Radiation Processing as a Sustainable and Green Technology to Ensure Food Security, Safety and Promote International Trade

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Preamble

With respect to production of horticultural and agricultural commodities India ranks second in the world. However, its rank in the global hunger index (GHI) is disappointing. Post-harvest losses are one of the prime reasons behind this paradox. Besides contribution of agriculture sector in national GDP has shown a gradual decline since independence. Technological and processing interventions could be considered as possible remedial measures. A significant amount of agricultural produce is lost during post-harvest storage primarily due to insect infestations, microbial contaminations, and other biological and physical damages. Prevention of post-harvest losses can help in ensuring food security to the greater extent. The chemical fumigants used for the control of insect pests, quarantine treatment of agricultural and horticultural produce and for microbial decontamination of food commodities are being phased due to their harmful effects on human health and environment. Therefore, there is an utmost need of an alternate environment-friendly green technology to address these issues.

The beginning of radiation technology

Radiation processing of food is more than 100 years old technology as the first related patent was granted in 1905 in the United Kingdom to bring about an improvement in the condition of foodstuffs and in their general keeping quality deploying radiation technology. However, the technical limitations worked as hindrance in its rapid growth. The radiation sources proposed to be used under this patent was alpha, beta or gamma rays from radium or other radioactive substances. The radium preparations suggested by these inventors as sources of ionizing radiation were not available in sufficient quantity to irradiate food commercially. Research in the area of radiation processing of food was sponsored by the Department of the Army, the Atomic Energy Commission, as well as private industries in the United States during the period between 1940 to 1953. Early research in this duration focused on the potential uses of different types of radiation including electrons, neutrons, alpha particles, X-rays as well as ultraviolet light for food preservation. It was concluded from this study that only electrons had the necessary characteristics of efficiency, safety, and practicality. X-rays was considered to be impractical that time due to very low conversion efficiency from electron to X-ray in the existing set up. As ultraviolet light and alpha particles have limited ability to penetrate the matter, were too considered to be impractical. Neutrons were considered inappropriate for use in food because of the potential for inducing radioactivity, although it exhibited great penetration and therefore very effective in the destruction of bacteria. In 1950, a coordinated research activity was initiated on the use of ionizing radiation for food preservation by United States Atomic Energy Commission (USAEC). It provided spent-fuel rods of nuclear reactors as source of ionizing radiation, which had limitations with regard to exact dosimetry. Subsequently ^{60}Co source was opted as sources of gamma radiation for food preservation by USAEC.

Radiation sources approved for processing of food products

FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food approved following four radiation sources for treating foods which was also endorsed by the Codex General Standard for Irradiated Foods:

(A) Radioisotopes based sources:

- Cobalt-60 radioisotope (Gamma Energy 1.17/ 1.33 MeV)
- Cesium-137 radioisotope (Gamma Energy 0.66 MeV)

(B) Machine based radiation sources

- X-rays (Energy not exceeding 5 MeV)
- Electrons (Energy not exceeding 10 MeV).

Food irradiation: Working principle

Food irradiation is a physical process in which food and agricultural commodities are exposed to a controlled amount of radiation energy to achieve desirable effects. These commodities can be exposed to radiation either in pre-packed form or in open bulk state depending upon the desired objectives. Food is placed in containers that are moved by a conveyor into a shielded room, where it is briefly exposed to radiation emanating from a source. Radiation by its direct effect on macromolecules and indirect effect through radiolysis of water inactivates essential biomolecules of insects, parasites, and microorganisms, and destroys them. At low doses, it also causes inhibition of physiological processes such as sprouting in potato and onion and delay in the ripening and senescence in certain fruits and vegetables.

Applications in food preservation

On the basis of radiation dose, food applications are classified into low dose (< 1 kGy), medium dose (1-10 kGy) and high dose (> 10 kGy) applications. Radiation dose is the measure of radiation energy absorbed per unit mass of material under consideration. The unit of absorbed dose is Gray (Gy). 1 Gray is the energy absorption of 1 Joule per kilogram.

