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Influence of continuous exposure to gaseous ozone on the quality of red bell peppers, cucumbers and zucchini

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ABSTRACT

The effect of continuous exposure to ozone on quality changes during the storage of red bell peppers, cucumbers and zucchini was investigated. Peppers were stored at 14 °C and were exposed to ozone at 0.1 and 0.3 μmol mol^{-1}, while cucumbers and zucchini were stored at 12 and 8 °C, respectively, and exposed to ozone at 0.1 μmol mol^{-1}. The content of fructose (2.75 g/100 g FW) and glucose (2.00 g/100 g FW) in red bell peppers exposed to ozone at 0.1 μmol mol^{-1} was increased by 8 and 7%, respectively, when compared to controls. Continuous exposure to ozone at 0.3 μmol mol^{-1}, on the other hand, had no effect on fructose (2.52 g/100 g FW) and glucose (1.88 g/100 g FW) content. The content of vitamin C was significantly enhanced in red bell peppers exposed to ozone at 0.1 and 0.3 μmol mol^{-1} after 7 d of storage, however, this effect was not maintained. After 14 d, vitamin C content in peppers exposed to ozone at 0.1 μmol mol^{-1} was not significantly different from the control, whereas it was reduced at 0.3 μmol mol^{-1}. Total phenolics content was increased in peppers exposed to ozone at 0.1 μmol mol^{-1}, but was unaffected at 0.3 μmol mol^{-1}. Continuous exposure of red bell peppers to ozone at 0.1 and 0.3 μmol mol^{-1} had no significant effect on weight loss, texture and colour. In cucumbers and zucchini, continuous exposure to ozone at 0.1 μmol mol^{-1} reduced weight loss by more than 40% and improved texture maintenance, while having no significant effect on their biochemistry. The findings from this study suggest that continuous exposure to ozone at 0.1 μmol mol^{-1} is a promising method for shelf-life extension of cucumbers and zucchini. Even though in red bell peppers continuously exposed to ozone at 0.1 μmol mol^{-1} sugars and phenolics content was increased, further work is still needed to better understand the exact mechanism of ozone action and its potential for the industrial use.

1. Introduction

The economic value of trade in fresh produce is constantly growing, due to increasing consumer demand. Consumers care more and more about what they eat and fresh produce has been recognised as a healthy food, for example being rich in antioxidants (Llorach et al., 2008; Alothman et al., 2010; Yeoh et al., 2014). The shelf-life of fresh produce, however, is shorter than other food products, and is determined by initial quality at harvest (Clarkson et al., 2003; Zhang et al., 2007) and subsequent storage conditions (Nunes et al., 2009). New techniques for reducing undesired microbial contamination, spoilage and decay, as well as maintaining the product's visual, textural and nutritional quality are required at all steps of the production and distribution chain.

Treatment with ozone (O_3) is currently being explored as a practical method to reduce/eliminate microorganisms present in food (Khadre et al., 2001; Guzel-Seydim et al., 2004). Ozone is a well-known strong oxidizing agent that has been used by the fresh produce industry as an antimicrobial agent for a number of years and has been generally recognised as safe (GRAS). The use of ozone by the fresh produce industry is a good alternative to chemical treatments, such as the use of chlorine as it leaves no chemical residues. Recently, there has been an increasing interest in the use of ozone as a postharvest treatment of fruit and vegetables (Horvitz and Cantalejo, 2014). Only those treatments that reduce microbial contamination and extend the shelf-life of the product without having an adverse effect on the product's visual, textural and nutritional quality (Allende et al., 2008) can be recommended and subsequently incorporated into the supply chain.

A number of studies (Ketteringham et al., 2006; Alexandre et al., 2011; Horvitz and Cantalejo, 2012; Alexopoulos et al., 2013) investigated the efficiency of ozone in reducing microbial counts on peppers, however, only one study (Horvitz and Cantalejo, 2012)

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assessed physicochemical properties of the produce. Microbial contamination of peppers can be reduced by applying ozone in either gaseous (Horvitz and Cantalejo, 2012) or aqueous (Alexandre et al., 2011; Alexopoulos et al., 2013) form. Ketteringham et al. (2006), however, did not observe reductions in microbial counts in fresh-cut peppers washed with ozonated water at 0.30–0.35, 0.38–0.45 and 3.85–3.95 μmol mol^{-1} for 20 s to 30 min, and suggested that this could be due to cut surfaces that promoted leaching of organic matter, thus providing a higher concentration of organic matter to react with ozone, thereby reducing the concentration of ozone available to act as an antimicrobial agent. Thus, Ketteringham et al. (2006) suggested treating whole rather than pre-cut peppers. Interestingly, ozonated water at 1 μmol mol^{-1} applied for 3–5 min, has recently been found to be efficient in reducing mesophilic and psychrotrophic bacteria, yeast and mould counts on fresh-cut peppers (Horvitz and Cantalejo, 2012). Furthermore, Horvitz and Cantalejo (2012) reported that gaseous ozone at 0.7 μmol mol^{-1} applied for 1–5 min prior to storage was even more efficient as a sanitizer when compared with aqueous form at 1 μmol mol^{-1} applied for the same time. These findings highlight the need to focus on the effects of gaseous ozone on the quality of red bell peppers. Fruit and vegetables can be treated either with high ozone concentration prior to storage (Yeoh et al., 2014) or they might be continuously/intermittently exposed to lower ozone concentration during storage (Aguayo et al., 2006; Tzortzakis et al., 2007b). There are no reports on continuous exposure of red bell peppers to low concentrations of ozone.

