Physico-chemical changes during growth and development of grapefruits (*Citrus paradisi* Macf.). I. Physical changes

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ABSTRACT

The physical changes during growth and development of seedy pinkfleshed 'Red Blush' grapefruits were evaluated, to provide base-line information regarding the biochemistry of the developing fruit and to assist in determining harvest maturity of grapefruits. The fruits followed a typical single sigmoid growth curve. Fruit fresh weight, volume, length, diameter, peel thickness, pulp diameter, juice content, and peel color progressively increased from 4 weeks after anthesis (WAA) up to 26 WAA at physiological maturity and then remained constant. Respiration rate exhibited a typical non-climacteric pattern. It decreased from 239.8 mg CO_2/kg-hr (4 WAA) to 21.1 mg CO_2/kg-hr (26 WAA). Peel/pulp ratio and fruit flesh firmness steadily decreased with advancement in growth and development, reaching minimum values at physiological maturity. Grapefruits should be harvested at least at physiological maturity, where the fruit attains maximum size and weight, juice content at maximum level, peel/pulp ratio at minimum, rind color develops, and it is still firm.

INTRODUCTION

Grapefruit (*Citrus paradisi* Macf.) is one of the most important fruit crops in Sudan for local consumption and export. It is produced in Kassala, River Nile, Northern, Sinnar, South Kordofan, and South and West Darfur States, with total annual production of 196,000 metric tons (HSA, 2014). Judging by palatability and external appearance, the quality of grapefruits grown in Sudan has been commended as superior to fruits grown in other leading citrus-producing areas (Robbie and Fisher, 1954).

Citrus fruits are non-climacteric and their respiration and ethylene production rates are low (Kader and Arpaia, 2002). Their compositional changes are minimal and they do not undergo rapid chemical or physical changes after the fruit is detached from the tree. Citrus fruits contain no starch and they cannot be picked green for after harvest ripening. There is no post-harvest improvement in fruit quality (Wills *et al.*, 1998).

Harvesting citrus at the proper stage of maturity is essential for good quality produce. Over-maturity or under-maturity affects the quality adversely (Salunkhe and Desai, 1984). Many physical and chemical changes undergone by the developing fruit have been used as means of assessing the optimal picking date for immediate consumption or storage. Sufficient data are not available on many commercial cultivars to fix maturity standards for harvesting on the basis of fruit growth and physical and chemical parameters (Abu-Goukh *et al.*, 2005). None of these parameters are reliable individually

for determining harvest maturity. It usually requires a combination of chemical and physical parameters, coupled with considerable experience (Salunkhe and Desai, 1984).

This study was carried out to evaluate the physical changes during growth and development of seedy pink-fleshed 'Red Blush' grapefruits, to provide base-line information regarding the biochemistry of the developing fruit to assist in determining harvest maturity of grapefruits.

MATERIALS AND METHODS Experimental material

Grapefruits of seedy pink-fleshed 'Red Blush' cultivar were selected for this study. Ten trees were selected in a private orchard in AlEzeirgab area, Khartoum North (15°43' N, 32°33'E) during 2014/2015 season. At the time of flowering (April), the newly open flowers were tagged and fruit samples were harvested at different stages of growth and development. The first sample was picked four weeks after anthesis, and then sampling continued every two weeks up to the physiological maturity (12 samples). Sixty fruits of uniform size per sample were picked and arranged in a completely randomized design with 4 replicates. The fruits were washed and air dried.

Parameters studied

Physical changes were determined on 15 fruits picked at the designated stage. Average fruit fresh weight was determined by an electrical balance and was expressed in grams. Fruit volume was estimated by water displacement and expressed in cubic centimeters. Fruit length, diameter, peel thickness and pulp diameter were determined using a vernier caliber (White-Grew Model) and were expressed in centimeters. Peel/pulp ratio was determined by dividing the peel thickness by half the diameter of the flesh. Juice content was determined from the fifth fruit sample. Fruit juice was extracted by squeezing the fruit in a juice squeezer (English aluminum juice squeezer) and the volume was measured by a graduated measuring cylinder and expressed in milliliters per fruit. Peel color was determined using the following color score: green (=0), light green (=1), trace yellow (=2), 20% yellow (=3), 40% yellow (=4), 60% yellow (=5), 80% yellow (=6), and 100% yellow (=7).

Fruit flesh firmness was determined by Magness and Taylor firmness tester (D. Ballauff Meg. Co.), equipped with an 8mm-diameter plunger tip. Two readings were taken from opposite sides of each fruit after the peel was removed. Flesh firmness was expressed in kilograms per square centimeters. Respiration rate was determined using the total absorption method (Mohamed-Nour and Abu-Goukh, 2010), and respiration rate was expressed in mg CO_2/kg-hr.

