrepreneurs, both in domestic and global markets, ultimately benefiting the public at large.

2. Historical developments

2.1. Early discovery of radiation and its potential uses

In 1895 and 1896, Rontgen and Becquerel discovered ionizing radiation X-rays, and Gamma rays, respectively. Shortly thereafter the bactericidal and therapeutic properties of these radiations were discovered. The whole idea of utilizing ionizing radiation for food preservation quickly gained importance, primarily due to its ability to penetrate deeply and effectively destroy spoilage organisms and harmful pathogens in the food. In the early year of 20th century, initial patents were granted in the United Kingdom and the United States, and Germany for the using ionizing radiation for food preservation. Food irradiation was primarily a part of the global efforts to explore biological effects of ionizing radiation during first half of the twentieth century. X-rays were shown to kill eggs, larvae as well as insects, in tobacco leaves, and *Trichinella*, a parasite in pork. In 1953 the then US president Eisenhower announced his famous 'Atoms for Peace' program that gave a much-needed boost for exploring peaceful uses of ionizing radiation including food irradiation in the R&D institutions around the world. In India this journey started in 1954 under the great leadership of Dr. Homi Jehangir

Bhabha, the founder of India’s Atomic Energy Program.

2.2. Start of coordinated research program

In the year 1950, Atomic Energy Commission of the United States (USAEC) launched a coordinated research program focused on using the ionizing radiation for food preservation. Under this program it started using spent fuel rods obtained from different nuclear reactors as a source of ionizing radiation. Soon it found several limitations of using spent fuel rods. These primarily included the presence of mixed radiation, including dangerous neutrons, in spent fuel. Also, precise dose delivery and dosimetry posed numerous challenges. It led to the development and use of cobalt-60, an artificially produced radioisotope from neutron irradiation of cold cobalt-59, that mainly emitted highly penetrating gamma rays of reasonable energy. Subsequently, in the early 1960's USAEC generated Cobalt-60 sources which were provided to various academic institutions in the USA including University of California at Davis, the Massachusetts Institute of Technology, Boston, and University of Florida at Gainesville. Soon after, a Cobalt-60 Marine Products Development Irradiator was developed at the National Marine Fisheries Services at Massachusetts, with an installed capacity of 235 kCi. This was followed by the development of a grain Irradiator at the Entomological Research Centre in Georgia with 35 kCi of cobalt-60. An important role was played by the United States Armed Forces in the primary stages of research in radiation processing of foods. To accomplish this, the US Army Natick Laboratories obtained a 1.3 MCi Cobalt-60 source for the purpose of food irradiation. At the same time 18-kW linear electron accelerator was also utilized for the same purpose. After 1960, as an alternative to frozen or canned military rations, the U.S. Army concentrated majorly on development of sterile meat products using high dose gamma irradiation. Similar facilities including a grain irradiator, an advanced cesium-137 based marine product irradiator, and a cobalt-60 food package irradiator, were procured by Dr. Bhabha and installed in the Food Irradiation Processing Laboratory of the Food Technology Division at BARC. Even today cobalt-60 remains the work horse of food irradiation, although the usage of X-rays and electron beam is finding favor with the modern industry.

2.3. Spread of radiation technology

Research on food irradiation was initiated in several countries including Belgium, Germany, Canada, Russia, France, The Netherlands, Poland, United Kingdom, and India after the successful demonstration of useful food applications in the United States. However, the concerns raised in certain quarters related to the wholesomeness and safety of food treated with ionizing radiations for human consumption became a major obstacle in its commercialization. Hence, marketing of gamma radiation processed foods was not permitted by the health authorities in these countries. This led to initiation of several safety and wholesomeness evaluation research programs in various laboratories around the world spanning more than a decade of seventies and eighties of the last century.

