APPLICATIONS AND COMMERCIAL DEPLOYMENT OF FOOD IRRADIATION TECHNOLOGY IN INDIA

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Abstract
India produces enough food grains annually for its growing population, but also incurs significant post-harvest storage losses. Food security and safety are the twin challenges that face the country's food and agricultural sector. These challenges demand modern technological interventions. Radiation processing being a physical process offers an eco-friendly and effective alternative. Bhabha Atomic Research Centre (BARC) has a comprehensive research programme in the domain of food and agriculture. R&D work pertaining to the utilization of ionizing radiation for shelf life extension of agricultural produce and allied food products has been extensively carried out for last 7 decades. Protocols for shelf-life extension have been standardized and effectively demonstrated in several food and agricultural commodities. Commercial deployment of the technology for diverse applications is now feasible. Multiple value-added benefits include reducing post-harvest losses, pest-disinfestation, microbial hygienization, phytosanitary treatment to meet export requirements, as well as shelf-life extension of ready-to-eat/ ready-to-cook processed food commodities. Large scale trials with potato and onion have been successfully demonstrated to the

concerned stakeholders. The export of Indian mangoes to the USA is made feasible using irradiation as a phytosanitary treatment. Protocols for treatment of other exportable fruits and vegetables are also worked out. Industry driven research and deployment of the technology in public-private partnership (PPP) mode is essential for accruing widespread societal benefits. It is essential to understand the key challenges and hurdles faced by the stakeholders in the adoption and propagation of the radiation technology at commercial level. A coherent and concerted approach involving various stakeholders is required for the wider adoption and dissemination of radiation technology for improving food security and safety

1. Introduction

Food irradiation is an effective food preservation modality. It is being practiced in more than 70 countries world-wide including India. Indigenous ability and expertise in cobalt-60 production in nuclear power reactors ensures its regular supply and sustainability for the food irradiation program in India. Growing awareness among the stakeholders has resulted in a steady rise in the number of food irradiation plants being commissioned in the country. Standard operating procedures including proper dose delivery, pre- and post-harvest storage and transport conditions, have now been developed in FTD for a broad range of food products. A concept of lab to land has also been developed for public outreach of the food irradiation program in the country. Under this concept, initially a semi-commercial scale trial in the tune of 15 to 30 tons of potato and onion was successfully accomplished with a private agency through Expression of Interest (EoI). Subsequently commercial trials with approx. 1200 tons of onion for long-term preservation have been successfully demonstrated along with NCCF and Department of Consumer Affairs. Several fruit products preserved through irradiation are also being marketed through the technology licensees further highlighting the importance and acceptance.

2. Applications of Radiation Processing

2.1. Sprout inhibition in bulb and tubers

Sprouting is a natural process by which tubers, bulbs, and rhizomes germinate under favorable environmental condition to give rise to shoots for growth. In general, it does not initiate immediately after harvest but starts after a certain duration termed as the dormancy period. The dormancy period, varies in different crops and may continue for several weeks or even months. The sprouting is suppressed during dormancy by the expression of a hormone, abscisic acid. After dormancy period, depending on the environmental conditions including relative humidity, temperature and light exposure the sprouting initiates. The level of expression of phytohormones such as cytokinins and gibberellins play important roles in breaking the dormancy and promote sprouting. Sprouting during storage is considered as one of the most obvious manifestations of quality deterioration. This is accompanied by associated issues including weight loss, reduction in nutritive value, bulb softening and loss of processing qualities. Ionizing radiation mediated Inhibition of sprouting in stored tubers, bulbs, and rhizomes isone of the important low dose applications of radiation processing. The radiation treatment during dormancy period at very low doses (<100 Gy) leads to inhibition of sprouting in onion, potato, garlic, ginger, and shallots. The mechanism of radiation-induced inhibition of sprouting was thought to be due to an effect on the metabolism of endogenous growth hormones as well as on nucleic acids. Gamma radiation was believed to inactivate the meristematic tissue and inhibit cell division (mitosis) in buds. It was also believed that irradiation suppresses nucleic acid synthesis in the meristem (as a result of suppression of oxidative phosphorylation and ATP synthesis. However, recent studies in a commercial trial on Indian potatoes have shown that genes responsible for the biosynthesis of abscisic acid were up-regulated and those related to its catabolism were observed to be down-regulated in radiation processed potatoes. Additionally, the genes implicated in the biosynthesis of phytohormone auxin were significantly down-regulated in radiation treated potatoes. On the contrary, irradiated potatoes displayed retention of processing quality attributes such as cooking and chip-making qualities, which was believed to be due to enhanced expression of invertase inhibitor. In another recent study in onion, the prime odor volatiles known for pungency and total soluble phenolics were reported to increase in irradiated onion during storage. Inclusion of radiation processing at commercial level may gradually replace the use of commonly utilized chemical sprout inhibitors like isopropyl N-(3-chlorophenyl) carbamate (CIPC) and maleic hydrazide (MH) which are known to leave chemical residue in the commodity that are harmful to health as well as environment.