Statistical analysis

Analysis of variance, followed by Fisher's protected LSD test with a significance level of $P \leq 0.05$ were performed on the data (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION Fruit fresh weight

Growth of grapefruits followed a typical sigmoid curve. The fresh weight progressively increased with advancement in growth from 10.0g (4 weeks after anthesis, WAA) to 275.7g (26 WAA), and then remained constant (Fig. 1-A). The increase in fruit fresh weight was 2.7-folds. Garray *et al*. (2002) found that fruit fresh weigh

sharply increased up to the seventh month from fruit set in four 'Valencia' orange cultivars and then slowed down. Similar results were reported in 'Kinnow' mandarin (Dhillon, 1986).

During the first eight weeks, the fruit fresh weight was increased in a slow rate of 2.9 g/week. Then it increased significantly in an exponential fashion during 8-22 weeks after anthesis at a rate of 18.0 g/week. Afterwards, the rate of growth was slowed down during the last four weeks of maturation (Fig. 1-A). These results are similar to those of Ting and Attaway (1971) who reported that growth and development of citrus fruits take place in three definite stages. Stage I, lasting between 4 to 9 weeks after fruit set, is distinguished as a 'period of cell division'. Fruit size and weight increase mainly due to growth of the peel by cell division and some cell enlargement, increasing both fresh and dry weight of the fruit. Stage II, is essentially a 'cell enlargement period'. The fruit increased in size accompanied by cell enlargement, differentiation and expansion of the albedo spongy tissue. Juice vesicles become enlarged and juice content increased in the enlarged juice cells. Stage III, is the 'maturation period' in which the growth slows down and color of the peel changes to the characteristic color of the fruit.

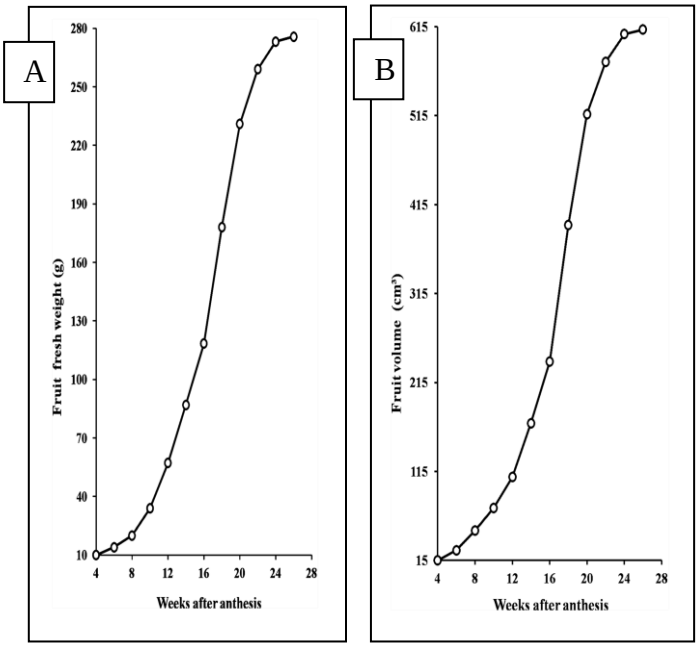


Fig. 1: Changes in fruit fresh weight [A] and fruit volume [B] during growth and development of "Red Blush" grapefruits.

Fruit volume and size

Changes in fruit volume during growth and development followed the same pattern of fruit fresh weight (Fig 1-B). It increased significantly from 15.0 cm^3 (4 WAA) to 611.8 cm^3 (26 WAA) with 40.8-folds increase. This is in agreement with the results of Ladaniya and Mahalle (2011) who reported that fruit volume of 'Mosambi' oranges had significantly increased from 178.6 cm^3 at 180 days to 267.3 cm^3 at 220 days, with

marginal increase thereafter up to 250 days. Fruit length and fruit diameter increased as growth advanced. The fruit length had increased from 2.5 cm (4 WAA) to 9.76 cm at fruit maturity (Fig. 2-A), while the fruit diameter had increased significantly from 2.5 cm (4 WAA) to 9.54 cm at fruit maturity (Fig. 2-B). This agrees with earlier reports in oranges (Garray *et al.*, 2002; Ladaniya and Mahalle, 2011).