3. Establishing safety along with wholesomeness of irradiated foods

Wholesome food means food conducive to the general human nutrition and well-being. This also implies that any deleterious substance is absent in food. Therefore, wholesomeness of food treated with ionizing radiations had to be evaluated for any physical, chemical, and biological, changes affecting microbiological, toxicological, and nutritional safety. Laboratories around the world including India spent a lot of money, time and efforts in establishing that food processed by ionizing radiation was safe for human consumption. These studies included, studies on radiological safety, safety of chemical changes, safety related to the changes, if any, in residual microflora, *in vitro* studies, animal studies (short as well as long term), and finally, studies involving human volunteers, generating huge volume of well documented data.

3.1. Radiological safety

The induction of radioactivity in foods treated with ionizing radiations and risk to the environment due to the food irradiation facilities were two major radiological concerns. Experiments with high dose irradiated foods clearly demonstrated that either gamma rays originating from cobalt-60 (1.25 MeV) or X-rays with energies up to 7.5 MeV or electrons accelerated up to 10 MeV, did not induce radioactivity in the atoms of the food material. Also, as the food during processing with the ionizing radiation never comes in contact with the radio isotope, there cannot be any radioactive contamination in the treated food. Radioactive cobalt-60 is used inside sealed stainless-steel pencils from which only gamma rays emanate. When foods were irradiated by kilocurie cobalt-60 source, no radioactivity could be detected in 24 elemental food constituents when analyzed by advanced scintillation counters. It was observed that X-rays up to 7.5 MeV did not induce radioactivity in food items and hence, USA extended the usable energy of X-rays from 5 MeV to 7.5 MeV. Regarding the risk to the environment, the facilities for radiation processing that use Co-60 would need replenishment and transport every 12 years. The transport of cobalt-60 and also, the operation of facilities using cobalt-60 is conducted under a well-regulated national and international protocol, and thus never causes any risk to the population or environment around these facilities.

3.2. Safety of chemical changes

It is observed that based on the properties and storage conditions of the irradiated commodities, the free radicals formed in these foods due to irradiation disappear. The process of irradiation with the prescribed doses has a minimal effect on the basic composition of foods that cannot be easily identified by either sensory evaluation or by any advanced instrumentation. Minor losses in some radiation sensitive vitamins may be observed. Nevertheless, these losses are often within the range allowed even under conventional processing techniques.

3.3. Safety of residual microflora

There are number of detailed studies regarding microbiological aspect of irradiated foods in terms of residual microflora. All the studies confirmed that radiation processed food does not cause any hazardous changes in the residual microflora for example heritable gene mutations, or making toxigenic or pathogenic microbes more toxigenic or virulent.

3.4. Short-term and long-term animal studies

To evaluate the wholesomeness of irradiated foods, animal feeding experiments were carried out in a number of small and large animal species in various laboratories around the world. These studies were expensive and at the same time most time consuming. In separate experiments, rats fed with freshly irradiated wheat did not induce dominant lethal mutations in these animals. In another experiment, Swiss male rats were fed with irradiated (25 kGy) and unirradiated diet for about 8 weeks and these rats were then mated with normal females. The females were tested for dominant lethal mutation in the mid-term pregnancy period. None of the females showed any dominant lethal mutation during the testing. Moreover, there was no pre as well as post implantation lethality in the rats fed on irradiated diet. Even the fertility of mice remained unchanged after consumption of irradiated diet. Wistar rats were fed with irradiated and unirradiated wheat diets within the period of 24 hours of irradiation, and the cytological analysis of the bone marrow cells in metaphase was carried out. No significant difference was observed in the frequency of polyploid cells in these Wistar rats indicating no genotoxic effect. Considering all the data of short term as well as long term animal feeding studies with various irradiated foods and number of species of laboratory animals it was concluded that there was no genotoxic effect of irradiated foods in these animals. Mutagenicity testing studies reiterated the findings. Even the human volunteers who were fed irradiated foods have shown no adverse effect, indicating safety of irradiated foods. In fact, radiation processed food is being consumed by both astronauts and cosmonauts during their space mission.

