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Review

Effects of radiation processing on phytochemicals and antioxidants in plant produce

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Consumption of natural, fresh plant produce rich in phytochemicals and antioxidants has been reported to overcome some of the degenerative diseases that affect humans. However, improper processing, handling, and long-term storage of produce might result in minimal availability of the health-promoting compounds. Food irradiation as a physical method for preservation has proved its efficacy over other common means of preservation, and is known to retain the quality of food and agricultural commodities. This paper summarizes the effects of ionizing (gamma and electron beam) and non-ionizing (UV) radiation on the compositional changes induced in health-promoting phytochemicals and antioxidants of plant origin. The information will be beneficial for further commercialization and exploration of this novel technology on a pilot scale in food industries.

Introduction

The current century has witnessed innovations and techniques that have been introduced and explored in the field of food preservation. These innovations are a result of the ever-increasing demand from consumers all over the world for high quality foods, with major emphasis placed on quality and safety attributes. One of the main demands consumers make is for minimally processed, high nutrition/low energy natural foods with no or minimal chemical preservatives. However, as each step during food processing affects the foods natural properties to variable extents, food authorities the world over have implemented HACCP and ISO standards to overcome these hindrances. Hence, in order to cope with this revolutionary development in the food industry, there should be a complete and thorough understanding of every single step the food product goes through from farm to table.

Food processing by employing radiation is well established as a physical, non-thermal mode of food preservation (cold-pasteurization) that processes foods at or nearly at ambient temperature. Irradiation of food products causes minimal modification in the flavor, color, nutrients, taste, and other quality attributes of food. However, the levels of modification (in flavor, color nutrients, taste etc.) might vary depending on the basic raw material used, irradiation dose delivered, and on the type of radiation source employed (gamma, X-ray, UV, electron beam) (Bhat & Sridhar, 2008; Bhat, Sridhar, & Yokotani, 2007; Mexis, Badeka, Chouliara, Riganakos, & Kontominas, 2009). Reports are available showing that ionizing radiation of food commodities, in the form of gamma rays or electron beams, is effective in overcoming quarantine barriers in international trade, as a mode of decontamination, disinfestation, and for improving nutritional attributes and shelf life (Hong *et al*., 2008; Lacroix & Ouattara, 2000; Teets, Sundararaman, & Were, 2008). There is also a renewed interest in the food industry to utilize non-ionizing radiation from UV light for disinfection purposes (Selma, Allende, López-Gálvez, Conesa, & Gil, 2008; Walkling-Ribeiro *et al*., 2008).

Dietary antioxidants have been proved to play a major health protective role. The available reports have confirmed that fresh fruits and vegetables possess rich antioxidant properties that are beneficial to human health (Craig, 1997; Gaziano *et al*., 1995; Heimler, Isolani, Vignolini, Tombelli, & Romani, 2007; Vasco, Ruales, & Kamal-Eldin, 2008; Verlangieri, Kapeghian, el-Dean, & Bush, 1985; Visioli & Galli, 1998). These antioxidants are recognized as bioactive compounds that act against possible ill effects of free radical-induced damage in humans. For example, polyphenolic compounds like flavonols, flavones or the

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flavonoids, have gained considerable interest as they are shown to be very effective protecting against cardiovascular diseases by reducing the oxidation of LDL as well as preventing other degenerative diseases (Neto, Amoroso, & Liberty, 2008; Pierini, Gee, Belshaw, & Johnson, 2008; Wang & Stoner, 2008). However, flavonoids are generally considered to be absorbed only in very small amounts *in vivo*; thus, there is a general tendency to increase the consumption of fresh fruits and vegetables, as this can help increase the intake of essential bioactive compounds and antioxidants. However, researchers worldwide are recommending further studies relevant to flavonoids, other related phytochemicals and related bioactive compounds, as the evidence provided are either inconclusive or sometimes contradictory (Hollman, 2001; Kris-Etherton *et al*., 2002).