2.2. Insect disinfestation

Cereal crops serve as the staple food for a large section of population around the globe, providing macronutrients, micronutrients, and functional ingredients. Cereals and legumes constitute a major source of carbohydrates and proteins, in the Indian vegetarian diet. Cereals are rich in sulphur containing amino acids and deficient in lysine, while the reverse is true for legumes. Hence, a proper mixture of cereals and legumes is important. Moreover, legumes are cheaper source of protein compared to animal proteins. It is therefore important to maximize availability of both cereals and legumes in the country as a part of the food security strategy. However, insect infestation of these commodities during storage and transport results in significant losses and quality deterioration. Radiation technology can help increase their shelf life and improve their quality.

Rice, wheat and wheat, the most commonly consumed cereals in India, have a shelf life of 3-4 months. Infestation and proliferation of insects of *Coleoptera* and *Lepidoptera* species are very common. Fumigation with fumigants like ethylene dibromide, phosphine and methyl bromide is used even by the large warehousing agencies. However, fumigation does not eliminate all the metamorphic stages of insects and thus requires repeated treatments, resulting in toxic residue built-up in the products. Fumigants are being gradually phased out worldwide owing to their environmental and health concerns, thus highlighting the necessity of deploying radiation technology. Moreover, pre-packed products are not amenable to fumigation. On the contrary, irradiation of packaged food commodities serves as a green, safer and an end-to-end solution.

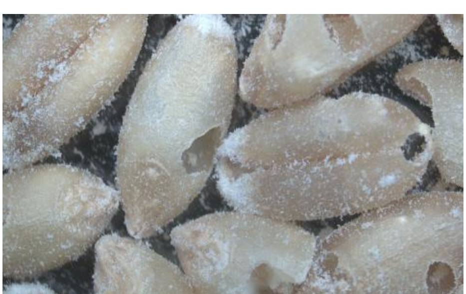
Radiation processing at a low dose (<1 kGy) is efficient in destroying all metamorphic stages of insects and sterilizing the adults of many known species of granary insects, thus preventing their reproduction and proliferation. Owing to high penetration of the gamma rays, the radiation treatment can effectively be used to disinfest pre-packed commodity. The process does not affect the wholesomeness, nutritional quality, and chapati making or cooking quality of grains (**Fig. 1A, B**). The shelf life of these products can be more than 12 months. The treatment in wheat improved the functional attributes by decreasing the gelatinization with concomitant increase in water absorption and better extensibility. The specific loaf volume wasF significantly higher in breads prepared by straight dough lean formula from 'maida' prepared from irradiated wheat. Sensory acceptability was higher for bread as well as chapatis made from irradiated wheat. Wheat, rice, rava and milled products including whole wheat flour (*Atta* and *Maida*) are also approved for radiation preservation under the FSSR (Food Product Standards and Food Safety Standards) Regulations (FSSAI, 2016).