On the other hand, the availability of information regarding the effects of ozone exposure on the quality of cucumbers is limited (Skog and Chu, 2001), while to our knowledge, there has not been any research dealing with effects of ozone exposure on zucchini.

Exposure of fresh produce to ozone is expected to induce production of reactive oxygen species (ROS) (Kangasjarvi et al., 2005); too much stress, however, leads to cell death, evidenced by discolouration and loss of texture. Thus, the dose of ozone has to be appropriately adjusted for each commodity (Forney et al., 2003). For safety reasons, within the fresh produce industry, it is important to keep the levels of ozone low; the recommended limit set for humans by the US Occupational Health and Safety Administration is 0.1 μmol mol^{-1} averaged over an 8 h shift. Ozone can also cause damage to equipment by, for example causing cracks in rubber. Thus, the aim of this study was to determine the effect of continuous exposure to low concentrations of ozone (0.1–0.3 μmol mol^{-1}) on quality changes during the storage of red bell peppers, cucumbers and zucchini.

2. Materials and methods

2.1. Plant material and handling

Red bell peppers (*Capsicum annuum* L.) variety Ferrari (commercially mature but not fully ripe; 75–85 mm in diameter) and mature cucumbers (*Cucumis sativus* L.) variety High Jack (~30 cm long) were supplied by a commercial greenhouse and pack-house facility, Thanet Earth, Kent, UK, whereas zucchini (*Cucurbita pepo* L.) variety Prometheus (small; 12–16 cm long) were supplied by Mack Multiples Ltd, Kent, UK. On arrival, all fruit were graded to be free from visible defects.

For experiment 1, that addressed the effect of ozone exposure on quality changes during the storage of red bell peppers, fruit were placed for 14 d in six (2 containers per treatment) 30 L sealable plastic containers (24 fruit per treatment) supplied with humidified air (RH, 92 ± 2%) at constant air flow of 0.05 m^3 h^{-1} as a continuous, flow-through system at 14 ± 1 °C, as recorded using temperature and humidity loggers (Lascar Electronics Ltd, UK). Ozone was supplied at approximately 0.1 ± 0.015 and 0.3 ± 0.030 μmol mol^{-1}, using FPU-02 ozone generators (Onnic International, UK) placed within the containers close to air inlet. Air was circulated inside the box to ensure even distribution of ozone. Ozone concentration was monitored periodically, on the sampling day before taking the produce out from containers for subsequent assessment, with an L-106 Ozone Monitor (2B Technologies, US). Produce quality (weight loss, texture, colour, sugars, soluble solids and pH, ascorbic acid and total phenolics) was assessed on arrival and after 7 and 14 d of storage, respectively.

For experiment 2, that addressed the effect of ozone exposure on quality changes during the storage of cucumbers and zucchini, fruit were placed for 17 d in sixteen (4 containers per treatment) 30 L sealable plastic containers (48 fruit per treatment) supplied with humidified air (RH, 90 ± 2%) at a constant air flow of 0.05 m^3 h^{-1} as a continuous, flow-through system at 12 ± 1 °C (cucumbers) and 8 ± 1 °C (zucchini), respectively. Ozone at 0.3 ± 0.030 μmol mol^{-1} was found injurious to the fruit, thus in experiment 2 only the lower dose at approximately 0.1 ± 0.015 μmol mol^{-1} was used. Produce quality (weight loss, texture, colour, ascorbic acid and total phenolics), however, was assessed more frequently, i.e. on arrival and after 6, 10, 13 and 17 d of storage, respectively.

Storage conditions for both experiments were advised by fruit suppliers to simulate the conditions that produce is facing at their facilities, so that the findings from this research could have a practical value for them.

2.2. Measurements

2.2.1. Weight loss

All fruit were labelled and weighed on arrival (day 0). Weight loss (%) was determined by comparing the weight of each fruit on the sampling day with their initial weight determined on day 0.

2.2.2. Texture analysis

Firmness of red bell peppers was determined following the method of Vega-Galvez et al. (2009) with some modifications. Fruit firmness was determined (4 measurements per fruit) using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a 2-mm diameter probe (puncture test) and a 0.05 kN load cell. The probe was driven 5.0 mm at a speed of 1.7 mm s^{-1} and the maximum force (N) was recorded.

Firmness of cucumbers and zucchini was determined following the method of Hurr et al. (2013) with some modifications. Fruit firmness was determined (5 measurements per fruit) using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a convex-tip probe; 8-mm diameter for whole fruit firmness and 2-mm diameter for mesocarp firmness, and a 0.05 kN load cell. The probe was driven 2.5 mm at a speed of 0.83 mm s^{-1} and the maximum force (N) was recorded.

2.2.3. Colour

Skin colour measurements were taken using a Minolta CR-400 chroma meter (Minolta, Japan) with an 8 mm diameter measuring head and a C illuminant calibrated with manufacturer's standard white plate. Colour changes were quantified for 12 fruit from each sample (5 measurements per pepper, 3 measurements per cucumber and zucchini) in the L^*, a^* and b^* colour space (Abbott, 1999). Hue angle (H°) was then calculated as $H^\circ = \tan^{-1}(b^*/a^*)$, when a^* and b^* were >0 and $H^\circ = 180 + \tan^{-1}(b^*/a^*)$, when a^* was <0 and b^* was >0.

2.2.4. Soluble solids and pH

Soluble solids content (SSC) was measured using an eclipse handheld refractometer (Bellingham & Stanley Ltd, UK) and