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Effect of low-dose gamma radiation and active equilibrium modified atmosphere packaging on shelf life extension of fresh strawberry fruits

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ABSTRACT

The effect of low-dose gamma irradiation (1 kGy) and active equilibrium modified atmosphere packaging (EMAP1: CO_2 10%: O_2 5%; N_2 85% and EMAP2: CO_2 5%: O_2 10%; N_2 85%) on quality of strawberry fruits stored at 4 °C was investigated. Several quality parameters were monitored during the storage period. Fruit firmness, fungal decay and sensory evaluation were analyzed on days 1, 7, 14 and 21. Strawberries kept in active EMAP1 maintained their texture and appearance better than those packaged under air and EMAP2. Strawberries stored in active EMAP were firmer than those stored in air during the storage time (21 days). The irradiated strawberry samples were not attacked by *Botrytis cinerea* during 7 days. Irradiation and EMAP1 increased the postharvest life of strawberries to 14 days, without any attack of fungus or any change in their external appearance. Low-dose gamma irradiation in combination with EMAP will enable food processors to deliver larger amounts of high quality strawberry with extended shelf life.

1. Introduction

Strawberry fruits have short shelf life due to high perishability and are susceptible to mechanical injury, physiological disorders, water loss, and decay (Caner, Aday, & Demir, 2008). The shelf-life of fresh produce is limited to 1–2 days at room temperature (Ghuoath, Arul, & Ponnampalam, 1991; Harker, Elgar, Watkins, Jackson, & Hallett, 2000; Lieten, Kinet, & Bernier, 1995). Storage quality can be improved by low temperature (Zhang, Xiao, Peng, & Salokhe, 2003) and altering the gas atmosphere surrounding the fresh strawberry (Church, 1994; Holcroft & Kader, 1999). In equilibrium-modified atmosphere packaging (EMAP), the gas atmosphere of package consists usually of a lowered level of O_2 and a heightened level of CO_2 (Caner et al., 2008). When selecting packaging films for equilibrium modified atmosphere packaging of fruits, the main characteristics to consider are gas permeability, water vapour transmission rate, mechanical properties, transparency, type of package and sealing reliability. Although an increasing choice of packaging materials is available to the MAP industry, most packs are still constructed from four basic polymers: polyvinyl choloride (PVC), polyethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE), for packaging of fruits (Ahvenainen, 2003; Barmore, Purvis, & Fellers, 1983; Calderon & Barkai-Golan, 1990; Ding, Chachin, Ueda, Imahori, & Wang, 2002; Exama, Arul, Lencki, Lee, & Toupin, 1993; Kader & Watkins, 2001; Kader, Zagory, & Kerbel, 1989; Mangaraj, Goswami, & Mahajan, 2012; Marsh & Bugusu, 2007; Van Willige, Linssen, Meinders, Van der Steger, & Voragen, 2002). Amongst these packaging