A

Non-irradiated 'Chana Dal'

Irradiated (D_{min} 650 Gy) 'Chana Dal'

B



Non-irradiated 'Wheat'

Irradiated (D_{min} 650 Gy) 'Wheat'

Fig. 1: Insect disinfestation by radiation processing in (A) Chana dal and (B) Wheat

2.3. Nutritional quality improvement of grains

Flatulence-producing oligosaccharides, stachyose and verbascose were observed to undergo degradation at varying rates during 0-4 days of germination with associated accumulation of sugars (which are relatively more metabolizable) n gamma irradiated (<1 kGy) legumes *viz*. mung, Bengal gram, horse beans (val), horse gram, cowpeas and rajma. Thus, radiation treatment (1 kGy) of the ragi (Finger Millet) prior to malting processes reduced further viscosity which helped in preparation of weaning foods with higher malt concentration causing increase in its energy density. High dose irradiation of soybean improved its functional properties by increasing protein solubility and improving emulsification and gelling properties. Reduction of beany flavor in the tofu prepared from irradiated soybean increased the acceptability of patties prepared by incorporating the soy tofu. The functionality of the legumes (chickpea and kidney beans) in terms of cooking time was also improved at higher dose (10 kGy) without affecting their antioxidant properties.

Gluten free (GF) multi grain flour

Gluten is a structural protein commonly found in cereals including wheat, barley & rye. It is responsible for the dough viscoelastic properties, which is essential for the quality of the end product. Although a lot of benefits are associated with gluten, however, in certain individuals it may trigger an unwanted immune response called Celiac disease (CD). CD is a chronic inflammatory autoimmune disease that is known to occur in genetically predisposed individuals owing to an immune response to the protein gluten. CD is a multi-system disorder, where some of its clinical manifestations include diarrhea, weight loss, mal-absorption, abdominal pain, bloating, anorexia and vomiting. In view of this, ICMR has recommended the gluten free (GF) diet for the management of complications associated with celiac disease (CD). Developing new gluten free food products often comes with various bottlenecks such as cost, availability, texture-taste, palatability and dietary compliance. Therefore, with increased incidence of CD, short fall in the dietary fibre consumption and rising demand for multi grain food commodities in India, technology for ‘Gluten free (GF) multi grain premix’ has been developed at BARC using irradiated dietary fibre and multigrain.

In the present technology, gamma radiation processing as a cost-effective tool (with an ease for bulk processing of the material) to bring these desired properties. Thereby, increasing the fibre fortification levels in GF food products. In addition to this, the combinations of grains constituting the multi grain premix for the present deployed technology were judicially selected not only for its low cost but also for better nutritional and sensory aspects. Currently, this product is being marketed by the technology licensee.

2.4. Microbial decontamination

Legume sprouts and sweet corn kernels are nutritious foods and consumed for health benefits, however, being high (>50%) moisture commodities, making the produce unsafe for consumption due to high microbial load. Combination treatment involving sonication / blanching, antioxidant dip and gamma irradiation ensured microbial safety of these processed products and also led to enhanced shelf life of mung, chickpea and sweet corn for 35 days and lucerne up to 21 days at 4-6°C. During storage, various quality parameters including physical, biochemical, nutritional & organoleptic attributes were found to be retained. Interestingly, anti-nutritional factors (phytate, trypsin inhibitors, cyanogenic glycosides &oxalate) were observed to be significantly reduced.

2.5. Spices and dehydrated products

In general, most spices get heavily contaminated during sun drying with microbes including pathogenic bacteria of public health concern including Salmonella, *Escherichia coli*, *Clostridium perfringens*, *Bacillus cereus*, &toxigenic molds. Mold spores grow under humid storage leading to formation of mycotoxins. Intra and inter country (Japan) transportation studies, confirmed quality retention in irradiated spices during transport & storage. Fumigation of spices with methyl bromide and ethylene oxide leaves carcinogenic residues. Recently, export consignments of fumigated spices have been rejected and returned by importing countries. Moreover, fumigants deplete atmospheric ozone layer. Hence, radiation processing is the most effective alternative for microbial decontamination of the spices. Gamma irradiation in the dose range of 6-14 kGy is required for microbial decontamination and extension of shelf life of these products (**Fig. 2**).

