

Performance of Grapefruit Under the Ecological Conditions of Central Sudan II. Physicochemical Evaluation of Fruits

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Abstract: The physical and chemical characters of fruits of 13 grapefruit (*Citrus paradisi*) cultivars were studied over the maturity period. Fruit weight increased with maturity and reached harvest size, 8-10 months after set. The edible portion (pulp) of the fruit increased, while the peel (rind) decreased in both weight and thickness with ripening. Percentage juice content increased with maturity and by the age of 10 months, all cultivars produced the level of juice (35%) acceptable by the industry. Both total soluble solids and sugar:acid ratio increased with maturity. Significant differences in total acidity, which decreased with maturity, were observed among cultivars. Ascorbic acid decreased with fruit maturity and significant differences were detected among the various cultivars. Reducing sugars, sucrose and total soluble sugars in pulp and rind increased with ripening. After maturity was attained, there was an appreciable increase in reducing sugars, and a slight decrease in sucrose, probably due to the inversion of sucrose to glucose and fructose.

Key words: Fruit, cultivar, sugars, acidity, maturity, quality.

Quality of citrus fruits is vital for consumer acceptance and their increased consumption. The quality is determined by parameters like flavor, color, total soluble solids, titratable acidity, sugar:acid ratio, stability and nutritional value as reflected by mineral, vitamin C and sugar contents (Soule *et al.*, 1967; Sinclair, 1972). Fruit quality is the ultimate result of fruit setting, growth, development and maturation. Grapefruits are slow to mature and may be left on the tree for several months after reaching edible quality, therefore, composition is important for both nutritive value and proper time of harvest (Sinclair, 1972). Quality of citrus fruits not only varies with

the degree of maturity, but also with climate, soil type, soil fertility, genotype, rootstock and cultural practices (Wutscher and Shull, 1972; Reuther, 1977). This study was carried out to obtain more information about the physical and chemical properties of fruits of 13 grapefruit cultivars grown under the ecological conditions of the heavy clay plains of central Sudan.

Materials and Methods

Grapefruit cultivars, Foster, White, Duncan, Marsh seedless, Miami, Brown, Red Blush, Shamber, Little River, Carpenter Marsh, Howell, Davis seedless, and Frost Marsh, budded to a sour orange (*Citrus aurantium* L.) rootstock, were evaluated

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Table 1. Average fruit weight (g) of different grapefruit cultivars over the maturity period

| Cultivar | Age (months) | | | | | |
|-----------------|--------------|-----------|----------|-------|-------|----------|
| | 2 | 4 | 8 | 10 | 11 | 12 |
| Marsh seedless | 18.6 | 112.6 abc | 336.8 ab | 381.4 | 463.8 | 460.0 bc |
| Little river | 13.6 | 90.8 a | 334.0 a | 395.0 | 401.4 | 400.2 ab |
| Davis seedless | 14.8 | 100.7 abc | 296.6 a | 354.6 | 379.2 | 357.3 ab |
| Frost March | 14.4 | 107.7 abc | 345.8 ab | 389.9 | 441.1 | 405.7 ab |
| Foster | 14.6 | 129.2 bc | 344.8 ab | 423.6 | 376.2 | 460.5 bc |
| Howell | 14.3 | 121.0 bc | 335.6 a | 407.8 | 447.8 | 453.3 ab |
| Duncan | 15.5 | 127.2 bc | 356.8 b | 388.2 | 412.8 | 415.0 ab |
| Carpenter Marsh | 13.9 | 94.5 ab | 379.4 b | 420.9 | 446.4 | 442.7 b |
| Shamber | 14.3 | 107.8 abc | 349.0 ab | 407.7 | 419.2 | 409.2 ab |
| Red Blush | 16.6 | 151.7 d | 310.4 a | 392.2 | 422.9 | 407.5 ab |
| White | 16.2 | 152.7 d | 365.8 b | 433.9 | 427.0 | 489.8 c |
| Brown | 14.3 | 127.3 bc | 336.8 ab | 396.3 | 403.5 | 403.0 ab |
| Miami | 13.5 | 133.1 bc | 371.0 b | 440.5 | 423.9 | 447.2 bc |
| | NS | | | NS | NS | |

