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Impact of combined postharvest treatments (UV-C light, gaseous O_3, superatmospheric O_2 and high CO_2) on health promoting compounds and shelf-life of strawberries

Ana Allende, Alicia Marín, Begoña Buendía, Francisco Tomás-Barberán, Maria I. Gil *

Research Group on Quality, Safety and Bioactivity of Plant Foods, CEBAS-CSIC, P.O. Box 164, Espinardo, Murcia 30100, Spain

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Abstract

Modified atmosphere packaging (MAP), ozone (O_3) and ultraviolet-C (UV-C) light, have been suggested as postharvest treatments to control decay of strawberries. However, the influence of these treatments on strawberry phytochemicals has not been thoroughly evaluated. Thus, the impact of individual and combined UV-C light (1 kJ m^{-2}), gaseous O_3 (5000 mg L^{-1}) and two active MAP conditions (superatmospheric O_2 and CO_2-enriched atmospheres) on the polyphenols, vitamin C content and shelf-life of strawberries was studied. Samples were taken initially, and after 5, 9 and 12 days of storage and microbial, nutritional and organoleptical qualities were evaluated. None of the evaluated samples showed visual signs of fungal growth after 12 days of storage, including non-treated samples stored in air. However, phenolic contents of UV-C and O_3 treated strawberries were significantly reduced after treatments, mainly due to a significant decrease in procyanidins. Ozonated samples showed the lowest vitamin C contents at the end of storage. On the other hand, when compared with storage in air, strawberries stored under superatmospheric O_2 and CO_2-enriched concentrations showed lower total phenolic contents after 5 days and a vitamin C reduction after 12 days of storage, accompanied by a more pronounced conversion from reduced to oxidized forms under superatmospheric O_2. In general, overall quality was good in all samples throughout the shelf-life except for flavour scores of MAP strawberries, which were clearly lower than air-stored samples after 9 and 12 days of storage. No additional effect was observed when combining the postharvest treatments compared with the effect of individual treatments.

Keywords: *Fragaria ananassa*; Microbial growth; Vitamin C; Procyanidins; Polyphenols; Anthocyanins; Modified atmosphere packaging; Quality

1. Introduction

The short postharvest shelf-life of strawberries encourages the use of decay-control techniques. The most commonly used postharvest treatments to control fungal growth and reduce respiration rate of strawberries are low temperature and modified atmosphere packaging (MAP) at 15–20 kPa CO_2 (Mitcham, 2004). Carbon dioxide (CO_2)-enriched atmospheres are used to reduce the incidence and severity of decay and therefore extend the postharvest life of strawberries (Li and Kader, 1989). However, in some cases, adverse effects on colour and flavour after exposure to very low O_2 and very high CO_2 concentrations have been reported (Ke et al., 1991; Shamaila et al., 1992). Superatmospheric oxygen (O_2) conditions (i.e. >70%) have been suggested as an alternative to conventional MAP of fruit and vegetables, since they have a growth inhibitory effect on bacteria, yeast and moulds and prevent undesired anoxic fermentation (Allende et al., 2002; Van der Steen et al., 2002).

Many researchers have reported the effects of MAP on the antioxidant constituents and microbial quality of strawberries (Gil et al., 1997; Pérez and Sanz, 2001; Pelayo et al., 2003; Siro et al., 2006; Zheng et al., 2007). Among the different postharvest technologies that can be used to maintain quality and increase safety of strawberry fruit, ultraviolet-C (UV-C) light and gaseous ozone (O_3) are two promising preservation techniques. Numerous studies have already been focused on the bactericidal and fungicidal capacity of O_3 and UV-C treatments (Kim et al., 1999; Marquenie et al., 2002a; Palou et al., 2002; Pan et al., 2004). Additionally, UV-C light and gaseous O_3 applications have been proposed to promote synthesis of health promoting compounds (Cantos et al., 2000; Artés-Hernández et al., 2003; González-Barrio et al., 2006). Nevertheless, little information is available on the effect of these treatments on the phytochemicals of strawberries when individually applied or in combination with other

* Corresponding author. Tel.: +34 968 396 315; fax: +34 968 396 213.
E-mail address: migil@cebas.csic.es (M.I. Gil).

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postharvest techniques. Therefore, the aim of this study was to determine the effect of UV-C light, gaseous O_3, superatmospheric O_2 and CO_2-enriched atmospheres applied individually and in combination on the health promoting compounds and shelf-life of strawberries.

2. Materials and methods

2.1. Plant material

Strawberry fruit (*Fragaria* × *ananassa* D. cv. Camarosa) at commercial maturity were obtained from commercial growers in Huelva (Spain) between April and June 2004. Fruit were transported in refrigerated conditions to CEBAS-CSIC (Murcia, Spain) and stored in darkness at 2 °C and 95% relative humidity (RH). The day after, strawberries were graded for uniformity of colour and size, and damaged berries were removed.

