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Review

Microbial decontamination of food by electron beam irradiation

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Electron-beam irradiation (EBI) is a novel food decontamination technology that uses low-dose ionizing radiation in the treatment of crops or food, to eliminate microbial contamination. Additionally, EBI inhibits the germination of crops and controls the ripening rate of vegetables and fruits, extending the shelf life of these products. EBI is a low cost, environment friendly, and time effective alternative to the traditional thermal decontamination technology. EBI, which has been approved by the USFDA, can be applied as an alternative to chemical fumigation of food. EBI inhibits a variety of foodborne pathogens, and effectively maintains food quality, significantly extending the shelf life. Better food preservation can be achieved by using EBI as a hurdle technology, in combination with other traditional or non-traditional food processing technologies. EBI uses low-dose radiation for decontamination, which reduces the risk of microbial hazards in food. However, from the perspective of food safety, it must be proven that EBI exerts no adverse effect on the nutrition or residual radiation in the food, before it is applied in the food processing industry.

Based on a previous literature review, this paper introduces the applications, and decontamination mechanism of EBI, and the radiation detection technology. Advances in EBI usage for a variety of fruits, vegetables, cereals, beans, poultry, meat, and seafood have been summarized. Emphasis is laid on a few important directions to be investigated in future research. EBI is expected to have wide commercial usage in the improvement of food and agricultural product quality, and in reducing the risk of microbial hazards in niche products.

Introduction

It is essential to overcome microbial contamination of food products during all stages of processing, including the raw crop stage, harvesting, preservation, processing, packaging, distribution, and marketing. According to the United Nations Food and Agriculture Organization (FAO), microbial contamination of crops results in significant economic losses in the world every year. In developing countries, almost 75% of the food that is produced is lost on-farm and during transport and processing, because of spoilage caused by poor storage conditions or improper handling and processing of crops. Previously, chemical fumigation technology (using sulfur dioxide, or potassium nitrate) was used to preserve crops after harvest (Pillai & Shayanfar, 2015). However, this technology has being banned by health authorities in many countries due to concerns regarding human health and environmental pollution. In this context, research institutions, relevant government departments, and non-governmental research institutions of various countries have been committed to develop more environment-friendly and efficient food preservation processes and applications. In order to aid in this research, the Joint Expert Committee on Irradiation, comprised of the FAO, World Health Organization (WHO), and the International Atomic Energy Agency (IAEA), proposed that "it is safe to appropriately use radiation for food decontamination; food irradiated at a dose lower than 10 kGy has no toxic hazards and only a minor effect is posed on the nutrition". Irradiation decontamination technology has been suggested as an alternative to microbial decontamination in the food industry. Meanwhile, the FAO/IAEA/WHO recruited research groups to organize seminars on irradiation applications (Cleland, 2013). It was summarized that an irradiation dose between 25 and 60 kGy would not cause any potential health risks or raise concerns regarding residual radiation,

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while retaining acceptable standards of nutritional value and sensory quality of food. Therefore, this irradiation technology can not only improve food safety but also reduce crop-related economic losses (Bhat, Alias, & Paliyath, 2012).

