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Fruit growth dynamics, respiration rate and physico-textural properties during pomegranate development and ripening

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ABSTRACT

The time course and pattern of fruit growth and changes in physical, physiological properties and texture dynamics of pomegranate fruit (cvs. 'Bhagwa' and 'Ruby') along the days after full bloom (DAFB) were studied over two different year seasons. Significant variations in fruit growth, respiration rate and physico-textural properties of the fruit were found at five maturity stages (S1–S5). Fruit lineal dimensions (length and diameter) exhibited a linear growth pattern and the fruit weight followed a similar pattern. Both fruit cultivars showed a decline in respiration rate during fruit development, with the highest respiration rate measured in immature fruits ('Bhagwa', 66.83 mL CO_2 kg^{-1} h^{-1}; 'Ruby', 51.17 mL CO_2 kg^{-1} h^{-1}) and declining with maturity to minimum rates in fully ripe fruit (stage 5) (S5) ('Bhagwa', 23.84 mL CO_2 kg^{-1} h^{-1}; 'Ruby', 19.16 mL CO_2 kg^{-1} h^{-1}). No ethylene gas was detected throughout fruit development. Fruit pigmentation increased with advancing maturity and the lowest total colour difference (TCD) between fruit peel and arils was noted in immature fruit. Textural dynamics of aril revealed increasing trend in bioyield force and elasticity with advancing maturity. Overall, the study indicated that fruit reached mature stage between the 132–139 DAFB for 'Ruby' and 140–165 DAFB for 'Bhagwa'. This period could be regarded as the physiological mature stage of the fruits that would present the optimum values of harvesting properties desirable in the investigated cultivars. This information could be used as a tool to assist growers in assessing fruit readiness for harvest.

1. Introduction

Pomegranate (*Punica granatum* L.) is a tropical and subtropical attractive deciduous or evergreen shrub belonging to Punicaceae family. It is native from Iran to the Himalayas in northern India and was cultivated and naturalized over the whole Mediterranean region since ancient times (Holland et al., 2009). Pomegranate plant is tolerant of many different soil conditions, but thrives well under sunlight and mild winters with minimal temperatures not lower than −12 °C, and hot dry summers (Levin, 2006). Pomegranate is one of the hardest fruit crops. Pomegranate fruit are round or spherical in shape, with a fleshy, tubular calyx and leathery skin often deep pink or rich red in colour (Morton, 1987). The interior of the fruit is separated by membranous walls and white spongy tissue into compartments packed with transparent sacs filled with fleshy, juicy, red, pink or whitish pulp called the arils. In each aril sac, there is one white or red, angular, soft or hard seed (Biale, 1981; Morton, 1987; Holland et al., 2009; Levin, 2006).

In recent years, pomegranate has gained popularity due to its multi-functionality and great nutritional benefit in the human diet. The fruit is now grown globally under different climatic regions, satisfying the nutritional and medicinal needs of populations of various countries (Holland et al., 2009; Wetzstein et al., 2011). Major pomegranate producers include India, Israel, Afghanistan, Iran, Egypt, China, Japan, USA, Russia, Australia, South Africa and Saudi Arabia and in the subtropical areas of South America (Elyatem and Kader, 1984; Artes et al., 2000; Holland et al., 2009; Faria and Calhau, 2010).

Like most fruit, the pomegranate has many generally well-defined stages of growth and development, and advancing maturity corresponds to a number of coordinated physiological, biochemical, and structural processes that result in changes in size, colour and flavour (Moing et al., 1998; Nunes et al., 2009; Opara, 2000). It has been demonstrated that a wide diversity in several physico-chemical and textural properties exists among pomegranate cultivars (Gozlekci and Kaynak, 2000; Martinez et al., 2006; Al-Said et al., 2009; Opara et al., 2009; Hasnaoui et al., 2011). In addition, fruit quality attributes such as size, colour, juiciness, taste, and seed hardness among others are influenced primarily by genetics, but could also be influenced by the environment in which the crop is grown (Jalikop, 2007; Holland et al., 2009). For pomegranate fruit

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maturity assessment, physical attributes are as important as biochemical indices. Studies have assessed pomegranate fruit maturity status based on a combination of fruit physical, physiological and biochemical indices (Ben-Arie et al., 1984; Cristosto et al., 2000; Martinez et al., 2006).

Commercial production of pomegranates is fairly new and increasing rapidly in South Africa and the cultivars 'Bhagwa' and 'Ruby' are amongst the most widely grown in the country and globally (Holland et al., 2009; Fawole and Opara, 2013a,b). However, producing higher yield with a good fruit quality with optimum maturity status is an important challenge for the South African pomegranate industry. The aim of this work was to study the time course and pattern of fruit growth as well as changes in physical and physiological properties and texture dynamics of pomegranate fruit along the days after full bloom in 'Bhagwa' and 'Ruby' cultivated under South African agro-climatic environment. The results obtained could be of value in defining the optimal time for fruit harvesting according to the future use, as well as allow pomegranate growers to have a tool to assess fruit maturity before harvesting and packaging for exportation.