Excellent reviews and monographs have been published on the impact of radiation on the preservation of fresh plant produce, especially fruits and vegetables (Kader, 1986; Thomas, 1984, 1986a, 1986b, 1988). However, there is a paucity of information pertaining to the effect of irradiation (ionizing and non-ionizing in the form of UV, gamma rays, and electron beam) on these foods' antioxidant properties.

This review focuses on the effect of irradiation on the antioxidants in plant produce, as we feel that much work should be done to clearly cover this aspect of the application of irradiation in the food industry.

Irradiation as a food preservation technique – current status

Irradiation treatment involves the exposure of food products (raw or processed) to ionizing or non-ionizing radiation for the purpose of food preservation. The ionizing radiation source could be high-energy electrons, X-rays (machine generated), or gamma rays (from Cobalt-60 or cesium-137), while the non-ionizing radiation is electromagnetic radiation that does not carry enough energy/quanta to ionize atoms or molecules, represented mainly by ultraviolet rays (UV-A, UV-B, & UV-C), visible light, microwaves, and infrared.

The safety and wholesomeness of irradiated foods has been well established and reviewed from time to time (Diehl, 2002; Wilkinson & Gould, 1998). The joint FAO/IAEA/WHO Experts Committee also confirmed that irradiation at 10 kGy and above does not produce any toxicological hazards or nutritional or microbiological problems in food (FAO/IAEA/WHO, 1999). Radiation processing has also been shown to decrease the antinutritional components in some proteinaceous leguminous seeds, thereby helping to provide food security (Bhat, Sridhar, Yokotani *et al*., 2007; Brigide & Canniatti-Brazaca, 2006).

Augmentation in international trade of tropical fruits and vegetables is considered to be one of the important modules for the economic development strategy of many underdeveloped countries (World Trade Organization, 2001). Hence, application of appropriate, reliable, and safer methods of preservation assumes importance in today's world. Even though radiation technology is considered an effective method for food preservation, public misconceptions about irradiation have delayed many of its potential applications in the food industry.

Irradiation, for the public and the consumer, is always related to carcinogenicity or destructive effects, and other aspects of irradiation still cannot be accepted due to a shallow understanding of the technique itself. Other technical obstacles include the source of radiation (like cobalt-60 or ultraviolet rays). Also, for example, UV irradiation has a weak or low penetration ability, which must be overcome to achieve satisfactory results from the process.

Of late, many preservation techniques have been introduced in the food industry for quality and shelf life improvement of fresh produce, which include: acidification, the addition of chemicals, modified-atmosphere packaging (MAP), ultrasound treatment, sonication, etc. Despite these techniques' aim of protecting the freshness of the food, these techniques will only control the activity of the microorganisms to varying degrees, without killing them, and most of the time sensory qualities have to be compromised. In many cases, this reason alone is enough to avoid the application of such techniques. On the other hand, there are few combined techniques that have been shown to be effective by causing complete destruction of all microorganisms present in the food, such as thermal (heat) and irradiation sterilization. It has been reported that less extreme use of heat and/or irradiation in different combinations with the other food preservation methods will not only provide a microorganism-free food, but might also be the best answer to successfully fulfilling the growing needs for a fresh food. According to Farkas (1990), the use of irradiation in combination with heat was first suggested in the 1950s when beneficial effects (of decontamination) were observed, and since then, irradiation has been applied with, prior, or after heat treatment as a food preservation method. For example, Pan, Vicente, Martínez, Chaves, and Civello (2004) reported that low dose UV-C irradiation (4.1 kJ m^{-2}) in combination with heat treatment (45 °C, 3 h in air) prior to fruit storage at 20 °C enhanced the benefits gained from applying each treatment individually, and could be useful to improve the shelf life of strawberries, despite the decrease in phenolics content and the decrease in the anthocyanins accumulation ratio when compared with the control fruits.

However, it is envisaged that the coming years, with more databases and research works available, will definitely help to increase the commercialization and acceptance of this novel technology.

Plant phytochemicals and their health-promoting effects

Phytochemicals are non-nutritive plant chemicals that possess protective roles in the human body – mainly against disease. These phytochemicals are considered to