2.2. UV-C and O_3 treatments

The UV-C equipment consisted of a bank of 17 unfiltered germicidal emitting lamps ($\lambda = 254$ nm) (Sylvania, G30T8, Philips, The Netherlands). A wooden box covered with aluminium foil and supported by a metal framework enclosed the UV-C lamps, reflectors, and treatment area, providing UV protection for the operator. The lamp bank was horizontally suspended over the illumination vessel at a distance of 60 cm. Strawberries were placed in a single layer on the illumination vessel for the treatment, and different UV-C doses were applied by altering the exposure time at the fixed distance. Twenty-five strawberries were treated for each illumination batch and each fruit was rotated manually once to ensure even surface exposure to UV light. The fluence rate of the lamps at the level of the samples was 2.82 ± 0.44 mW cm^{-2}, measured with a Blak-Ray J-225 photometer (Ultra-Violet Products, Inc., San Gabriel, CA). To produce O_3, extra-dry compressed air (0.7 Pa) was let through a water-cooled corona discharge generator (model 1A, Steriline, Ozono Electónica Ibérica, Granada, Spain) (González-Barrio et al., 2006). Gaseous O_3 concentration was measured with an O_3 gas analyser (model H1-SPT, IN USA Inc., Needham, MA). Ozone gas was supplied in air constant flow of 0.16 N m^3 h^{-1}, with productions of 1.7, 3.5, 5.2 and 6.9 g h^{-1} produced by the O_3 generator in a 50 L methacrylate chamber at 22 °C and 95% relative humidity (RH). The chamber temperature and RH were determined with a data logger (model Tinytag TGU-1500, Gemini Dataloggers Ltd., Sussex, UK). The values of O_3 obtained were constant throughout the experiments, and the gas mixture expelled from the chamber was destroyed by a catalytic destroyer (OIE, Granada, Spain). The experiments with O_3 were made in the pilot plant of CEBAS-CSIC in accordance with strict safety and protection rules. Preliminary assays were carried out to select the optimum UV-C light and gaseous O_3 treatment doses. Four different UV-C light doses (1, 5, 10 and 15 kJ m^{-2}) and O_3 concentrations in the gas carrier (air) of 5000, 10,000, 15,000 and 20,000 mg L^{-1} were tested. All the treatments were applied in a cold room at 10 °C.

2.3. Respiration rate and gas analysis

Strawberries (250 g) were placed in a 1 L glass jar at 2 °C and 95% RH. A continuous humidified air flow was pumped into the jars to avoid dehydration and excessive CO_2 accumulation. The respiration rate as CO_2 production was monitored every day for up to 6 days. On each sampling date, triplicate jars per treatment were evaluated. Samples of 1 mL of headspace gas were taken from each glass jar with a calibrated syringe and monitored by using a gas analyser (Horiba Via 510, Irving, USA).

2.4. Superatmospheric O_2 and CO_2-enriched atmospheres

Strawberry samples of 250 g each, were packaged and sealed in polypropylene (PP) trays (185 mm × 138 mm × 32 mm) using perforated film (control air) as well as in an active modified atmosphere by using an O_2 barrier film with an OTR of 0 pmol s^{-1} m^{-2} Pa^{-1} (Tecknopack S.L., Barcelona, Spain). The perforated packages were prepared using the same barrier film with 50 perforations made with a syringe (Ø 0.6 mm, 979 perforations m^{-2}). Active modified atmospheres were generated by flushing the packages with the desired gas composition: (1) superatmospheric O_2 of 80 kPa O_2 (balanced with N_2) and (2) CO_2-enriched concentrations of 10 kPa CO_2 (10 kPa O_2, balanced with N_2). A gas exchange device with a vacuum packaging machine (Zermat, Carburos Metálicos S.A., Madrid, Spain) and a mixing station (Witt-Gasetechnik, model KM 100-3 M, Carburos Metálicos S.A.) were used. All preparation steps were performed at 10 °C under sanitary conditions. Subsequent evaluation of atmospheric composition, microbial growth, vitamin C and polyphenols of strawberry samples were carried out at day 0 and after 5, 9 and 12 days of storage at 2 °C and 95% RH.

2.5. Microbial analysis

Strawberry samples of 30 g each were homogenized in a 1:10 dilution of 1% sterile peptone buffered water (AES Laboratoire, Combourg, France) by using a stomacher (IUL Instrument, Barcelona, Spain) for 90 s. Filter stomacher bags (Seward Limited, London, UK) were used to eliminate solid particles from the strawberry homogenates. Ten-fold dilution series were made in peptone buffered water as needed for pour plating. The following culture media and conditions were used to evaluate the microbial growth: 1 mL of the appropriate sample dilution was pour-plated on (1) plate count agar (PCA, Scharlau Chemie S.A., Barcelona, Spain) incubated at 30 °C for 24–48 h for aerobic mesophilic bacteria and at 4 ± 1 °C for 7 days for aerobic psychrophilic bacteria; (2) Chromocult coliform agar (Merck, Darmstadt, Germany) incubated at 37 °C for 24–36 h for coliform counts; (3) Lactobacilli MRS broth (Difco Lab, Sparks, MD, USA) with addition of BactoTM agar (10 g L^{-1}) (Difco Lab, Sparks) and overlaid with the same medium, incubated aerobically at 30 °C for 72 h for lactic acid bacteria, and (4) 100 μL of the appropriate sample dilution was spread-plated on Rose Bengal agar (Scharlau Chemie S.A.) and incubated at 30 °C for 48–72 h for moulds and yeasts. Microbial counts were expressed as $\log_{10}$ cfu g^{-1}.