Within a column, means with same letter in common do not differ significantly at 5% level according to Duncan's multiple range test; NS = No significant differences.

at Sennar Horticultural Research Station (Lat. 13° 14' N, Long. 33° 44' E), central Sudan. The soil is non-saline (EC = 0.56 dS m⁻¹), dark-gray calcareous clays with a clay content of 57%, pH 8.5 and cation exchange capacity of 55 mg per 100 g soil. The experimental design was a randomized complete block replicated 5 times with 3 trees per plot. Tree spacing was 8 x 8 m. Irrigation water was applied at fortnight intervals, except during the rainy season (July-October), during which period irrigation water was applied only when necessary. Twenty to fifty fruits were randomly collected from each plot around the tree at 1 to 2 m above the ground level at a 2 month interval. Fruits were weighed, peeled and the weights of the pulp and peel were recorded. Rind thickness and fruit diameter were measured by Vernier

Calliper. The extractable juice volume was determined by a measuring cylinder and its weight by a top-loading balance, analyzed for total soluble solids with a hand refractometer, total titratable acidity was measured by titration with 0.1 N NaOH to a phenolphthalein end point and expressed as percentage citric acid (Soule *et al.*, 1967; Sidahmed and Kliewer, 1980). Ascorbic acid was determined by a visual titration method based upon the reduction of 2,6-dichlorophenolindophenol dye by an acid extract of ascorbic acid (Khalil, 1985). Reducing sugars were estimated by the cuprimetric method of Nelson (1944) as modified by Asatoor and King (1954). Total sugars were estimated by Nelson's modified procedure. The difference between the amount of reducing sugars, before and after hydrolysis, was taken as the amount of

Table 2. Percentage rind and pulp weights to whole fruit of grapefruit cultivars over the maturity period

| Cultivar | Rind (%) | | | | Pulp (%) | | | |
|-----------------|--------------|-----------|---------|-----------|--------------|-----------|---------|-----------|
| | Age (months) | | | | Age (months) | | | |
| | 2 | 4 | 8 | 10 | 2 | 4 | 8 | 10 |
| Marsh Seedless | 84.8 abc | 62.5 ab | 35.2 ab | 25.8 ab | 15.2 bcd | 37.5 cd | 64.8 ab | 74.2 cd |
| Little River | 80.8 a | 67.7 ab | 36.0 ab | 33.0 cd | 19.2 d | 32.3 a | 64.0 ab | 67.0 ab |
| Davis Seedless | 84.1 abc | 66.8 cd | 32.3 ab | 27.9 abc | 15.9 bcd | 33.2 ab | 67.7 ab | 71.2 bcd |
| Frost March | 90.0 cd | 66.7 cd | 34.4 ab | 34.8 d | 10.0 ab | 33.3 ab | 65.6 ab | 65.2 a |
| Foster | 89.3 cd | 63.4 abc | 30.9 a | 29.1 abcd | 10.7 abcd | 10.7 abcd | 69.1 b | 70.9 abcd |
| Howell | 87.3 abc | 64.6 abcd | 37.8 b | 31.9 bcd | 12.7 abcd | 35.4 abcd | 62.2 a | 68.1 abc |
| Duncan | 89.4 cd | 67.8 d | 30.9 a | 25.5 ab | 10.6 ab | 32.2 a | 69.1 b | 74.5 cd |
| Carpenter Marsh | 84.0 abc | 66.9 cd | 30.0 a | 30.5 abcd | 16.0 bcd | 33.1 ab | 70.0 b | 69.5 abcd |
| Shamber | 86.7 abcd | 61.9 a | 36.6 ab | 24.6 a | 13.3 abcd | 38.1 d | 63.4 ab | 75.4 d |
| Red Blush | 88.7 bcd | 66.1 bcd | 38.4 b | 29.8 abcd | 11.3 abc | 33.9 abcd | 61.6 a | 70.2 abcd |
| White | 87.9 bcd | 66.6 cd | 29.9 a | 26.0 ab | 12.1 abc | 33.4 ab | 70.1 b | 74.0 cd |
| Brown | 90.9 d | 65.7 abcd | 29.6 a | 28.1 abc | 9.1 a | 34.3 abcd | 70.4 b | 71.9 bcd |
| Miami | 82.2 ab | 65.5 abcd | 33.5 ab | 26.0 ab | 17.8 cd | 34.5 abcd | 66.5 ab | 74.0 cd |