The first commercial-scale gamma irradiator for food processing in India was the Radiation Processing Plant, BRIT, Vashi (RPP) which was commissioned on January 1, 2000. It is ISO 9001:2015, ISO 22000:2018 and ISO 13485:2016 certified facility which is also enlisted in the list of approved plants by European Union.

Non-irradiated Black pepper **Irradiated Black pepper**

Fig. 2: Microbial decontamination of black pepper by gamma irradiation.

2.6. Overcoming quarantine barriers

Radiation processing was included as a phytosanitary measure through a regulation 'Plant Quarantine (Regulation of Import into India) Order, 2003 notified by the Ministry of Agriculture & Co-operation, Government of India in the year 2004. This inclusion facilitated the signing of a Frame Work Equivalence Work Plan agreement in 2006 between United States Department of Agriculture-Animal and Plant Health Inspection Services (USDA-APHIS) and the Ministry of Agriculture & Co-operation, Government of India, which resulted in use of radiation as a phytosanitary treatment of mango for export to USA. Radiation processed mangos were exported to four countries (USA, Australia, South Africa and Malaysia). Quantum of mango exported in 2024 through air-route is approx. 3000 Tons. Besides, through sea-route also a trial commercial shipment containing 16 Ton of Kesar mangoes, processed as per the BARC developed protocol, was successfully shipped to USA in 2022. Upon arrival at port in USA, the mangoes were found in excellent physical condition by the USDA-APHIS, US-FDA & US-custom's and border protection force. This mode of shipment through the sea-route is advantageous as it is cost-effective and more quantum of processed mangoes can be exported, and the said technology has been advertised at the BARC website for commercial deployment.

3. Value Addition

3.1. Ayurvedic and medical products

Radiation processing of ayurvedic herbs, formulations, and medicines ensures their microbial safety assurance without affecting their functional properties. Most studies indicated a dose of ≤10 kGy to be sufficient in eliminating most microbes. However, for the complete microbial hygienization a dose of ≤ 25 kGy is required. Health foods, dietary supplements and nutraceuticals as well as body care and cleansing products can also be radiation processed.

Radiation is also effective in sterilizing packaging material used in aseptic processing of foods and pharmaceuticals. Radiation sterilization (at a dose of 25 kGy) is being used to sterilize medical products and their packaging, both thermoplastics and thermosets.

3.2. Guar gum

Dietary fibre is a nutritive component considered quite important for human health. Among these, guar gum (polygalactomannan derivative) is a promising soluble dietary fibre obtained from seeds of *Cyamopsis tetragonalobus*. Its molecular weight is from 2000 to 3000 kDa. It is widely used in various food products as thickener. Even at low concentrations, it can have very high viscosity in aqueous solutions. Further, for guar gum de-polymerization, gamma radiation is found to be advantageous alternative method.

3.3. Animal feeds

Animal feeds are also prone to insect infestation resulting in their short storage life, besides being a source of diverse pathogenic microbes. Gamma radiation is an effective alternative to heat or ethylene oxide. Treatment ease of packaged products prevents recontamination during transport and storage. Exposure to doses ≤ 10 kGy is effective in ensuring this. Animal feeds are also irradiated for insect disinfestations for meeting quarantine requirement for export to various countries.

3.4. Cut flowers

Fresh cut flowers require quarantine treatment for export/import. Methyl bromide is used for disinfestation of cut flowers, however, irradiation is a superior and effective alternative. A combination of modified atmosphere packaging (MAP) and irradiation followed by storage at 5 to 15°C is very effective in extending shelf life of cut flowers while retaining its freshness.

4. Flesh foods

Fish, meat and their products though important for a healthy diet, but these are highly vulnerable to microbial spoilage that leads to quality losses during post-mortem storage. Therefore, it is important that proper preservation approaches are incorporated to such products to ensure their microbial safety with significant shelf-life extension.