Low Dose Applications

Sprout inhibition in bulbs and tubers:

Irradiation in the range of 0.06 to 0.15 kGy inhibits sprouting in tubers such as potato, bulbs such as onion, rhizomes like ginger and corms such as taro. Potato and onion needs to be cured for two weeks just after harvest followed by radiation treatment. For better shelf- life radiation treated potato and onion are recommended to be stored at low temperature. For potato, post-irradiation storage temperature of 14-15°C and relative humidity 93-95% are considered effective in yielding better shelf- life whereas for onion temperature of 0.2-0.5°C and relative humidity 65-68% is considered to be highly effective. Conventionally, in commercial cold storage, potato is stored at 2-4 °C. Though sprouting is inhibited at this temperature, the commodity starts sprouting profusely as soon as it is taken out from the cold storage and moved down the supply chain. Thus, radiation processing of potato and subsequent storage at 14 to15°C conserves energy and also prevents sweetening of potato. Such phenomenon commonly occurs at very low temperatures. Therefore, it gives advantage to the chip making food industry because low sugar potato give desired lighter color to chips and fries.

The alternate process such as use of chemical sprout inhibitors like isopropyl-N (3-chlorophenyl) carbamate (CIPC) and maleic hydrazide (MH) has not found to be very effective under subtropical or temperate climates. CIPC has also recently banned by many countries.

Non-irradiated Irradiated

Control of Sprouting in Potato and Onion using radiation processing
(Shelf life around 8 months in cold storage at specified conditions)

Delayed ripening of fruits (e.g. Mango)

India is a major producer of tropical fruits and vegetables. The Alphonso and Kesar varieties of mango are popular all over the world and have great export potential. Irradiation of these fruits at hard mature pre-climacteric stage at $\leq$0.75 kGy delays the ripening process up to 2-3 weeks if stored at low temperature. Thus, the extent of delay in ripening will depend upon the storage temperature as well as varieties of mango. The radiation doses used for delay in ripening are also effective in destroying quarantine pests.

Indian mangoes were not allowed to be imported in USA for 18 years prior to 2007 due to quarantine issues. When the United States Department of Agriculture (USDA), approved KRUSHAK (Krishi Utapdan Sanrakshan Kendra) irradiation facility, Lasalagaon, Nashik, export of Indian Mangoes to USA started in 2007 and is continued till date. At present, mangoes after radiation treatment are exported to USA by air that has quite high transportation cost. This also limits its volume of export and therefore share of Indian mango in the USA resulting in low export earnings. Use of sea route for transportation would result in substantial cost reduction and enable export of larger volumes enabling deeper penetration in the USA market. A technology has been developed at BARC for delayed ripening of Indian 'Kesar' mangoes which will enable its sea-route shipment to USA. The SOP of the technolopgy has been approved by USDA.

Delay in ripening of mango using radiation treatment (Shelf life extension up to 30 days in cold storage)

Radiation processing to control insect infestation in grains

Grains including cereals and pulses are often infested with insect pests leading to huge post-harvest losses during storage. Current existing practices of using fumigants such as ethylene dibromide (EDB), methyl bromide (MB), ethylene oxide (ETO), malathion, aluminum phosphide etc. are deleterious to the health as well as environment. Therefore, use of such chemicals has been recommended to be phased out by the statutory bodies including WHO.

However, radiation treatment of such commodities provide a green and safe technology to control their losses. As the quantum of grains being produced is quite high and therefore their storage requirement, radiation technology needs to be customized to fulfill the need possibly through design development to operate in continuous mode and integration with modern storage facilities like silos.