Within a column, means with same letter in common do not differ significantly according to Duncan's multiple range test at 5% level.

non-reducing sugars (sucrose). After alcoholic extraction of the soluble sugars the residue was reflexed for 2.5 hours with 2N HCl to hydrolyze starch to simple sugars. The released sugars were then estimated by Nelson's modified procedure.

Results and Discussion

Fruit growth

Fruit weight increased with maturity and reached harvest size 8 to 10 months after set (Table 1). Two months after set, fruit weight of different cultivars ranged from 13.5 to 16.6 g. A rapid, 6-9 fold increase in fruit weight was obtained two months later (Table 1). Subsequently, increase in

fruit weight slowed down and leveled off at the 10th month of age. The results were in agreement with those of Sidahmed and Genief (1984), Khalil (1985) and Shikhamany *et al.* (1993). The data revealed that there were large variations in fruit weight within cultivar, among cultivars and developmental stages. Significant differences were observed when fruits were sampled at the age of 4, 8 and 12 months after set, while at the age of 2, 10 and 11 months, no significant differences were detected between the cultivars.

Variation in both fruit weight and size within a single cultivar, among cultivars and seasons were reported (Sidahmed and Genief, 1984; Hamid *et al.*, 1993). The

Table 3. Rind thickness : Fruit diameter ratio of different grapefruit cultivars over the maturity period

| Cultivar | Age (months) | | | |
|-----------------|--------------|---------|---------|---------|
| | 2 | 4 | 8 | 10 |
| Marsh seedless | 64.0 ab | 32.6 a | 26.4 ab | 22.0 ab |
| Little River | 68.8 bcde | 36.2 ab | 22.2 ab | 27.8 c |
| Davis seedless | 63.2 cde | 41.2 b | 23.0 ab | 23.6 bc |
| Frost March | 65.8 bcd | 35.0 ab | 22.2 ab | 22.0 ab |
| Foster | 63.0 ab | 33.2 a | 25.4 ab | 19.8 ab |
| Howell | 55.4 ab | 34.4 ab | 22.3 ab | 24.0 bc |
| Duncan | 74.4 de | 42.2 b | 21.6 a | 21.6 ab |
| Carpenter Marsh | 69.2 bcde | 37.6 ab | 25.8 ab | 21.6 ab |
| Shamber | 77.2 cde | 38.0 ab | 24.8 ab | 19.6 ab |
| Red Blush | 63.8 abc | 36.4 ab | 28.4 b | 18.2 a |
| White | 79.4 e | 36.6 ab | 20.0 a | 17.8 a |
| Brown | 67.2 bcde | 39.2 ab | 20.4 a | 22.0 ab |
| Miami | 63.8 abc | 37.2 ab | 22.8 ab | 20.6 ab |

Within a column, means with same letter in common do not differ significantly at 5% level according to Duncan's multiple range test.

mean weight of mature fruits ranged from 295.6 to 379.4, and 354.6 to 440.5 g at the age of 8 and 10 months, respectively (Table 1). At the age of 8 months, maximum fruit weight was recorded in Carpenter Marsh, while at the age of 10 months, the variety Miami produced the heaviest fruits.

Increase in the fruit weight at the early stages of fruit development was primarily due to increase in peel weight (Table 2). Two months after fruit set, the peel constituted 80.8 to 90.9% of the total fruit weight and it decreased to 61.9 to 67.8% after 4 months and 24.6 to 34.8% after 10 months. With maturity, however, the rind weight and thickness decreased, while the pulp weight increased steadily (Tables 2 and 3). The ratio of rind thickness to fruit diameter (Table 3) decreased from 55.4 to 79.4 at two month stage to 17.8

to 27.8 at the age of 10 months. Significant differences in percentage rind and pulp weight to whole fruit, and the ratio of rind thickness to fruit diameter were observed over all sampling dates (Tables 2 and 3).