3.5. Reassurance of safety at BARC

Even though the issue of safety and wholesomeness of irradiated food is settled for all times to come, recent studies at FTD, BARC continue to inspire confidence. In these studies, two gene loci, tk-/+ (thymidine kinase), and hprt+ (Hypoxanthine Phosphoribosyl transferase) of human lymphoblast thymidine kinase heterozygote (TK6) cell lines were sub-cultured for 100 generations in various foods irradiated to a high dose of 25 kGy. Similarly, subculturing of *E. coli* MG1655 (wild type) cells for 3000 generations was carried out in a medium comprising of irradiated food. Various analysis including comet assay, micronucleus test, Ame's test as well as DNA sequencing along with restriction digestion profiling of phagemid DNA present in *E. coli* cells that were grown in medium containing food treated with gamma radiation were also carried out. Results indicated no induction of mutagenesis during long-term subculturing in medium having food treated with ionizing radiation. No changes were observed in the profiles of micronucleus as well as comet in the sub-cultured cells. There was no difference in the restriction digestion profile and randomly amplified polymorphic DNA in these cells. DNA sequences also showed no changes confirming non-occurrence of silent mutation in the genome. Further, studies were done using high dose (10-70 kGy) irradiated goat meat, chicken, fish and shrimp samples and enumerating mutation frequency after long-term sub-culturing of *E. coli* MG1655 cells till 1500 generations in the media containing 1% irradiated food and till 250 generations in the media containing 5and 10% irradiated food. Human lymphoblast cells (TK6) cells were grown till 156 generations in the medium containing 2% irradiated food. Another study used 'Differential loss of Plasmid Antibiotic Resistance' (DPAR) assay and subsequently analyzing the sequence of tetracycline resistance gene of pBR322 plasmid that was isolated from the *E. coli* cells cultured on irradiated food medium for 1500 generations. Same cells were subjected to RAPD analysis of the entire genome. All these studies showed no induction of any mutation and no change in nucleotide sequence suggesting non-existence of silent mutations. Thus, the above studies provided strong evidence of absence of any mutagenic effect due to high dose gamma irradiated foods, and thus endorsed their genotoxic safety and highly credible molecular evidence supporting the safety of food treated with ionizing radiations.

3.6. Investigations in human volunteers

In China, number of studies on healthy human volunteers were carried out at Shanghai Institute of Nuclear Research. The studies included diets including about 70 food items. These food items were irradiated using a Cobalt-60 irradiation source and the radiation doses used were from 1 kGy to 8 kGy. After irradiation, the food products were stored for different time period ranging from one week to 6 months. Staple food items including flour and rice were stored for about 50 and 180 days, respectively. Unirradiated or irradiated diets were fed to the volunteers for the period of 90 days. Peripheral blood lymphocytes from these volunteers were used for chromosomal preparation to score numerical as well as structural aberrations. No significant differences were observed in the occurrence of polyploid cells in the volunteers fed with either unirradiated or irradiated diets, both before or after feeding.

4. Contributions of IAEA, FAO & WHO

4.1. Joint FAO/IAEA/WHO Expert Committee on Food Irradiation

In the year 1970, two agencies namely, International Atomic Energy Agency (IAEA), Vienna, and the Food and Agriculture Organization (FAO), Rome came together to form an International Food Irradiation (FIP). The project initially involved 19 countries with the project headquarter at Karlsruhe, Germany. Five more countries joined this group later. Subsequently, The World Health Organization (WHO), Geneva also joined this project. Various food items including rice, wheat, fruits, spices, meat and fish were irradiated with gamma radiation and evaluated for chemical changes as well as used for animal feeding studies. The Joint FAO/IAEA/WHO Expert Committee on Food Irradiation (JECFI) convened series of meetings in the year 1970 and 1976 for analyzing the emerging data, and evaluation of wholesomeness and safety. In the last meeting in the year 1980, the committee inferred that the foods irradiated at an overall average dose of 10 kGy does not pose nutritional or microbiological hazards. They further confirmed that food commodity irradiated up to average dose of 10 kGy does not require any toxicological testing as no toxicity is generated at this dose. Based on the findings of

JECFI, in the year 1981, the World Health Organization published a document titled "Wholesomeness of Irradiated Foods" in which the organization reiterated the above claims.