In our country, in general, meat and fish are sold either fresh or in frozen forms. However, fresh meat & fish have very short shelf life. Frozen flesh food is expensive, and has poor texture, and consumer acceptability. India is major exporter of frozen fish, buffalo and goat meat. However, if these products could be exported in the chilled state it would not only save energy but also increase their export potential. In this context, radiation processing offers a cost-effective alternative to the currently practiced preservation methods that can make this possible. Our studies have shown that fresh buffalo and goat meat could be stored at 0-3°C for 30 days when irradiated at 4 kGy, while the non-irradiated samples are spoiled within 3-6 days. Irradiated meat was organoleptically acceptable and microbiologically safe. Diverse range of ready-to-cook meat products (mutton mince, chicken mince, chicken chunks, and chicken legs) are available in Indian supermarkets. However, they have limited market due to their short shelf life. Faecal coliforms were eliminated by irradiation treatment. When these samples were irradiated (2.5 kGy), followed by cold storage(0-3°C) they were safe for consumption up to twenty-one days. Irradiated samples had relatively lower counts of *Staphylococcus* spp and the organoleptic quality was found to be retained in these irradiated samples stored at chilled temperatures. Similarly, whole fresh & marine water fish under chilled condition showed an increased shelf-life from 9 to 15 days in whole fish varieties (Silver Pomfret, Indian Oil Sardine, Gold-spot Mullet) when processed with 4 kGy and stored at 4 °C. Further shelf-life extension of 20-25 days was obtained when whole fish varieties, Indian Mackerel, Seer fish and Hilsa, were irradiated 4 kGy and stored at 1 °C. Radiation processing and chilled storage of processed fishery products such as dispersion coated steaks from Seer and Rohu fish resulted in shelf-life extension from 5-10 days as compared to un-irradiated fish steaks which had only 1 day of shelf-life. Radiation processed whole fish and processed fish steaks resulted in significant reduction in microbial counts thus extending shelf-life of the products and acceptability on the basis of its biochemical and organoleptic quality during entire storage period (**Fig. 3**).

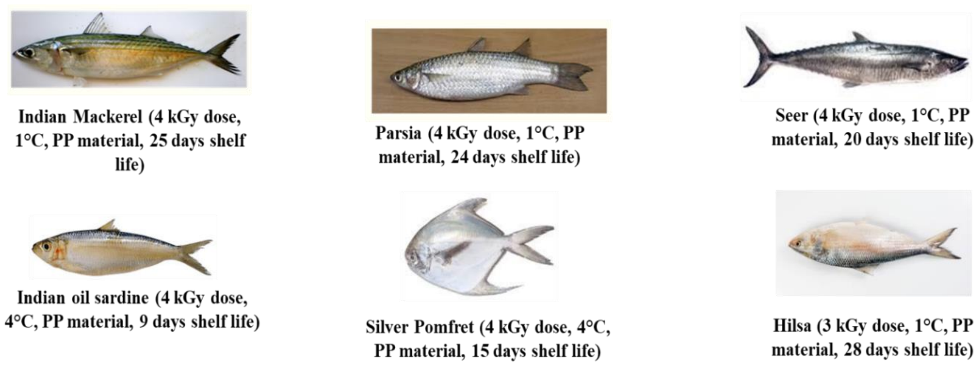


Fig. 3: Preservation of packaged fish samples for 20-25 days using radiation processing (3-4 kGy) and cold storage (1 ± 0.5°C).

A successful market trial of whole Hilsa, mackerel, and seer fish was conducted at low temperature irradiator at the Board of Radiation and Isotope Technology (BRIT), Vashi, Navi Mumbai. Effect of radiation processing on the shelf-life and microbial safety of some ethnic Indian processed meat products during chilled storage was also investigated. Besides, ready to eat shelf stable processed meat products which could be stored at ambient temperature for 1 year were also developed using high dose of irradiation (25 kGy). Additionally, various value-added fish products including Intermediate-Moisture (IM) Shrimp, were developed using radiation processing. These products were amenable to storage at either chilled or ambient temperature. Value addition of fish is done in order to utilize the valuable fishery resources sustainably and reduce post-harvest losses.