Irradiation treatment of crops or processed food is still considered a new technology in some countries. EBI is the process of generating electrons off a cathode in a vacuum environment from commercial electricity. The electrons are then fired or pulsed from an electron gum in sequence, creating a beam of electrons. The beam of pulsed electrons is carried across a radio frequency wave length in the linear accelerator, which has positively and negatively charged cavities that increase the speed of beam as it travels across the radio frequency waveform through the accelerator. The electron's speed is increased to 99.99% the speed of light at energies not to exceed 10 MeV, which are able to break molecular or atomic bonds releasing free electrons and ions that react with additional particles, charged molecules or atoms, to release secondary ions (Clemmons, Clemmons, & Brown, 2015). However, according to literature, related studies have already been conducted since the early 20th century. In 1905, patents utilizing radiation to reduce microbial contamination were issued in the United States and Britain. The irradiation treatment exposes food or agricultural products to free energy that is presented as gamma (γ) rays (cobalt-60 and caesium-137) or machine-generated X-rays (up to 5 MeV) and high-energy accelerated electrons (8–10 MeV). In general, the radiation exposure is measured by dose, and expressed as Grays or kiloGrays (kGy) (1 kGy = 1000 kJ or megarads (MR); 1MR = 1,000,000 erg/g) (Brown, 2015). The delivered dose of radiation varies depending on the food product or the raw material or purpose. In 1963, the United States Food and Drug Administration (USFDA) approved the use of 0.5 kGy radiation for the prevention of pest contamination in wheat and flour. So far, irradiation technology has been applied in the preservation of a variety of crops, and the microbial decontamination of food, including spices, cereals, meat, aquatic products, fruits, and vegetables (Sommers, 2012). The commonly used types of radiation treatments can be roughly divided into three levels based on dosage: (1) low-dose treatment (<1 kGy) for insect disinfestation (e.g., spices, cereals, and dried fruits), delay in fruit maturity (e.g., bananas), and prevention of germination (e.g., potatoes, ginger, garlic, and onions); (2) intermediate-dose treatment (1–10 kGy) to eliminate microbial contamination and extend shelf life of commodities (such as spices, spice powder, coffee beans, fruits/vegetables and their products, seafood, and poultry); and (3) high-dose treatment (10–60 kGy) used in the irradiation of food prepared for medical patients (with a low levels or lack of immunity) and astronauts (Fan, Sommers, & Marshall, 2012).

Early radiation treatment of food was mostly conducted using γ-rays. Despite its wide use in the preservation of various food products, consumers doubt the safety and efficacy of γ-ray-treatment of food products. The development of electron accelerators during the 1930s contributed to the research breakthrough by Cleland in the late 1950s (Bhat *et al*., 2012). Thereafter, the accelerator technology matured, with lower production costs of equipment; therefore, this technology could be used for the purpose of food irradiation. Electron accelerators appear to be more successful compared to γ-rays because of the following advantages: (1) source (machine) that can suspend the irradiation at any time; (2) non-nuclear energy that can accelerate the generation of radiation when required; (3) little risk for occupational injuries; and (4) applicability in high-flow and high-dose irradiation (Clemmons *et al*., 2015). In recent years, EBI has been used in the food (for decontamination and disinfection), pharmaceutical (disinfection of disposable medical equipment), and chemical (cross-linking and polymerization of polyethylene and polypropylene) industries, hospital and medical applications (radiation therapy and brachytherapy), and environmental applications in various industries (sludge disinfection and pollution monitoring and control) (Moosekian, Jeong, Marks, & Ryser, 2012). However, the main disadvantage of using EBI is the problematic low penetrability of the e-beam. The decontamination effect of EBI may be influenced by the size, thickness, direction (single- or double-side exposure), and packaging of the food. EBI treatment is especially effective in low-density and uniformly-packaged food (Henson, 1995). Han, Castell-Perez, and Moreira (2007) assessed the effect of EBI on antimicrobial agent-coated low density polyethylene (LDPE)/polyamide films. A dose of 3 kGy was observed to cause small or negligible changes in the functionality of the films, but did not alter the inhibitory effect on *Listeria innocua* and *Escherichia coli*. In addition, some consumers still hold a negative view towards a few terms, such as "radiation," and "radioactivity." Therefore, consumer education through database, reports, and seminars is required. Based on a literature review, this paper introduces the decontamination principles of EBI, and its potential applications in the food industry. Further, the possibility of future use of EBI as an alternative to traditional food decontamination methods (e.g., fumigation) has been discussed.

Decontamination mechanism of EBI

EBI can inhibit microbial growth in food through the direct or indirect damage of the physiological metabolism and chemical reactions performed by microorganisms, leading to injury or death. When exposed to EBI, the microorganisms generate energy transfer within their body, resulting in the destruction of chemical and molecular bonds (e.g., breaks in DNA structure, and denaturation of enzymes and membrane proteins). Therefore, the cells can no longer perform normal physiological metabolism activities, and lose the function of chromosomal replication