4.2. International Consultative Group on Food Irradiation (ICGFI)

In 1984 the three UN agencies (FAO, IAEA and WHO), and the 19 founding member states signed a declaration in 1983, establishing ICGFI with the major objective to assess global advances in the field of food irradiation and to serve as a central source of guidance on the various application of food irradiation for IAEA member countries. Its top priority was to promote public awareness about food irradiation and objectively discuss the process through publications addressing its safety and effectiveness. It also focused on different aspects required to commercialize food irradiation as well as legislative aspects of irradiation facilities. Additionally, emphasis was also given on the process of organizing training courses for the persons involved in the plant operations, food inspectors and other key stakeholders and regulatory control of these facilities. In the year 1995, the total number of ICGFI member states increased to 44.

5. Major applications of food irradiation

5.1. For ensuring food security

Major technological benefits of radiation processing that can help control food losses include, sprout inhibition in bulbs, tubers, and rhizomes, insect disinfestation in grains and grain products, delay in the process of ripening as well as senescence in fruits and vegetables, and destruction of microorganisms causing spoilage of foods. These benefits can be classified into low, medium, and high dose applications, based on the specific dose requirements. These objectives are fulfilled using recommended doses ranging from 0.1 to 10 kGy, for different classes of foods. India houses one of the major domestic markets of the world with vast amounts of fruits, vegetables, cereals, pulses, spices and seafoods are acquired, and distributed throughout the country after the storage for the variable period. Due to improper storage conditions, grains of the value of crores of rupees are lost due to damage caused by insect infestation and associated issues. Radiation processing offers a solution for storing the bulk and consumer-packed products, aiding in retail marketing and stockpiling. In order to control the huge losses if India wishes to process even a small portion of the total production using radiation, numerous new facilities would be required in the future.

5.2. For improving food safety

There are several studies in India documenting incidences of food-borne pathogens in different food samples. Prevalence of Salmonella in various food samples, mainly poultry meat and seafood. Salmonella load in raw poultry is a cause of major concern to the regulators around the world including India. The incidence of Campylobacter with seasonal variation in food has also been documented. Other important pathogens studied in great detail in food included, Yersinia, Listeria and E. coli. Apart from the major food-borne pathogens, incidence of many emerging pathogens like Cronobacter, Enterobacter, Klebsiella, Shigella and Aeromonas. Radiation processing can be deployed as one of the critical steps in Hazard Analysis and Critical Control Points (HACCP) in food industry along with good manufacturing practices (GMP) and good agriculture practices (GAP). Rapid detection of pathogens enables quality control professionals to meet quality standards. The traditional detection methods for microbiological analysis are time intensive and tedious. In FTD, approaches based on PCR have been developed for detection of Salmonella, Aeromonas and E. coli. These methods can detect even a single bacterium in food after a short period enrichment. Escherichia coli is a fecal indicator, among which some of the virotypes are pathogenic, making its detection and prevention in food crucial. Newer methods developed recently focus mainly on detection of pathogenic E. coli. In these studies, a certain fraction (7.3%) of E. coli isolates tested positive for different virulence genes including aggR, lt, stx1, eaeA, ipaH, and stx2. Among others 2 isolates showed presence of toxicity marker stx genes.

