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Impacts of low and super-atmospheric oxygen concentrations on quality attributes, phytonutrient content and volatile compounds of minimally processed pomegranate arils (cv. Wonderful)

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ABSTRACT

This study investigated the impact of modified atmosphere (MA) storage: at low oxygen (O_2) (MA-1; 5 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2), (MA-2; 10 kPa O_2 + 5 kPa CO_2 + 85 kPa N_2); super-atmospheric O_2 (MA-3; 70 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2); and air (MA-4; 21 kPa O_2 + 0.03 kPa CO_2 + 78 kPa N_2) on the physicochemical, phytonutrient, volatile organic compounds (VOCs) and microbiological quality of minimally processed 'Wonderful' pomegranate arils stored at 5 °C for 12 d. In addition, the effect of temperature fluctuation on the physical and microbiology quality of arils was evaluated. Samples were removed from cold storage on each sampling day, and kept for 2 d at ambient (20 °C) condition. Low O_2 atmosphere (MA-1) best maintained phytonutrient content of arils at 5 °C. Aerobic mesophilic bacteria, yeast and mould counts were found to be significantly lower under super-atmospheric O_2 (MA-3) storage in comparison to other treatments at 5 °C and ambient. A total of 25 volatile organic compounds (VOCs) were detected and identified for pomegranate 'wonderful' across the different MA conditions. Highest relative composition of VOCs was found in samples stored under MA-3. Temperature fluctuation had a significant impact on the physical and microbiology quality of pomegranate arils.

1. Introduction

Several studies have demonstrated that minimally processed pomegranate arils is a rich source of bioactive compounds and phytochemicals, which provide potential health promoting benefit, as well as fresh characteristics and convenience for consumer (Aindongo et al., 2014; O'Grady et al., 2014). However, maintaining postharvest quality and microbial safety of pomegranate arils is a critical challenge (O'Grady et al., 2014). The limiting factors affecting the overall quality and shelf life of minimally processed pomegranate arils include microbial growth, loss of nutritional and physicochemical attributes caused by active metabolic processes related to enzyme activity, enhanced respiration rate or oxidation of phenolic compounds (Ersan et al., 2010; Ghasemnezhad et al., 2011; Maghoumi et al., 2013).

Creating and maintaining a desired atmosphere have been shown to provide benefits of quality preservation of fresh produce (Jo et al., 2014). One of the important goals in atmosphere modification was to generate sufficiently low O_2 conditions to influence the metabolic process and reduce respiration rate, oxidative stress, tissue senescence and ethylene synthesis (Beaudry, 1999). Thereby, maintaining postharvest quality and extending shelf life of fresh produce (Artés et al., 2000). Various studies have been investigated on the effect of low O_2 atmosphere on quality attributes of different cultivars of pomegranate arils such as 'Primosole' (Aquino et al., 2010), 'Mollar de Elche' (Artés et al., 2000), 'Acco' and 'Herskawitz' (Caleb et al., 2013), and 'wonderful' (Banda et al., 2015). It was established from these studies that low

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O_2 atmosphere have potential for reducing chilling injury, decay and weight loss, inhibit fungal growth and retard postharvest ripening. However, the O_2 concentration in most of the studies decreased to a lower limit, which could induce anaerobic respiration and further lead to the synthesis of fermentative metabolites and off-odour (Saenmuang et al., 2012).

Recently, the use of super-atmospheric O_2 (≥70 kPa) have been shown as an effective alternative to low O_2 atmosphere, for inhibition of microbial growth and enzymatic deterioration as well as maintaining quality (Jacxsens et al., 2001; Allende et al., 2004). For pomegranate arils studies reported on the application of super atmospheric O_2 were focused on selected quality attributes and shelf life (Ayhan and Esturk, 2009; Maghoumi et al., 2014; Banda et al., 2015). Among the studies that have been performed on pomegranate arils, none have evaluated the effect of super-atmospheric O_2 on the change in volatile organic compounds (VOCs), phytonutrient and microbial safety for pomegranate arils (cv. Wonderful). Furthermore, there is limited information on the impact of super-atmospheric O_2 and temperature fluctuation on the quality attributes and microbial stability of pomegranate arils. Thus, the objective of this study was to investigate the effect of modified atmosphere (MA) storage and the impact of temperature fluctuation on the quality attributes, change in VOCs and microbial stability of pomegranate arils at 5 °C for 12 d.