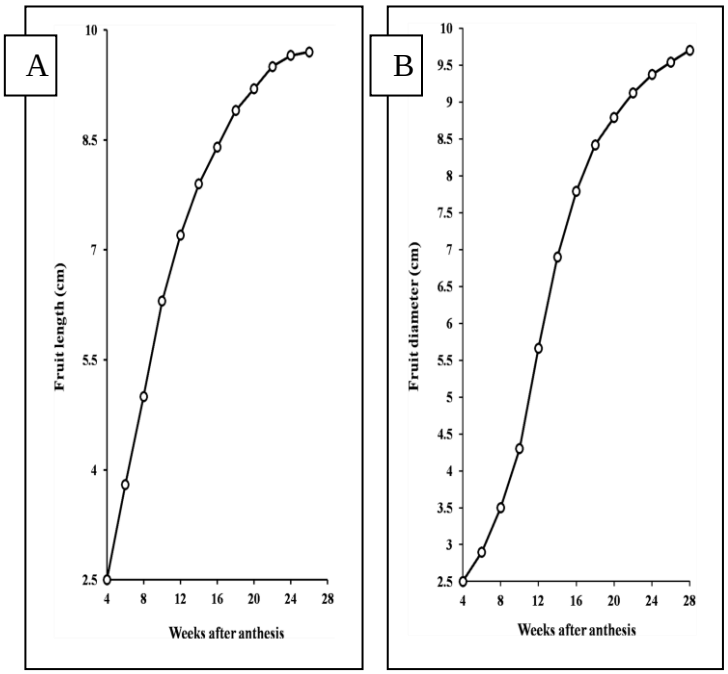


Fig. 2: Changes in fruit length [A] and fruit diameter [B] during growth and development of 'Red Blush' grapefruits.

Peel thickness and pulp diameter

Pulp diameter steadily increased during fruit growth and development (Table 1), in the same manner of fruit weight, volume and size (Figs. 1 & 2). It increased significantly from 1.0 cm (4 WAA) to 8.5 cm (26 WAA) (Table 1). Peel thickness decreased from 0.75 cm (4 WAA) to 0.48 cm (8 WAA), then increased to o.80 (16 WAA), and finally, decreased afterwards to 0.52 cm (26 WAA) (Table 1). Similar results were reported in oranges (Ladaniya and Mahalle, 2011).

Peel/pulp ratio

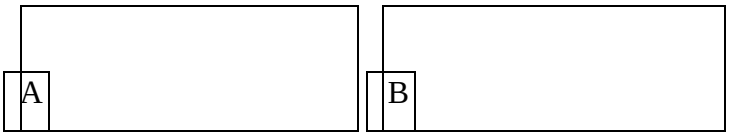
The peel/ pulp ratio progressively decreased during growth and development. It decreased from 0.50 (4 WAA) to 0.122 (26 WAA), with 12.3-folds (Table 1). This was due to the greater rate of growth of the pulp than that of the peel, as supported by Ladaniya and Mahalle (2011) who reported that the increase in pulp volume and its cell division is greater than that of the peel during growth and development of 'Mosambi' oranges.

Table 1. Changes in peel thickness (cm), pulp diameter (cm) and peel/pulp ratio during growth and development of 'Red Blush' grapefruit.

Parameters	Weeks after anthesis												LSD (5%)
	4	6	8	10	12	14	16	18	20	22	24	26	
Peel thickness (cm)	0.75	0.52	0.48	0.54	0.60	0.72	0.80	0.76	0.75	0.74	0.73	0.52	0.02
Pulp diameter(cm)	1.00	1.86	2.55	3.21	4.45	5.45	6.20	6.90	7.30	7.60	7.90	8.50	0.25
Peel / pulp ratio	1.50	0.56	0.37	0.34	0.27	0.26	0.25	0.22	0.21	0.20	0.18	0.12	0.01

Fruit juice content

The juice content steadily increased during fruit growth and development. It increased significantly from 2.5 ml per fruit (12 WAA) to 93.4 ml per fruit (26 WAA), with 37.4-folds increase (Fig. 3-A). Ting and Attaway (1971) reported that during the exponential growth of the fruit (cell enlargement period), juice vesicles become enlarged and juice content increased in the enlarging juice cells. Juice content steadily increased during growth and development of oranges (Garray *et al.*, 2002; Ladaniya and Mahalle, 2011) and mandarins (Ladaniya, 1996). Juice content is positively related to fruit size and higher juice content was reported in larger fruits in oranges (Garray *et al.*, 2002) and tangerines (Ketsa, 1988).



