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Effect of superatmospheric oxygen exposure on strawberry (*Fragaria* × *ananassa* Fuch.) volatiles, sensory and chemical attributes

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ABSTRACT

The effect of superatmospheric oxygen exposure on the sensory quality, decay incidence, total phenolics, antioxidant capacity, aroma volatiles of strawberries during storage at 0 °C were explored. Freshly harvested strawberry fruits were stored under modified atmosphere 1 (MA1, 90% O_2/10% N_2), modified atmosphere 2 (MA2,3% O_2/5% CO_2/92% N_2) and control (CT, air). The exogenous superatmospheric oxygen (MA1) had a beneficial effect on maintaining sensory quality and strawberry firmness, and reduced the decay incidence. Titrable acidity and total soluble solid were only slightly affected by superatmospheric oxygen atmosphere. Additionally, superatmospheric oxygen exposure maintained higher levels of total phenolics content and antioxidant capacity than that of CT. Strawberries stored in superatmospheric oxygen emitted more esters, 4-methoxy-2,5-dimethyl-3(2*H*)-furanone (DMHF) and γ-decalactone. In conclusion, superatmospheric oxygen exposure could be a good alternative for maintaining sensory quality, antioxidant capacity, and aroma volatiles of strawberry.

1. Introduction

Flavor has great influence on consumer satisfaction and further consumption of fruits. Therefore, flavor and aroma together with nutritional value should be incorporated into the postharvest life concept. Strawberries (*Fragaria* × *ananassa* Duch.) are one of the most popular fresh and processed fruits worldwide. However, strawberries are highly perishable, mostly due to their increased susceptibility to mechanical injury, water loss, physiological deterioration and microbial decay (Ulrich et al., 2007). And strawberries are metabolically active after harvest and can rapidly deteriorate even in the absence of any spoilage microorganisms. Strawberry are popularly consumed for their desirable taste and attractive aroma. Compounds contributing to the flavor of strawberries, especially the volatile ones. Over 360 aroma volatiles have been identified (Latrasse, 1991), including esters, aldehydes, ketones, alcohols, terpenes, furanones, and sulfur compounds (Mcfadden et al., 1965). And the composition of individual aroma volatiles are in a postharvest treatment dependent manner (Pérez and Sanz, 2001). Moreover, strawberries contain high concentration of anthocyanins, flavonoids, and phenolic acids (Zheng et al., 2007). Many of these compounds exhibit a wide range of biological effects, including antioxidant (Kähkönen et al., 2001) and antifungal (Lattanzio et al., 1994). Preservation and extension of shelf life of strawberry has been a major challenge for researchers, and more researches were done to preserve and enhance stawberry aroma and antioxidant capacity during postharvest handling.

Among these techniques available, modified atmosphere packaging (MAP) has been reported to have some positive impacts on extending shelf life of fruit or vegetable (Arteshernandez et al., 2006). In MAP, fruits and vegetables are packed in a plastic polymeric film and passively or actively, the atmosphere is modified in terms of the O_2 and CO_2 (mainly) concentrations. Gases in MAP may reduce the fruit or vegetable metabolic activity and enhance their shelf-life. Almenar et al. (2006) reported that 10% CO_2/11% O_2 combination could efficiently prolong the shelf life of wild strawberries. Conversely, various drawbacks related to off-odor development, physiological decay as well as loss of texture have been observed when CO_2 accumulates inside the

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package in the presence of low O_2 levels (Allende et al., 2004; Larsen and Watkins, 1995).

The application of novel gas mixtures (e.g. high O_2, argon and nitrous oxide) are new methods for designing modified atmospheres (MA) capable of overcoming the many disadvantages of the current high CO_2 and/or low O_2 in MA and CA. Superatmospheric oxygen atmospheres have been suggested to overcome the disadvantages of low O_2 MAP. Superatmospheric oxygen was found to be particularly effective at inhibiting microbial growth and reducing decay of the fresh produce, preventing anaerobic fermentation reactions and undesirable moisture and odor losses (Berna et al., 2007; Steen et al., 2002). Moreover, oxygen concentrations higher than 60 kPa significantly affected antioxidant capacity of fruit during storage (Zheng et al., 2007). Limited data are reported on the influence of superatmospheric oxygen on the flavor and antioxidant capacity preservation of strawberry.

The objectives of the present study were (i) to investigate the sensory quality of strawberry variety cv. Akihime exprosed superatmospheric oxygen; (ii) to identify and to quantify volatile compounds in strawberries under superatmospheric oxygen atmosphere.

2. Materials and methods

2.1. Sample preparation, treatment and storage

Ripe fresh strawberry fruits (*Fragaria* × *ananassa* Duch. cv. 'Akihime') were harvested from a local farm in Hangzhou, China. The strawberries were transferred to the laboratory within 1 h. Damaged or unripe fruit were eliminated and fruit with a uniform maturity, size and color were selected. Strawberries were divided into three groups of 315 fruits each. Each group was further divided into seven sub-groups of 45 fruits each including three replicates (n = 15). One group was packaged in MA1 (90% O_2 + 10% N_2), another group was packaged in MA2 (3% O_2 + 5% CO_2 + 92% N_2) and the third group was packaged in air (control, CT). All groups were sealed and stored at 0 ± 0.5 °C. The headspace volume inside the packages was approximately 3 L. One subgroup of each treatment were randomly removed for analysis on the 1st, 2nd, 4th, 6th, 8th and two sub-groups of each treatment were removed for 10th d.

