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Effect of active-modified atmosphere packaging on the respiration rate and quality of pomegranate arils (cv. Wonderful)

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ABSTRACT

Two experiments were conducted to investigate the effects of active- and passive-modified atmosphere packaging (MAP) on respiration rate (RR) and quality attributes of minimally processed pomegranate arils (cv. Wonderful) stored at 5 °C for 12 d. In experiment 1, pomegranate arils were packaged in low barrier bi-axially oriented polyester (BOP) film under active-MA (5 kPa O_2 + 10 kPa CO_2, 30 kPa O_2 + 40 kPa CO_2), passive-MA and in clamshell trays. In experiment 2, a high barrier Polylid® film was used with arils packaged under three active-MAs (5 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2; 30 kPa O_2 + 10 kPa O_2 + 60 kPa N_2; 100 kPa N_2) and passive-MA. Arils packed in clamshell trays had lowest RR (RCO_2) compared to the other MA treatments in experiment 1, ranging from 41.1 nmol kg^{-1} s^{-1} on day 3 to 238.8 nmol kg^{-1} s^{-1} on day 12. Respiration rate of arils packaged in the high barrier polylid film was significantly affected by MA treatments. At the end of 12 d storage, total anthocyanin content (TAC) in arils was highest for clamshell packages (0.31 ± 0.01 g L^{-1}) and lowest in passive-MAP (0.27 ± 0.02 g L^{-1}). Packaging arils in high O_2 atmosphere and 100 kPa N_2 significantly lower aerobic mesophilic bacteria counts throughout the storage duration. Based on sensory scores obtained and microbial load, the shelf life for arils packaged in clamshell trays, passive-MA, and high O_2 level MA was 6, 9 and 12 d, respectively.

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1. Introduction

Modified atmosphere packaging (MAP) combined with low temperature storage has been successfully used to prolong the shelf life of fresh fruit and vegetables (Mahajan et al., 2014). Modified atmospheres are achieved by hermetically sealing fresh respiring produce in polymeric film and allowing the atmosphere within the package to be modified passively by the interplay of produce respiration rate (RR) and the film permeability properties, or actively by flushing the desired gas mixtures inside a package before sealing (Kader and Watkins, 2000; Rico et al., 2007; Mangaraj et al., 2009). Modified atmosphere packaging slows down physiological and biochemical processes and retards senescence (Caleb et al., 2012a). Thereby maintaining packaged produce freshness, quality attributes and microbial safety. Failure to create this suitable atmosphere may result in a shortened shelf life (Mangaraj et al., 2009). Suitable equilibrium atmospheres are achieved by proper matching of fresh produce RR and film permeability characteristics (Jacxsens et al., 2002; Kader, 2002; Caleb et al., 2012a).

Desired atmospheric equilibrium/compositions inside packaged fresh produce are low oxygen (O_2) (2–5 kPa) and/or moderate carbon dioxide (CO_2) (~10 kPa) (Rico et al., 2007; Sandhya, 2010). Previous studies have reported on the RR of minimally processing pomegranate arils under different conditions (Ersan et al., 2010; Caleb et al., 2012b). Ayhan and Estürk (2009) reported an increase in antioxidant activity and lower mesophilic bacteria counts in minimally processed pomegranate arils (cv. Hicaznar) stored under super atmospheric O_2 (70 kPa) atmospheres compared to those stored under low O_2 (5 kPa) and in normal air at 5 °C. Super atmospheric O_2 atmospheres (>21 kPa) have also been used in MAP of minimally processed products because of their ability to prevent anaerobic fermentation, inhibit enzymatic discolouration and microbial growth (Jacxsens et al., 2001). O_2 concentrations >25 kPa are nonetheless considered highly explosive and, as they pose a hazard should be used with caution (Jacxsens et al., 2001).

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Nitrogen (N_2) is a non-reactive gas that is used to exclude more reactive gases from packages and acts as a filler gas to prevent package collapse (Brandenburg and Zagory, 2009). Several studies with minimally processed products have explored the use of 100 kPa N_2 atmospheres in MAP (Ayhan and Estürk, 2009; Ahmed et al., 2011) because of their ability to maintain fresh produce quality. Firmness, colour and chemical properties were maintained and shelf life extended in persimmon fruit packaged in 100 kPa N_2, stored at 0 °C and 85–95% relative humidity (RH) for 90 d (Ahmed et al., 2011). Similarly, fresh-cut cabbage and lettuce in packages initially flushed with 100 kPa N_2 atmospheres at 1 and 5 °C maintained their quality and appearance by the end of the 5 d storage period (Koseki and Itoh, 2002).

Active-MAP achieved by flushing desired gas mixtures into packages allows earlier establishment of equilibrium atmospheres than passive-MAP and has, therefore, been recommended for minimally processed products (Bai et al., 2003; Rodov et al., 2007). Equilibrium atmospheres in active-MAP of litchi (cvs. Mauritius and McLeans Red) were established almost from the first day of storage, whereas those in passive-MAP were established 6–10 d after packaging (Sivakumar et al., 2008). Thus, the selection of packaging films with suitable barrier properties is of crucial importance in developing a suitable gas composition to maintain quality and assure a long shelf life for packaged fresh produce (Martínez-Romero et al., 2013). Despite the successful application of active-MAP in a wide range of minimally processed products, few studies have investigated the effects of active-MAP and the use of different barrier polymeric film on the physiological response and overall quality of minimally processed pomegranate arils. The objective of this study was, therefore, to determine the effects of different packaging atmospheres on respiration rate (RR), quality attributes and shelf life of minimally processed pomegranate arils (cv. Wonderful) packaged in low barrier bi-axially oriented polyester (BOP) and polylid film and stored at 5 °C and 90 ± 2% RH.