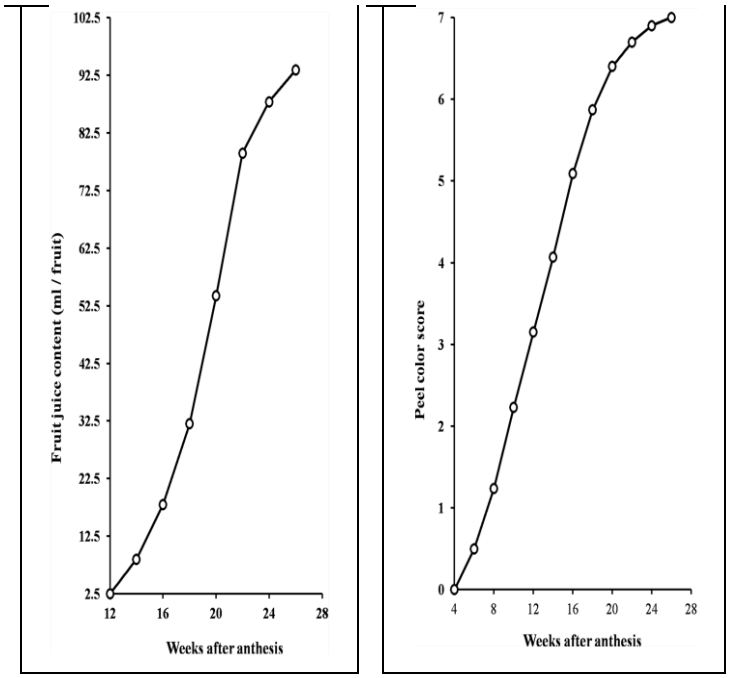


Fig. 3: Changes in fruit juice content [A] and peel color score [B] during growth and development of 'Red Blush' grapefruits.

Peel color

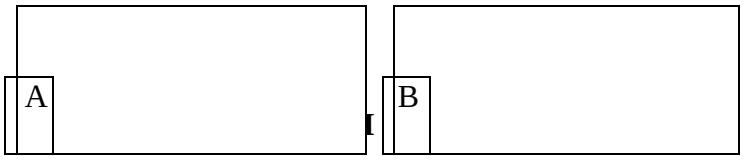
Peel color progressively increased during fruit growth and development. The fruits reached a color score of 3.15 (20% yellow) at harvest 5 (12 WAA) and full yellow color at harvest 12 (26 WAA) (Fig. 3-B). Ting and Attaway (1971) reported that the peel begins to change color when citrus fruit approaches maturity. During development and maturation, citrus fruits change color from green to yellow or orange or orange-red with respect to the genetic character of cultivar under favorable climatic and growing conditions. This is called natural color development (Ladaniya, 2008). Color changes result largely from the loss of chlorophyll (green), the synthesis of carotenoids (yellow and red) and synthesis of pigmented phenolic compounds (Burton, 1982). Chlorophyll and carotenoids are contained in the chloroplasts and the loss of chlorophyll with the simultaneous increase in the carotenoids constituents result in change from green chlorophyll to yellow or red chromatophores (Williams *et al*., 1967). As the chlorophyll disappears, the total carotenoids increase several folds (Ting and Attaway, 1971). The carotenoids pigments of the pulp of colored grapefruit are lycopene and β-carotene, although colorless carotenoids are present (Ting and Attaway, 1971). Umeda and Kawashima (1971) reported that citrus carotenoids increased during the development of skin color. While carotene synthesis is temperature independent, lycopene synthesis and breakdown are affected by temperature. A temperature of 15.6-21.0 ° C is optimal for lycopene synthesis (Umeda and Kawashima, 1971). Temperatures above 30°C may inhibit lycopene formation in tomatoes (Takahashi and Nakayama, 1963) or may even enhance lycopene synthesis in grapefruits (Purcell and Shultz, 1964).

Fruit flesh firmness

Fruit flesh firmness steadily decreased during growth and development of grapefruits. It decreased significantly from 1.4 kg/cm^2 (4 WAA) to 1.2 kg/cm^2 at physiological maturity (26 WAA) (Fig. 4-A). This is in agreement with the findings of Ladaniya and Mahalle (2011), who found that the fruit firmness of 'Mosambi' oranges decreased gradually with advancement in maturity and finally remained almost constant at 240 days, indicating no change in firmness between 230 and 250 days after fruit set.