2. Materials and methods

2.1. Geographic data and climatic parameters

Two pomegranate cultivars 'Ruby' and 'Bhagwa' grown on a commercial orchard in Porterville, 33°01′00″S, 18°58′59″E (Western Cape, South Africa) were used in this study. 'Ruby' is an early cultivar and considered sweeter than 'Bhagwa' which is a mid cultivar. The orchards were located on sandy loam soil, and the trees received the same fertilizer programme and irrigation delivering about 32 L per hectare daily. Values of maximal, minimal and mean daily air temperatures (°C) and rainfall (mm) were collected from a nearby meteorological station between October to May for the 2010/11 and 2011/12 fruit growing seasons. Mean daily air temperature was 19.2 °C for the two seasons, with the highest mean daily air temperature of 26.2 °C and 25.2 °C in February 2011 and January 2012, respectively. The heat units were measured as the sum of the differences between mean daily temperatures and a base temperature of 10 °C which corresponds to the temperature at which bud development is activated (Melgarejo et al., 1997). Average monthly rainfall was 24.7 mm in 2010/11 and 17.6 mm in 2011/12, the highest rainfall being in May (47.0 mm) and April (32.0 mm) in 2011 and 2012, respectively (Fig. 1).

2.2. Fruit growth attributes

2.2.1. Plant material, samplings, and measurements

The trees (6 years old) used were at planting distance of 5 m × 3 m, with same row orientation and tree training. Ten trees per cultivar were randomly selected for studying fruit growth measurements and analysis. Ten sun-exposed fruits (∼20 mm diameter) per tree, were tagged after fruit set and monitored by measuring lineal fruit growth parameters (length and diameter) at 2-week intervals from 28 days after full bloom (DAFB) phenological stage in December to full-ripe stage (139 DAFB for 'Ruby' and 160 DAFB for 'Bhagwa') in the two seasons. Fruit length (L) and diameter (D) were measured at two opposite longitudinal and equatorial fruit perimeters (excluding the fruit calyx) using a digital Vernier calliper (Mitutoyo, Kawasaki, Japan, ±0.01 mm). Using a mathematical relationship assuming spherical shape, fruit volume (V, cm^3) was determined using Eq. (1) and shape index (S) was calculated in Eq. (2) according to Al-Yahyai et al. (2009):

$$\text{Fruit volume(V)} = \left[\left(\frac{4}{3}\right) \times \pi \times r^3\right] \quad (1)$$

Table 1
Description of fruit maturity at different sampling stages along days after full bloom (DAFB).

Stage	DAFB (Month) 'Bhagwa'	DAFB (Month) 'Ruby'	Description of maturity stages
S1	54 (January)	54 (January)	Immature: Green skin, immature white arils with immature kernels
S2	82 (February)	82 (February)	Mature/unripe: Light-red skin, mature white arils with mature kernels
S3	110 (March)	110 (March)	Mature/semi-ripe: Red skin, mature pink arils with mature kernels
S4	140 (April)	132 (April)	Mature/ripened: Red skin, mature red arils with mature kernels
S5	165 (May)	139 (April)	Mature/full-ripened: Deep-red skin, deep-red arils with mature kernels

where r is the average of the fruit radius of the fruit diameter and length

$$\text{Shape index(SI)} = \left(\frac{L}{D}\right) \quad (2)$$

2.3. Fruit maturity evaluation

Fruit maturity was evaluated at five distinct developmental stages (Table 1). For each cultivar, twenty identical fruit free of blemish, cracks, cuts and sunburn from ten randomly selected trees were collected per fruit maturity stages (Table 1) and transported in an air-conditioned vehicle to the Postharvest Research Laboratory, Stellenbosch University. The fruits were evaluated for respiration rate and physico-textural attributes.

2.3.1. Fruit respiration and ethylene production

Fruit respiration rate was measured in a controlled environment at 20 °C and 80–85% RH using the closed system method as described by Caleb et al. (2012). The respiration rate was measured by the amount of CO_2 evolved by the fruits, and based on fresh weight unit. In 5 replicates, a fruit was placed in a 3 L glass jar hermetically sealed for 3 h with a lid containing a rubber septum in the middle. CO_2 production within the glass jars was measured from the jar head space through the rubber septum using an O_2/CO_2 gas analyzer (Checkmate 3, PBI Dansensor, Denmark). Measurements were done over 10 days after harvest and results are presented as mean ± S.E (mL CO_2 kg^{-1} h^{-1}) of five determinations. Similarly, using a static system, the production of ethylene was checked with a gas chromatograph (Model N6980, Agilent Inc., Wilmington, U.S.A.) fitted with a Porapak® Q column, and flame ionization and thermal conductivity detectors.

2.3.2. Colour attributes

Fruit peel colour along the equatorial axis of each fruit at two opposite spots were recorded in CIE coordinates (L^*, a^*, b^*) using a Minolta Chroma Metre CR-400 (Minolta Corp, Osaka, Japan) after calibration with a white tile background. Similarly, duplicate colour measurements (L^*, a^*, b^*) were made on the arils placed in a colourless glass Petri dish. The colour parameter Chroma (C^*_{ab}) 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 such vector were calculated according to the following equations:

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (3)$$