2. Material and method

2.1. Material preparation

Pomegranate fruit (cv. Wonderful) were obtained at commercially ripe stage with characteristic deep-red skin and deep red arils with mature kernel (Mphahlel et al., 2016), from Sonlia pack house, Wellington, Western Cape, South Africa (33°38′23″S, 19°00′40″E). The fruit was transported in an air-conditioned and ventilated vehicle to the Postharvest Research Laboratory at Stellenbosch University and stored in MAP bags at 5 °C and 95% RH for four months prior to processing. This was done to simulate long-term shipping duration from southern hemisphere production region to the northern hemisphere market and vice-versa. Damaged fruit was removed and the outer skin of healthy whole fruit was surface disinfected using 70% ethanol prior to aril extraction (Aindongo et al., 2014). Arils were extracted manually by carefully removing the husk. Extracted arils were collected in a tray and mixed to assure uniformity. Arils (350 g) were transferred to 3000 mL air-tight glass jar which were designed to achieve a completely hermetic seal. Glass jars were prepared in triplicate for each gas mixture. Four types of modified atmosphere (MA) conditions were selected, these includes: i) low O_2 (MA-1; 5 kPa O_2 + 10 kPa CO_2 + 85 kPa N_2) and (MA-2; 10 kPa O_2 + 5 kPa CO_2 + 85 kPa N_2), ii) super atmospheric oxygen (MA-3; 70 kPa O_2 + 10 kPa CO_2 + 20 kPa N_2), and iii) air (MA-4; 21 kPa O_2 + 0 kPa CO_2 + 78 kPa N_2) as control. Sampling was carried out on 0, 3, 6, 9, and 12 d of storage. To evaluate the effect of temperature fluctuation; samples were removed from cold storage on each sampling day, and kept at ambient temperature (20 °C) for additional 2 d. Only physical and microbiology quality of arils were evaluated.

2.2. Physical properties

2.2.1. Firmness

Firmness of individual arils was measured using texture analyser (TA-XT Plus, Stable Micro Systems, Surrey, UK) with a 35 mm diameter cylindrical probe. Magness Taylor test (MTT) which is an empirical hardness indicator test was performed according to (Szychowski et al., 2015). Measurements were recorded by modifying the input parameters of the 35 mm diameter cylindrical probe to the penetration rate of 0.3 mm^{-1} for 5 s after contacting the surface of pomegranate arils, and results were expressed as N. A total of 20 arils were measured per treatment.

2.2.2. Colour

Pomegranate arils colour was measured using a colour metre (CR-400 Minolta Chroma Meter, Minolta Corp, Osaka, and Japan) according to the method presented by Caleb et al. (2013). Colour parameters of (L^*, a^*, b^*) were measured and results were expressed as the CIELAB colour space unit. Colour parameter Chroma (C^*) which describes the length of the colour vector in the plane formed by a^* and b^*, and the hue angle (h°) that determines the position of the vector were calculated. Mean of 15 measurements were calculated for each treatment.

2.3. Ascorbic acid

Ascorbic acid was determined spectrophotometrically against a standard curve using 2, 6-dichlorophenolindophenol (DCP) dye and metaphosphoric acid (MPA) as described by O'Grady et al. (2014). Combination of blue coloured DCP dye and colourless MPA resulted in a pink coloured solution, which was decolourised or reduced in the presence of ascorbic acid. Ascorbic acid of unknown concentrations in pomegranate juice samples was quantified using a standard curve of known concentrations from a stock solution (1 g L^{-1}) L-ascorbic acid. Both the stock solution and the juice samples were diluted with a DCP-MPA solution and absorbance was measured at 515 nm wavelength. Pomegranate juice samples were thawed at room temperature, diluted with MPA, vortexed (Model nr. G560E, Scientific Industries, USA) and sonicated (Ultrasonic Cleaner DC400H, MRC Ltd., Holon, Israel) for 3 min in cold water to extract the ascorbic acid present in the juice. Extract was centrifuged at 12,857 *g* at 4 °C to obtain a clear homogenous solution, diluted with DCP dye and kept in a dark cabinet for 10 min. To correct for the natural pink colour of pomegranate juice, another set of centrifuged extract samples were taken and diluted with distilled water instead of MPA. The absorbance of the samples (MPA and water diluted extracts) and standard curve was read at 510 nm wavelength. Ascorbic acid values were extrapolated from a standard curve with $R^2 > 0.90$. Ascorbic acid content was expressed as mg ascorbic acid per unit volume pomegranate juice (mg L^{-1}).

2.4. Total phenolic content

Total phenolic concentration (TPC) was measured using the Folin–Ciocalteu (Folin–C) method as described by Mphahlel et al. (2014). The mixture was vortexed and absorbance read at 725 nm using a UV–vis spectrophotometer (Thermo Scientific Technologies, Madison, Wisconsin). Gallic acid standard curve (0.02–0.10 g L^{-1}) was used and TPC was expressed as mass Gallic acid equivalent (GAE) per unit volume of pomegranate juice (mg L^{-1}).

2.5. Total monomeric anthocyanins

Total anthocyanin content was determined by the pH-differential method described by Banda et al. (2015) using 2 buffer systems: potassium chloride buffer for pH, 1.0 (0.025 M) and sodium acetate buffer for pH, 4.5 (0.4 M). The sample diluted with corresponding buffer and absorbance was measured at 520 and 700 nm using a Helis Omega UV–vis spectrophotometer (Thermo Fisher Scientific, Madison, WI, USA). Duplicate readings were done for the triplicate arils juice samples Total anthocyanins were calculated as cyanidin-3-glucoside according to the following