Respiration rate

The respiration curve exhibited a typical non-climacteric pattern. The respiration rate decreased significantly with advancement in growth and development, from 239.8 mg CO_2/kg-hr (4 WAA) to 21.1 mg CO_2/kg-hr (26 WAA). (Fig. 4-B). Aharoni (1968) studied the pattern of respiration of different cultivars of grapefruits and oranges picked at different stages of growth and development. The low rate of respiration and the unobservable climacterics are associated with the slow rate of chemical reaction that occurs in these fruits during growth and development. Fruits harvested near horticultural maturity showed gradual decline in the rate of respiration and produced no ethylene. Grapefruits are classified as non-climacteric fruits (Kader and Arpaia, 2002). Similar results were reported with pink-fleshed 'Foster' grapefruits (Abu-Goukh and Elshiekh, 2008).



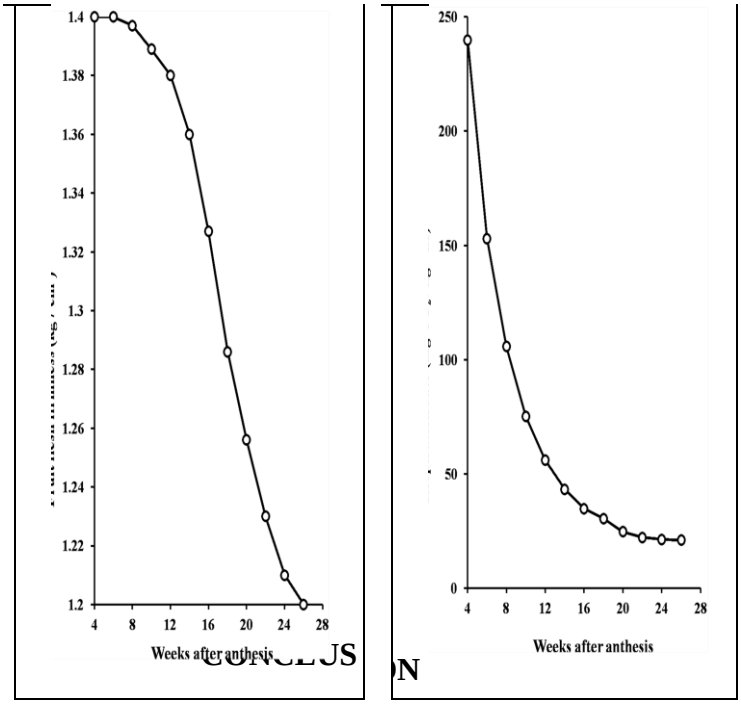


Fig. 4: Changes in fruit flesh firmness [A] and respiration rate [B] during growth and development of "Red Blush" grapefruits.

CONCLUSION

Grapefruits should be harvested at least at physiological maturity, where the fruit attains maximum size and weight, juice content at maximum level, peel/pulp ratio at minimum, rind color develops, and it is still firm.

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المجلد 15،العدد 1،2017م مجلة الجزيرة للعلوم الزراعية

التغيرات الفيزيائية والكيميائية أثناء نمو وتطور ثمار القريب فروت. I. التغيرات الفيزيائية

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الخلاصة

"رد بلش"، أحمر اللب ذي البذور من الصنف التغيرات الفيزيائية أثناء النمو والتطور لثمار القريب فروت قومت وذلك لتوفير المعلومات الأساسية المتعلقة بكيمياء الثمار أثناء تطورها لتساعد في تحديد مرحلة اكتمال النمو لثمار القريب فروت في نموها نمط منحنى النمو المنفرد. زادت الثمار في الوزن الطري والحجم ثمار القريب فروت. اتبعت والطول وقطر الثمرة و سمك القشرة وقطر اللب وكمية العصير ولون القشرة زيادة مضطردة من أربعة أسابيع بعد تفتح الأزهار إلى 26 أسبوعاً بعد تفتح الأزهار عند مرحلة اكتمال النمو الفسيولوجي، وثبتت في مقاديرها بعد ذلك. تبع كجم- / ملجم ثاني أكسيد الكربون 239.8معدل تنفس الثمار نمط التنفس غير الكلايماكتيرى، حيث انخفض من كجم- ساعة (26 اسبوعاٌ بعد تفتح الأزهار). /ساعة (4 أسابيع بعد تفتح الأزهار) إلى 21.1 ملجم ثاني أوكسيد الكربون انخفضت نسبة القشرة إلى اللب وصلابة لب الثمار على الدوام مع تقدم الثمار في مراحل النمو والتطور. لذلك يجب حصاد ثمار القريب فروت عند مرحلة اكتمال النمو الفسيولوجي، على الأقل، حيث تكون الثمرة قد بلغت الحجم والوزن النهائي، وكمية العصير في أعلى مستوياتها، ونسبة القشرة للب في أدنى حدودها، والقشرة قد تلونت، وتكون الثمرة ما زالت صلبة القوام.