2.2. Gas compositions

The concentrations of O_2 and CO_2 inside the packages were monitored using an Oxybaby (HTK, Hamburg, Germany). Results are expressed based on the average of three replicates.

2.3. Sensory evaluation

A generic descriptive analysis method was used to characterize strawberry sensory qualities (Lu et al., 2017). A panel of twenty-four assessors (twelve males and twelve females, ages 20–52 years) with no known taste or odor detection problems were trained for 11 h over a period of 28 d to evaluate six attributes, namely, color, aroma and flavour (strawberry flavor, off-flavor), taste (sweet, sour), mouthfeel (firmenss, astringency, juiciness), and overall quality. Sensory evaluation was performed using samples of twenty-four fruits (three replicates of 8 fruits each) on the 10th d of storage. Three samples (fruit of MA1. MA2 and CT group) randomly labeled with a 3-digit code were presented to each assessor for sensory evaluation. Sensory analyses were performed in a sensory panel room at 22–25 °C and assessors sat at individual cabins and made independent evaluations. The strawberries were removed from storage 90 min prior to evaluation to equilibrate to room temperature. There was a 3 to 5 min interval between servings and water was provided between servings. The panelists were asked to assign a score between 0 and 10 for each sample evaluated. The 0 represented a low rating for the specific property being evaluated, while 10 represented a high level and it was opposite to sourness and off-flavor. Strawberries with scores above 6 were considered to have an acceptable quality (Jouki and Khazaei, 2014).

2.4. Firmness, titrable acidity (TA), total soluble solid (TSS) and decay incidence

Strawberry firmness was measured using a TA-XT2i texture analyzer (Stable Microsystems Texture Technologies Inc., UK) with a 5-mm diameter cylindrical probe. Cut off one side of strawberry fruit and formed a flap providing stability. Firmness was expressed as the maximum compression force (N). Test speeds of 0.5 mm/s and a distance of 7 mm were used. Fruit firmness was measured at 1 or 2 locations in the middle of the strawberry fruit and the results are expressed based on the average of ten replicates (n = 10).

Fresh strawberry fruits were mixed and mashed to obtain puree and 10 g of puree was diluted in 100 mL of distilled water. The pulp was removed through filter paper and the filtrate was used for titratable acidity (TA) analysis. TA was determined by means of an acid–base titration method, whereby the filtered strawberry extract was titrated with sodium hydroxide (0.01 mol/L), and TA was expressed as equivalent as follows:(Samykanno et al., 2013)

Citric acid (g/L) = $\frac{V_{NaOH} \times N_{NaOH} \times 0.064 \times 100\,\%}{V_0}$ Where V_{NaOH} is volume of NaOH solution used for titration (mL), N_{NaOH} is normality of NaOH solution and V_0 is volume of filtered extract used for titration (mL). Three independent determinations were made for each strawberry sample collected.

Ten fruits from each replicate were wrapped in cheesecloth and squeezed with a hand press, and total soluble solid (TSS) was measured in fruit juice for each treatment by a PAL-1 digital refractometer (Yuze Co., Ltd., Suzhou, China) and results were expresed as %.

Fruit decay was visually estimated by measuring the extent of decayed area on 10 fruits from each replicate. The decay incidence was classified into 4 levels, on basis of the decayed area on strawberry surface: level 0 - no decay; level 1 - decayed area was less than 25% of the whole fruit; level 2 - decayed area was 25%–50%; and level 3 - decayed area was more than 50%. The decay incidence was calculated based on the following equation: Decay incidence (%) = Σ (the decay level*fruits number of this level)/(the highest decay level* total fruits number) × 100.

2.5. Total phenolics (TP) and antioxidant capacity

Two grams of frozen samples at −80 °C from each treatment were ground into a fine powder, ultrasonic extracted for 20 min with 20 mL of 80% ethanol, then centrifuged at 10,000g for 15 min. The supernatants were collected for the analysis.

TP content were measured according to the Folin-Ciocalteu procedure (Slinkard and Singleton, 1977). The results were expressed as grams of gallic acid equivalent (GAE) per kilogram fruits.The antioxidant capacity of strawberry extracts was estimated in the 2,2-diphenyl-1- picrylhydrazyl (DPPH) radical-scavenging capacity assay, according to Skupień and Oszmiański (2004) with some modifications. A 0.2 mL sample of extract was diluted 10 times and then added to 2.8 mL of DPPH (60 μmol/L). The mixture was shaken and allowed to react at room temperature for 25 min. The absorbance was then measured at 517 nm using an UV-5800PC ultraviolet visible light spectrophotometer (Shanghai METASH instruments CO.LTD., China). The antioxidant capacity was expressed as grams of ascorbic acid per kilogram fruits. Three determinations were made on 10 fruits.