Non-irradiated **Irradiated**

Control of insect infestation in cereals (Shelf life extension for a year at ambient storage in packed condition)

Medium Dose Applications

Shelf-life extension of sea-foods, meat and meat products:

India is one of the major producer and exporter of sea-foods. With a coastline of over 4500 km, fish production has steadily increased over the years. Fresh catch of fish is prone to rapid spoilage due to improper storage conditions, and contamination with pathogens under usual handling and processing practices. This poses serious health risk to consumers. Under ice, fish like Bombay duck, pomfret, Indian Salmon, Mackerel, and shrimp can be stored for about 7-10 days. Studies have demonstrated that irradiation at 1-3 kGy followed by storage at melting ice temperatures increases its shelf- life nearly threefold. In India, meat and meat products are marketed either fresh or in frozen form. Meat and meat products including poultry have a shelf-life of about a week at 0-3ºC, which could be extended up to four weeks by applying a dose of 2-5 kGy, which inactivates spoilage bacteria. Radiation treatment has been employed to enhance the shelf-life of intermediate moisture fish and meat products.

High Dose Applications

Hygienization of spices: India is a major spice producing and exporting country. However, due to inadequate handling and processing conditions, spices often get contaminated with insect eggs and microbial pathogens. When incorporated into semi-processed or processed foods, particularly, after cooking, the microbes, both spoilers and pathogens can outgrow causing spoilage and posing risk to consumers. Many of the spices develop insect infestation during storage. An average absorbed dose of 10 kGy brings about commercial sterility while retaining the natural characteristics of spices.

Non-irradiated **Irradiated**

Control of insect infestation and microbial decontamination in spices
(Shelf life extension for a year at ambient storage in packed condition)

Regulatory approval

Determination of required radiation dose is one of the major parameters for optimal processing which is addressed through R&D activities at Food Technology Division, BARC, Mumbai. This is based upon the nature of commodity as well as the purpose. First of all, Government of India approved radiation processing of onion, potato and spices for domestic market in 1994 by amending the Prevention of Food Adulteration Act (1954) Rules. Recently, Food Safety and Standard Authority of India (FSSAI) has endorsed 'Generic class-based approval of radiation processing of food" which is as per the Radiation processing of food and Allied Products Rules, 2012. This has been subsequently Gazette notified by the Government of India in 2016 (F.No.1-120(2)/Standards/Irradiation/FSSAI-2015) (Table 1& 2).

Food irradiation facilities

In India, the first pilot radiation processing facility "The Food Package Irradiator" was commissioned in 1967 at the Food Irradiation Processing Laboratory (FIPLY), Bhabha Atomic Research Centre, Mumbai. Later four food irradiation facilities were commissioned in the Government sector in states of Maharashtra and Gujarat namely, Krishi Utpadan Sanrakshan Kendra (KRUSHAK) at Nashik; Irradiation Facility Centre (IFC), Maharashtra State Agriculture and Marketing Board (MSAMB), Vashi; Radiation Processing Plant (RPP), Vashi; and Gujarat Agro Industries Corporation Limited, Ahmedabad. Three of these facilities (except RPP, Vashi) were used primarily to treat fresh fruits and vegetables. In the last two decades additional 20 plants have been established under private entrepreneurship. Thus, currently 24 gamma irradiation plants are operational in the country treating food and allied products

Conclusion

Radiation technology provides a very effective solution to the post-harvest losses of food while ensuring their safety. It has helped in overcoming quarantine barrier of trade enabling the import of fruits and vegetables across the countries including USA. Existing numbers of food irradiation plants are minuscule in India with respect to the quantum of produce limiting the visibility of radiation treated food in domestic market(s). Therefore, India is in dire need of many more food irradiation plants coupled with cold chain, storage and appropriate transportation facilities. Government of India has launched many schemes to promote establishment of such facilities including cold storage and pack houses to cater the need. Ministry of Food Processing and Industries (MoFPI) is providing financial support to establish food irradiation and other required facilities. Under the reforms proposed in the atomic sector, the Honorable Finance Minister, Government of India too has announced the establishment of irradiation technology facilities in public-private partnership (PPP) mode for food preservation. Research activities at BARC are aimed to develop Standard Operating Procedures (SOPs) for preservation and quality evaluation of various food commodities and allied products deploying radiation technology. With increasing awareness and educated population in the country food irradiation has a promising future ahead as a green and ecofriendly technology to ensure national food security.

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