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materials, polyethylene has been widely used for modified atmosphere packaging of fruits and vegetables (Alasalvar, Al-Farsi, Quantick, Shahidi, & Wiktorowicz, 2005; Antmann, Ares, Lema, & Lareo, 2008; Ares, Parentelli, Gámbaro, Lareo, & Lema, 2006; Darvishi, Fatemi, & Davari, 2012; Ding et al., 2002; Jouki & Khazaei, 2012, 2013; Khazaei, Jouki, & Jouki, 2011; Pretel, Fernández, Romojaro, & Martínez, 1998). Alasalvar et al. (2005) reported that the MAP treatment ($5\%O_2 + 5\%CO_2 + 90\%N_2$) gave better sensory quality and extended shelf-life for purple carrots (2–3 days longer shelf-life than other treatments,) but, no difference was observed for orange carrots. They also reported that shredded purple carrot can be stored under $5\%O_2 + 5\%CO_2 + 90\%N_2$ treatment for up to 10 days and high nitrogen treatment may be used in maintaining the storage quality of shredded purple carrots. Jouki and Khazaei (2013) showed that the saffron samples packaged under modified atmosphere and irradiated with dose 2.0 kGy were acceptable under storage for 60 days, compared to 30 days for air-packaged non-irradiated samples. Current knowledge and use of EMAP are mainly empirical, but a systematic approach to designing optimal EMAP is being developed (Caner et al., 2008; Del-Valle, Hernández-Muñoz, Catalá, & Gavara, 2009; Jacxsens, Devlieghere, & Devebere, 2004; Rotabakk, Wyller, Lekang, & Sivertsvik, 2008; Van der Steen, Jacxsens, Devlieghere, & Debevere, 2001). Application of ionizing radiation treatment of foods on an industrial scale was started at the beginning of the 1980s after the joint FAO/IAEA/WHO expert committee accepted it to be a safe method for preservation. The recommended dose levels are: low level at 1 kGy to inhibit insect infestation and delay ripening; medium at 1–10 kGy to reduce bacterial load (particularly of pathogens); and high at 10–50 kGy for commercial sterilization and elimination of viruses (WHO, 1999). Ionizing radiation is a method for preservation of foods that uses high energy gamma rays or accelerated electrons (Andrews et al., 1998). Drake, Sanderson, and Neven (1999) found that <900 Gy can be used as a quarantine treatment for 'Fuji', 'Gala', 'Granny Smith' apples and 'Anjou', 'Bosc' pears, and that fruit response to irradiation was cultivar dependent. Olsen, Hungate, Drake, and Eakin (1989) found that <1000 Gy can be used as a quarantine treatment for 'Red Delicious' apples. Perez et al. (2009) reported that irradiation as a quarantine treatment can be applied with doses <800 Gy for apples and pears of Argentina, preserving exportation quality grade. Jouki and Khazaei (2013) showed that saffron samples packaged under modified atmosphere and irradiated with dose 2.0 kGy were acceptable under storage for 60 days, compared to 30 days for air-packaged non-irradiated samples. Several studies have been carried out on the physical, chemical composition, sensory properties and nutritive values of strawberry during storage (Jouki & Khazaei, 2012; Jouki & Dadashpour, 2012; Nielsen & Leufven, 2008). Although exposure to low UV-C radiation doses has been reported to reduce postharvest decay of Fresh 'Kurdistan' Strawberry (Darvishi et al., 2012), no data has been published on the preservation of strawberry by gamma irradiation and modified atmosphere packaging. The objectives of the present study were to evaluate the effect of gamma irradiation and active equilibrium atmosphere packaging on fungal decontamination, physical and sensory properties of strawberry fruit, and to follow quality parameters during storage.

2. Materials and methods

2.1. Sample preparation

Ripe fresh strawberry fruits grown in Sanandaj area in Kurdistan, Iran (cultivar Kurdistan) were harvested in the morning in September 2012. After harvesting, sorting and cutting their stems, they were transported in air-conditioned vans to the laboratory of Packaging and Postharvest Physiology of fruits at the University of Tehran and divided into two groups: to be irradiated and not to be irradiated. Then two groups were packaged under normal conditions and EMAP packaging methods, storing at 4 °C for further analysis. The analyses were made at 1st, 7th, 14th and 21st days. Each measurement was repeated six times.

2.2. Packaging methods

Polyethylene (PE) packaging rolls were used for preparation of packages of 30 cm × 20 cm. Oxygen permeability (O_2P), carbon dioxide permeability (CO_2P), water permeability (H_2OP) and thickness at 25 °C for polyethylene were 69 $cm^3/m^2/24$ h/atm, 251 $cm^3/m^2/24$ h/atm, 3.2 $g/m^2/24$ h/atm and 62 μm, respectively. The headspace volume inside the packages was approximately 1.5 L. Twelve strawberries, approximately 200 g, were placed in polyethylene packages. In this study three different gas compositions such as AP: (normal atmosphere), EMAP1: (CO_2 10%: O_2 5%; N_2 85%) and EMAP2: (CO_2 5%: O_2 10%; N_2 85%) were applied with the modified atmosphere packaging machine (200A), combined with a triple gas mixer (B20-010). After the experiment was set up, fruits were stored in a cold room maintained at 4 °C, for 21 days. Quality parameters were evaluated after 1st, 7th, 14th and 21st days.

2.3. Irradiation

The packaged samples were exposed to dose levels of 0.0 (control) and 1.0 kGy by Co-60 source (gamma cell px-30 dose rate = 0/749 Gy/s and activity = 4600Ci) in Nuclear Agriculture Department of Agricultural, Medical and Industrial Research Institute, Atomic Energy Organization of Iran. The dose rate was established using alanine transfer dosimeter to make sure that the dose reached the target dose.

2.4. Gas composition inside the packages

The concentrations of O_2 and CO_2 inside the packages were monitored using an Oxybaby (HTK, Hamburg, Germany). The gas analyzer needle was inserted through an impermeable rubber seal attached on the outside of the film (Aday, Caner, & Rahvalı, 2011). Measurements were performed day 0, 7, 14 and 21. Three replicates were used to determine the gas composition.

2.5. Fungal decay

The presence of *Botrytis cinerea* was estimated visually in each individual fruit immediately after opening the packages. Strawberry fruits showing surface mycelial development were