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Influence of packaging system and long term storage on physiological attributes, biochemical quality, volatile composition and antioxidant properties of pomegranate fruit

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ABSTRACT

Commercially ripe pomegranate fruit were packed in ventilatedcarton with polyliner (referred to as passive modified atmosphere packaging, MAP), individual shrink wrap and open top carton (control) and-stored under 7 ± 0.5 °C and 92 ± 2% RH for 4 months. Incidence of physiological disorders and changes in biochemical properties, phenolic compounds, total phenolics, total flavonoids, total tannins, total anthocyanins, antioxidant activity and vitamin C were analysed monthly. The results showed that fruit stored under polyliner and individual shrink wrapped significantly minimized weight loss compared to control. Significantly higher fruit decay incidence was observed after 3 months, irrespective of package type. TSS content, citric acid, and L-malic concentrations decreased considerably in all packaging systems with increasing storage time. Fructose and glucose concentrations fluctuated during storage with the lowest value observed at the end of storage infruit packed under polyliner and shrink wrapped packaging. Amongst phenolic compounds identified, catechin and rutin increased by 65.43% and 139.39%, respectively, in fruit packed inside polyliners and individual shrink wrap after 4 months of cold storage. Total phenolic and total tannin concentrations declined by 23.86 and 65.89% in fruit stored under polyliner and individual shrink wrap packaging after 3 months of storage, respectively. Furthermore, total anthocyanin concentration was significantly higher in fruit packed in MAP (103.59 g L^{-1} of cyanidin-3-glucoside of pomegranate) than individual shrink wrap (84.78 g L^{-1}) after4 months of storage. Volatiles organic compounds including ethanol, alpha-pinene and beta-pine accumulation increased significantly with prolonged storage regardless of packaging material used.

1. Introduction

Pomegranate fruit (*Punica granatum* L.) is one of the oldest known fruit belonging to the Punicaceae family. Pomegranate is highly appreciated for its unique organoleptic properties and hence its wide production across the world and most recently in South Africa (Al-Said et al., 2009; Holland et al., 2009; Fawole and Opara, 2013a,b). The fruit contains a substantial amount of polyphenols of high biological value including flavonoids (anthocyanins, flavonols), hydrolysable tannins (ellagitannins, gallotannins, condensed tannins) (proanthocyanidins) (Hernandez et al., 1999; Gil et al., 2000; Li et al., 2006). These polyphenols have been reported to have a broad range of potentially therapeutic uses, including treatment and prevention of cancer, cardiovascular diseases, Alzheimer's disease and inflammatory diseases (Fuhrman et al., 2005; Hong et al., 2008). These effects have been attributed to the exceptionally high amount of antioxidant capacity often attributed to the high concentration of polyphenols in the juice (Gil et al., 2000; Fischer et al., 2011).

The incidence of postharvest losses and poor keeping quality of pomegranate are largely attributed to the high sensitivity of the fruit to temperatures below 4 °C and above 10 °C (Arendse et al., 2014; Fawole and Opara, 2014). The storage temperature recommended for pomegranates varies from 5 to 7.5 °C, with shelf life ranging from 8 to 16 weeks depending on cultivar (Opara et al.,

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2008; Fawole and Opara, 2013a; Arendse et al., 2014). Pomegranate fruit is also highly susceptible to moisture loss due to the presence of micro-cracks that allow free movement of water from its surface (Elyatem and Kader, 1984; Opara et al., 2010). To reduce postharvest losses and maintain fruit quality, modified atmosphere packaging (MAP) in combination with postharvest treatments has been introduced (Caleb et al., 2013a; Opara et al., 2016). Modification of the atmosphere inside the package preserves the quality of produce by retaining moisture and reducing pathological deterioration and metabolic activities (Mir and Beaudry, 2004; Caleb et al., 2012). Nevertheless, extending the shelflife of pomegranate has been made possible with the use of modified atmosphere packaging (MAP) system (Caleb et al., 2013a).

For instance, Nanda et al. (2001) reported a significant reduction in weight loss with an increased loss of vitamin C concentration after 12 weeks storage at 8 °C in individually shrink wrapped fruit treated with sucrose polyester (SPE) Semperfresh^{TM}. Furthermore, D'Aquino et al., (2010) found that film wrapping in combination with fludioxonil completely inhibited weight loss, husk scald and overall improvement of fruit freshness stored at 8 °C for 6 or 12 weeks. The authors also found a significant reduction in total phenolic concentration whereas antioxidant activity remained relatively stable until the end of the storage. Furthermore, Selcuk and Erkan (2014) observed that prolonged storage up to 4 months at 6 °C resulted in decreased total anthocyanin concentration in fruit treated with Prochloraz under modified atmosphere packaging. On the other hand, none of the above studies investigated the volatile evolution of pomegranate fruit with prolonged storage. Volatile organic compounds play a major role in determining the flavour life and the quality of pomegranate fruit during cold storage (Caleb et al., 2013a). It is only recently that Mayuoni-Kirshinbaum et al. (2013) investigated sensory quality and aroma profile during prolonged storage of 'Wonderful' pomegranate fruit stored in MAP. The authors found that the sensory quality of pomegranate arils decreased considerably after 16 and 20 weeks of cold storage at 7 °C. Additionally, none of the studies reported on individual flavonoids and phenolic compounds.