The radiation dose required to eliminate population of the given pathogen, called ‘radicidation’ dose, has been determined for all important food-borne pathogens in FTD. The earliest work was on Vibrio and Salmonella. The decimal reduction dose, D10, was determined for Salmonella Typhimurium, Listeria monocytogenes and Aeromonas inoculated in a variety of minimally processed fruits and vegetables. Gamma radiation has been shown to effectively kill various human pathogens in food products, yet its efficacy varies depending on the pathogen, its growth form, stage, and the nature of the attachment surface. For Shigella spp. and Aeromonas spp., gamma radiation demonstrated no significant difference in sensitivity between planktonic and glass-associated biofilm cells, but a significant increase in resistance was noted for carrot-associated biofilms. Klebsiella pneumoniae, an opportunistic pathogen, was completely eliminated from mixed sprouts, poultry, and fish samples with a 1.5 kGy dose of gamma radiation, demonstrating no recovery during storage. Similarly, a 1 kGy dose effectively eradicated Campylobacter from poultry meat, ensuring its safety. Additionally, gamma radiation improved the microbiological quality of minimally processed pineapple by eliminating Salmonella Typhimurium, thus highlighting the prospects of radiation treatment in ensuring food safety, especially in food for immunocompromised patients.

5.3. Meeting phytosanitary requirements

A Final Rule pertaining to the ‘Irradiation Phytosanitary Treatment for Imported Fruits and Vegetables’ was issued by The Animal and Plant Health Inspection Service (APHIS) of the USDA in the year 2003. At the same time, India, along with New Zealand and Australia also amended their quarantine regulations to include radiation processing as a quarantine treatment for processing the tropical fruits meant for export. World Trade Organization (WTO) has issued clear incentives to the traders who adopted radiation processing as an SPS measure in the international trade through the Agreements on Sanitary and Phytosanitary Practices and Technical Barriers to Trade. Thus, in the global trade, radiation can be used for the hygienization of the product as well as for overcoming the quarantine barrier. International organizations such as International Plant Protection Convention and Codex Alimentarius Commission administer the agreements under their standards and recommendations. Thus, WTO member states would experience improvement in international trade of horticultural produce using radiation processing. For export purpose, the food can undergo radiation processing mainly to achieve hygienization, shelf life extension and overcoming quarantine barrier. Globally due to extended shelf life, trade in fresh agricultural commodities is increasing steadily among the countries. India exports various food commodities including onion, Basmati rice, spices, meat, poultry and seafood. Radiation processing can benefit the export of bulk commodities by restructuring the cost and it can also assist in selling the value-added packed commodities in the retail market directly.

6. International regulatory approvals

In 1958 the Soviet Union was the first country to grant clearance to potatoes for sprout inhibition, and later to disinfestation of grains treated with ionizing radiations for human consumption. In 1960 Canada granted clearance for sprout inhibition in potatoes and later to irradiation of onions. USFDA too granted approval in 1963 for the processing of wheat and wheat products for insect disinfestations. In 1984 the Codex Alimentarius, under the umbrella of FAO and WHO, published the 'Codex General Standard for Food treated with ionizing radiations and recommended International Code of Practice for the Operation of Radiation Facilities'. Codex reiterated that the foods irradiated up to 10 kGy average dose presents no microbiological as well as nutritional issues. It also identified usable ionizing radiation sources, provided dose and energy limit guidelines as well as global GMP standards recommendations for operating gamma irradiation facility. Both USA and Canada recorded gamma irradiation under their respective legislations that regulated additives in food. Later in the year 1989, irradiation was recategorized as a physical process by Health Canada whereas, USFDA continues with its earlier stand

6.1. Labelling of food treated with ionizing radiation

The JECFI also suggested that there was no valid scientific reason for identifying the food treated with ionizing radiations with a label at the retail level when similar labelling is not required for the other commonly used processing methods (WHO, 1981). However, The Codex Alimentarius Commission wanted that the Codex member states follow uniformity in labelling for the facilitation of international trade. The labelling committee recommended that usage of an international logo or ‘*Radura*’ can be optional, it should have a statement ‘treated with ionizing radiation’. In most of the countries the irradiated food that is sold in prepacked or bulk form is easily identified by the logo of *‘Radura’*. The package should contain one of the statements including ‘Irradiated’, ‘Treated by Irradiation’, ‘Treated with Irradiation’. Additional statements explaining the benefits of irradiation may also be used. The idea of using a label is to provide consumers the choice of selection. The ‘*Radura*’ logo is a symbol of quality rather than warning. On the ingredients list, if the finished product contains irradiated ingredients $\geq$ 10%, then the product has to be described as “irradiated”. The finished products containing $<$ 10% irradiated ingredients or spices, do not have labelling compulsion. As per the Indian regulations, the foods treated with ionizing radiation must have a label with the treatment name written close to the product name. Moreover, the label of radiation processed food should have 'RADURA' symbol in green color as given below:

7. Food Irradiation in India

In India, R&D in nuclear sciences started in 1954 at the Atomic Energy Establishment,

Name of the Facility ____________________
Processed by Irradiation Method
Date of Irradiation ___________
License No. of Facility ______________
Purpose of Irradiation ________________

Trombay, which was subsequently called Bhabha Atomic Research Centre (BARC) after the name of the founder. In 1961 research in radiobiology was initiated. In 1967, a first of its kind in this part of the world, a Food Package Irradiator (FPI) was installed for carrying out the R&D in food irradiation at the Food Irradiation and Processing Laboratory, at the Food Technology Division, BARC. For according regulatory approval for irradiated foods, a National Monitoring Agency (NMA) was established by the Government of India in the year 1987 for considering different aspects of food irradiation. In 1992, the committee approved irradiation of onion and potato for sprout inhibition, spices for hygienization while frozen seafood for export. Subsequently, under the Prevention of Food Adulteration Act (PFA), Rules (1954), the proposal was draft notified. In the year 1994, the draft notification for both export as well as domestic consumption was approved and published vide GSR No. 614(E) dated August 9, 1994. In 2003, quarantine regulations were amended by the Ministry of Agriculture in order to include radiation processing as a quarantine measure to facilitate international trade. In 2006 a framework equivalence work plan was signed between USDA-APHIS and MOA (GOI) for export of mangoes. This enabled export of about 150 tons of irradiated mangoes to the USA in the year 2007 from the KRUSHAK irradiation facility, a technology demonstration unit at Lasalgaon, dist. Nashik, which got approval from USDA-APHIS that year. In June 2012, a notification for class-wise approval for radiation processing of food items was issued vide G.S.R 158 dated June 26, 2012 under Atomic Energy (Radiation Processing of Food & Allied Products) Rules, 2012. In 2016, a class wise approval for irradiation of foods was gazette notified by the Government of India under the Food Safety and Standards (Food Products Standards and Food Additives) Sixth Amendment Regulations, 2016. The regulations stress on: -(a) Approval of facilities - No irradiation facility shall be used for the treatment of food unless such facility -has been approved and licensed under the Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012; complies with the conditions for approval, operation, license and process control prescribed under the above said rule; and carries out irradiation in accordance with the provisions of this rule. -(b) Besides irradiated food will not exit the irradiation plant if it has not been irradiated as per the requirements of this rule and the certificate of irradiation displaying both the dose as well as purpose of irradiation is furnished by the irradiation plant. The irradiation will strictly adhere to the dose limits, the approved radiation source, and the specified conditions for every category of food for processing by radiation, under the Atomic Energy (Radiation Processing of Food and Allied Products) Rules, 2012.

8. Conclusion

Early discoveries of ionizing radiations and their properties set the stage for their exploitation in the fields of medicine, food, and industry, with pioneering research in the United States. The establishment of international bodies such as the IAEA, FAO, and WHO provided a structured approach to evaluating and standardizing food irradiation practices, ensuring that the technology is both safe and effective. The checkered history of food irradiation ultimately reflects convergence of international cooperation in achieving common R&D goals, establishing safety and wholesomeness of irradiated food, and preparing and harmonizing international regulatory frameworks and SOPs. The country's progress from early research and development initiatives to developing a comprehensive regulatory framework demonstrates its commitment to reducing food spoilage, providing safe food to consumers, and meeting international trade standards. The establishment of rigorous safety protocols, combined with advancements in detecting foodborne pathogens and assessing the genotoxic safety of irradiated foods, underscores India’s proactive stance in ensuring both the quality and safety of irradiated food products in the country.

9. Acknowledgement

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