2. Materials and methods

2.1. Sample preparation and packaging

Pomegranate fruit (cv. Wonderful) was harvested at commercially ripened stage with characteristic deep-red skin and deep-red arils with mature kernels (Mphahlele et al., 2015), from Houdconstant Farm, Porterville, Western Cape (33°01′00″S, 18°59′00″E), South Africa. Fruits were sorted, cleaned and minimally processed at the farm pack house. Fruit free from visible physical defects were washed in sterilised water and arils extracted using a commercial extraction machine (Arilsystem, Juran Metal Works, Israel). Extracted arils were bulk packaged in sterilized polyethylene bags and transported in sterile ice boxes to the postharvest research laboratory at Stellenbosch University. Arils (300 g) were packaged in polyethylene terephthalate (PET) trays (ZIBO Containers, Pty, Ltd., Kuilsrivier, South Africa) and flushed with food grade gas mixtures (Air Products Pty, Kempton Park, South Africa) using a tray sealer (Model T200 Multivac, Wolfertschwenden, Germany).

Two experiments were conducted consecutively. In the first experiment, a low barrier BOP polymeric film (with 26 μm thickness, permeance rate 3.5×10^{-13} mol m^{-2} s^{-1} Pa^{-1} O_2, 7.0–9.4 $\times 10^{-14}$ mol m^{-2} s^{-1} Pa^{-1} CO_2 and 9.4×10^{-5} mol m^{-2} s^{-1} Pa^{-1} water vapour at 23 °C and 85% RH) supplied by Knilam Packaging (Pty) Ltd. (Cape Town, South Africa) was used to heat-seal the PET trays. The following gas mixtures were used: MAP-A (5 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2); MAP-B (30 kPa O_2 + 40 kPa CO_2 + 30 kPa N_2); MAP-C (normal atmospheric composition; passive-MAP). Additionally, arils were packaged in PET clamshell containers (420 μm thickness, 11.5 × 11.5 × 3.5 cm^3) as control. In the second experiment, a high barrier polymeric film Polylid® 107HB55 (with 55 μm thickness, permeance rate of 9.8–10.8 $\times 10^{-14}$ mol m^{-2} s^{-1} Pa^{-1} O_2, 7.0–9.4 $\times 10^{-14}$ mol m^{-2} s^{-1} Pa^{-1} CO_2 and 2.4–3.3 $\times 10^{-5}$ mol m^{-2} s^{-1} Pa^{-1} water vapour at 23 °C and 85% RH) supplied by Barkai Polyon Industries Ltd. (Tel Aviv, Isreal) was used. The following gas mixtures were applied in the second study: MAP-D (5 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2); MAP-E (30 kPa O_2 + 10 kPa CO_2 + 60 kPa N_2); MAP-F (100 kPa N_2) and MAP-G (passive-MAP). All the samples were stored at 5 °C and 90 ± 2% RH for 12 d and analyses were conducted in triplicate on days 0, 3, 6, 9, and 12.

2.2. Headspace gas composition

Headspace O_2 and CO_2 composition of packaged pomegranate arils was determined using an O_2/CO_2 gas analyser (Checkmate 3, PBI Dansensor, Ringstead, Denmark). Gas analysis was done by inserting a needle attached to the gas analyser through a rubber septum on the packaging film. Gas sampling was done before opening the package to remove the arils. Three additional replications per treatment were used to monitor in-package head space gas composition during the entire storage period.

2.3. Respiration rate

Post-storage RR of pomegranate arils was determined using the closed system method at 5 °C. On each sampling day, 150 g pomegranate arils from each of the MAP treatments were separately weighed into 1.1 L glass jars using a balance (Bosch SAE200, Denver Instrument GmbH, Germany). The glass jars were hermetically sealed by incorporating Vaseline petroleum jelly in the gap between the lid and the jar. Gas samples were drawn at hourly intervals over a period of 4 h through a rubber septum fitted on the jar and the gas composition was monitored by gas analyser (Checkmate 3, PBI Dansensor, Ringstead, Denmark). Measurements were repeated on each of the sampling days using fresh samples each time in order to determine the effect of modified MAP and storage duration on pomegranate arils RR (Fonseca et al., 2002; Bhatia et al., 2013).

The RR was calculated by fitting experimentally obtained data in the following Eqs (1) and (2):

$$y_{O_2} = y^i_{O_2} - \frac{R_{O_2} W}{V_f}(t - t_i) \quad (1)$$

$$y_{CO_2} = y^i_{CO_2} + \frac{R_{CO_2} W}{V_f}(t - t_i) \quad (2)$$

where R_{O_2} and R_{CO_2} are the O_2 consumption and CO_2 production rate (RR); $y^i_{O_2}$ and y_{O_2} are O_2 concentration (kPa) at the initial time t_1 (s) (time zero) and at time t (s), respectively and $y^i_{CO_2}$ and y_{CO_2} are the CO_2 concentration (kPa) at the initial time t_1 (s) (time zero) and at time t (s), respectively. W is the total weight of product (kg) and V_f is the free volume inside jar (L); determined by subtracting volume of product from the total volume of the glass jar (Caleb et al., 2012b). RR values were expressed as nmol kg^{-1} s^{-1} (Banks et al., 1995).

2.4. Total soluble solids, titratable acidity and pH

Arils were juiced separately for each of the treatments on each sampling day using a LiquaFresh juice extractor (Mellerware, Cape Town, South Africa). Pomegranate juice was used to determine pH using a pH metre (Crison, Barcelona, Spain), total soluble solids

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