Despite the significant improvement in the fruit quality, effect of packaging on the bioactive compounds and volatile composition is often overlooked. In addition, cultivars may vary in sensitivity to modified atmospheres. Consumer acceptance of this crop requires that fruit is in excellent condition and exceptionally be rich in nutritional and sensory quality. Pomegranate 'Wonderful' is the most widely grown and consumed pomegranate cultivar globally (Holland et al., 2009) and during the past ten years, South Africa has seen tremendous increase in commercial production, accounting for over 1000 ha of total planted area and 56% of total production (Pomegranate Association of South Africa (POMASA), 2012). Moreover, there has been vast research on pre- and postharvest handling of pomegranate fruit, however, less information has been reported on modified atmosphere packages and their influence on concentrations of individual phenolic compounds, volatile composition and antioxidant activity of pomegranate fruit during prolonged storage conditions. The aim of the study was to determine the effect of modified atmosphere packaging and individual shrink wrap film on the biochemical, physiological attributes polyphenols, volatile composition and antioxidant activity of pomegranate fruit cv. Wonderful during long term storage.

2. Materials and methods

2.1. Plant material

Pomegranate fruit (cv. Wonderful) were sourced during commercial harvest from Sonlia packhouse in Western Cape (33°34′851″S, 19°00′360″E), South Africa. Fruit were transported to the Postharvest Technology Laboratory at Stellenbosch University, where healthy with no defect were sorted based on uniform size shape and colour.

2.2. Fruit packaging

A batch of 600 fruit were randomly separated into three lots and each lot comprising 200 fruit was assigned the following three treatments: (1) control, with fruit packed in open-top cartons without liner bag (dimensions: width 0.3 m, length 0.4 m, height 0.133 m and a total of 21 perforations (70.9%); (2) passive MAP, with fruit packed in open-top cartons with polyliner bag (ZOEpac, O_2 permeability of 73. 56 $mm^{-3}\,m^{-2}\,s^{-1}$, CO_2 permeability of 398.87 $mm^{-3}\,m^{-2}\,s^{-1}$, Water vapour transmission rate of 0.00074 $g^{-1}\,m^{-2}\,s^{-1}$); (3) shrink film wrap, with each fruit shrink-wrapped using a double-layered co-extruded polyolefin film (BDF-2001, Mipaq, South Africa), thickness of 0.025 micrometer, oxygen and carbon dioxide transmission rate of 48.61 and 196.10 $mm^{-3}\,m^{-2}\,s^{-1}$, respectively). Fruit were individually wrapped using a portable I-bar sealer (model: ME450IP-450SP) followed by heat-shrinking of the film using a portable heat gun (model: ME-1200-HG) with the operating temperature range of 315–537 °C. Dry cup technique (ASTM, 2005) method E96-95 was used with slight modification to determine water vapour transpiration rate (WVTR) gravimetrically (Hussein et al., 2015; Opara et al., 2015) at 7.5 ± 0.5 °C and 90 ± 2% RH over a period of 4 months. In triplicate, aluminium test cups (diameter 5.6 cm and depth 1.5 cm) with open top-screw lid (Comar International, Cape Town, South Africa) were filled with 8.0 ± 0.5 g of anhydrous calcium chloride salt ($CaCl_2$). Film was placed on top of each test cup and firmly closed exposing film surface area of 25 cm^2. Each cup was first sealed using an O-ring rubber and lubricated to ensure airtight and moisture proof condition. The WVTR ($g^{-1}\,m^{-2}\,s^{-1}$) of films calculated on basis of mass gain in water by $CaCl_2$ salt in the test cup over time 4 months (Eq. (1)):

$$WVTR = \frac{Wi - Wt}{\Delta t} - \frac{1}{\Delta P} \quad (1)$$

W_i represents the initial weight of the test cup; Wt is the weight (g) of the test cup at time Δt (daily); ΔP is the differential water vapour pressure (kPa). However, during each test, the cup was kept in a constant environment (°C and% RH) and therefore differential water vapour was not considered during calculations. Water vapour transmission rate of shrink wrap film obtained was 0.00013 $g^{-1}\,m^{-2}\,s^{-1}$.

2.3. Gas composition analysis

Six cartons each containing 12 fruit were used to monitor MAP gas composition for the entire storage duration. Temperature (°C) inside the storage room was monitored using data loggers (Gemini Data Loggers, West Sussex, UK). Internal atmospheres created by the polyliner bag (MAP) were assessed daily during cold storage using a gas analyser with an accuracy of 0.5 kPa (Checkmate 3, PBI Dansensor, Ringstead, Denmark).

2.4. Respiration rate (RR)

Respiration rate of pomegranate fruit was determined using the closed system method at 7 ± 0.5 °C. Fifteen fruit were randomly selected from each treatment after each month of storage. Of these, 4 sound fruit were equilibrated in air for 2–3 h before placed in hermetically sealed glass jars (3000 mL) equipped with rubber sampling ports at 7 ± 0.5 °C. Gas samples were drawn at hourly intervals over a period of 4 h through a rubber septum fitted on the jar and