5. Relief food

There is a demand for nutritionally adequate and microbiologically safe shelf-stable food products which can be deployed during relief operations under adverse conditions including natural calamities. A product ‘Stuffed Baked Food (SBF)’ has been developed using radiation technology, which is stable for 8 months at ambient temperature. The product was well acceptable after storage while retaining its quality attributes. SBF can also be useful for others like defence personnel, school lunch programme, expeditions, and astronauts. This ready-to-eat (RTE) meal was supplied through a technology licensee to National Disaster Response Force (NDRF) as well as to the natural calamity affected people at Kullu district of Himachal Pradesh.

6. Processed fruit products

Syzygium cumini (‘Jamun’) is a highly perishable and seasonal fruit, limiting its availability and trade. A shelf-stable, chemical preservative & additive free, microbiologically safe product has been developed through the utilization of radiation processing. This technology has already been advertised and the product is being marketed by a licensee on various online and offline channels.

Strawberry is a seasonal, non-climacteric fruit which is prone to rapid spoilage and microbial growth. A secondary product using strawberry pulp has been developed incorporating a a sweetener as well as an anti-browning agent to reduce the extent of drying induced sourness and discoloration, respectively. The packed and radiation processed (≤ 5 kGy) product (strawberry roll) is shelf stable for 9 months under ambient conditions. Physical, biochemical, functional (antioxidant and antimutagenic) and organoleptic properties (including flavor compounds) are either retained or even enhanced in the processed product even after storage. The product has been commercially available on both online and offline mode.

Processing of fresh fruits (mango, banana, papaya, pineapple, and apple cubes) into intermediate moisture (IM) a ready-to-eat (RTE) product is a suitable option to control their post- harvest losses as these products are shelf stable, retain nutritional value, convenient to use, and can be stored at ambient temperature. Intermediate moisture foods (IMF) are defined as shelf-stable products having water activities of 0.6-0.84 and moisture content in range from 15- 40% & are edible without subjecting to rehydration. The peeled and diced fruits of uniform size are blanched, osmotically dehydrated using concentrated sugar (> 30%) solution bringing down the water activity to about 0.9. Further dried either by hot air, infrared, or food dehydrators (around 60°C) to 35-40 % moisture gave a slightly firm and chewy texture. After drying the cubes are cooled down to ambient condition to prevent condensation inside the packaging. The packed fruit cubes in airtight containers or vacuum-sealed bags can maintain their moisture content and freshness. Since such fruit cubes with 0.72 water activity cannot prevention growth of fungus, the further microbial decontamination by gamma irradiation is recommended for shelf-life extension of IM fruit cubes. Gamma radiation dose range of 2-5 kGy was used for microbial decontamination of intermediate moisture (IM) fruits. Processing ensured microbiological safety, nutritionally adequacy, as well as organoleptic acceptability. The product prepared is of high calorie value on dry weight basis compared to the unprocessed fresh fruit. The products are safe for consumption and can be stored at ambient temperature storage condition for more than 6 months.

7. Large-Scale Trials

7.1. Onion

Onion grown during *rabi* season is amenable to storage as compared to Kharif variety. However, onion prices rise significantly when the onion stocks of rabi variety get depleted and arrival of kharif variety is awaited. A seasonal trend is noted for onion prices which usually peak during the lean period spanning from July-October and later display a dip during April & May. Therefore, technological interventions specifically in the onion sector are very much essential not only in ensuring a sustained supply of quality produce during the lean period but also in effectively controlling the price fluctuation to a greater extent. There are several interlinked factors that affect the long-term storability of onions. Primarily, high humidity coupled with tropical high temperatures serve as deteriorating factors for the stored onions resulting in weight loss (~35-40%), fungal contamination & rotting, and sprouting. Onions that are kept in routine and traditional storage facilities are vulnerable to this spoilage affecting their long-term extended preservation.

Through the R&D efforts at the BARC, a SOP has been developed that maintains the overall quality of onions stored for extended duration (7.5 months). Through an integrated approach involving radiation technology and specific storage conditions, radiation processed (Dose: D_{min} 60 Gy) onion can be practically stored for 7.5 months with minimal weight loss (≤ 10%) and retention of quality attributes. Through the R&D efforts undertaken at BARC, 15 &30 Tons and subsequently 1200 Tons commercial storage trials were undertaken in 2023 in association with National Cooperative Consumer's Federation of India Ltd. and Department of Consumer Affairs, Ministry of Consumer Affairs, Government of India. In 2024, the newly constructed cold storage at KRUSHAK is being fully utilized by a FPO (Farmer's producer organization) for the storage of 250 tons of radiation processed 'Rabi' onions (**Fig. 4**).

Fig. 4: Onion specific cold storage facility for technology demonstration commissioned at KRUSHAK, Lasalgaon

7.2. *Potato*

In general, chemical sprout suppressants including propan-2-yl (3-chlorophenyl) carbamate (CIPC) or chlorpropham are routinely used at commercial level for the purpose of sprouting inhibition during long-term storage of potatoes. However, herbicides are restricted and recently banned by European Union. For demonstration of the efficacy of radiation technology at the commercial level, a storage trial (with ~28 tons potato) was undertaken with a industry. Three different potato cultivars (‘Santana’, ‘Frysona’ and ‘HYSM’) were utilized in this trial. Properly suberized potatoes were subjected to low dose (D_{min}: 73 Gy) gamma radiation processing followed by cold storage (in a cold storage facility, Mehsana, Gujrat) at 14°C and RH > 90% and CO_2 level 2500 ppm. During storage, the non-irradiated potatoes manifested complete sprouting within 100 days. On the contrary, radiation treated potatoes retained the quality attributes without any sprouting even till 7-8 months of storage depending upon the potato cultivars. Irradiated potatoes were suitable for table consumption as well as for industrial processing. After 8 months, these irradiated potato samples were further successfully channelized to a processing industry for the manufacturing of end products including chips and French fries (**Fig. 5**).

The above commercial trials contribute to the ‘Operation Greens’ scheme of the Government of India for integrated development of Tomato, Onion and Potato (TOP) value chain.

Non-irradiated potato (7 months of storage) **Irradiated potatoes (7-8 months of storage)**

Fig. 5: Commercial trial for potato irradiation and storage

8. Future Prospects

Currently radiation processing can be considered as the most effective modality to control storage and quarantine pests in agricultural & horticultural produce. It can therefore play a significant role in strengthening national food security, and international trade. India being the major producer of grains but the climatic conditions of the country are highly non-conducive for their ambient storage. A huge number of radiation facilities with high throughput handling capacity are required to set up. The recent market trials have proven that well informed consumers are keenly interested in buying irradiated food. It has been suggested that the trade organizations, government agencies, and university extension departments can utilize digital and social media platforms to endorse the multifarious advantages of radiation technology. Radiation is also a very effective food safety tool, as it can penetrate deep and kill hidden microbes in packaged food.

Future focus is required on combining and integrating irradiation with complementary modalities for improving storability, safety as well as quality of food. Overall, the success of this technology predominantly depends upon the cooperation amongst various stakeholders including the processors, retailers, policymakers, regulators, and scientists.

Strategy for pan India deployment of radiation technology requires:

a) Adequate financial planning and outlay for pan India deployment

b) Encouraging innovative design and development in material handling equipment, logistics warehousing for high throughput applications

c) Encouraging design and development in indigenous machine sources for high throughput applications and multitasking

c) Developing a unified national policy framework involving relevant stakeholders for easy adoption and wider dissemination of the technology

d) Planning outreach activities and awareness programs among stakeholders

9. Conclusion

Radiation processing of food being a physical method offers a superior alternative to other food preservation modalities. The technology is safe and approved under Indian food regulations. There are a number of operational food irradiation facilities existing in the country, but this number is quite small considering the volume of annual agricultural output and its storage. A highly focused and coherent unified policy framework is required involving various stakeholders in food and agriculture enterprise for a wider adoption and spread of the food irradiation technology. Continuous R&D would be required for developing SOPs for conservation of several nutritionally important but highly perishable underutilized foods. For enhanced commercial adaptability, large scale trials with concerned agencies need to be promoted to establish techno-commercial feasibility. A market driven R&D can catalyze transition of this advanced yet unexploited - technology to an indispensable processing tool in the national food supply chain.

10. Acknowledgement

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