The results were in agreement with the findings of Sidahmed and Genief (1984) and Hamid *et al.* (1993), that at early stages of fruit development, a large part of the cross section of the fruit consisted of the peel, but later on, the pulp portion increased.

Juice content

The immature fruits contained comparatively less juice. By the 10 month of age, all cultivars more or less produced the minimum (35%) level of juice accepted by the citrus industry (Table 4). No significant differences in percentage juice were ob-

Table 4. Juice content and chemical composition of fruits of different grapefruit cultivars 10 months after set

| Cultivar | Juice by wt. (%) | Juice pH | Total acidity (% citric acid) | Total solids (% sucrose) | Sugar: acid ratio | Ascorbic acid (mg/100 ml) |
|-----------------|------------------|----------|-------------------------------|--------------------------|-------------------|---------------------------|
| Marsh Seedless | 36.8 | 3.30 | 1.45 ab | 11.0 | 7.61 b | 41.22 bcdef |
| Little River | 34.1 | 3.25 | 1.84 d | 11.0 | 6.00 a | 37.89 ab |
| Davis Seedless | 36.3 | 3.35 | 1.41 a | 11.0 | 7.80 b | 38.28 abc |
| Frost March | 39.2 | 3.35 | 1.48 abc | 11.0 | 7.48 b | 41.61 cdef |
| Foster | 41.7 | 3.35 | 1.42 ab | 11.0 | 7.74 b | 42.90 ef |
| Howell | 37.7 | 3.35 | 1.46 ab | 11.0 | 7.54 b | 39.46 abcde |
| Duncan | 38.5 | 3.35 | 1.48 abc | 11.0 | 7.49 b | 40.04 abcdef |
| Carpenter Marsh | 35.0 | 3.25 | 1.40 a | 11.0 | 7.96 b | 39.65 abcde |
| Shamber | 37.0 | 3.20 | 1.60 bc | 11.0 | 6.99 ab | 39.06 abcd |
| Red Blush | 40.3 | 3.25 | 1.48 abc | 11.0 | 7.44 b | 37.00 a |
| White | 37.3 | 3.35 | 1.36 a | 11.0 | 8.12 b | 43.33 f |
| Brown | 35.8 | 3.35 | 1.67 c | 11.5 | 7.54 b | 43.75 f |
| Miami | 37.0 | 3.20 | 1.40 a | 10.5 | 7.50 b | 40.44 bcdef |
| | NS | NS | | NS | | |

Within a column, means with same letter in common do not differ significantly at 5% level according to Duncan's multiple range test; NS = No significant differences.

served between the cultivars, however, the cultivar Foster numerically out yielded the others. The juice content of 11 of the 13 cultivars under investigation were above the satisfactory level (35%), despite the hand-press-squeeze method used for juice extraction. The percentage juice obtained was lower (46.0 to 47.0%) than that reported by Dinnar and Osman (1984), but in line with that reported (34.0 to 42.0%) by Khalil (1985) and Hamid *et al.* (1993).

pH and acidity

The pH of fruit juice at maturity revealed no significant differences between the cultivars (Table 4). The acidity of the juice decreased with fruit maturity. Differences in acidity of mature fruit juice were sig-

nificant, with lowest in White and highest in Little River (Table 4).

Total soluble solids and sugar:acid ratio

The total soluble solids increased with fruit maturity and by the 10th month of age, no significant differences were observed among cultivars (Table 4). The percentage total soluble solids recorded were well above the standard requirements in many parts of the world (Cruse *et al.*, 1982; Hamid *et al.*, 1993). The edible quality of grapefruit depends largely on the ratio of sugar to acid in the juice. Significant differences in sugar:acid ratios, which ranged from 6.0 to 8.1, were recorded among the cultivars (Table 4). Furthermore, the sugar:acid ratios reported in this study are

Table 5. Reducing sugars and sucrose in the edible portion (pulp) of fruit of different grapefruit cultivars over the maturity period

| Cultivar | Reducing sugars (% dry wt.) | | | | Sucrose (% dry wt.) | | | |
|-----------------|-----------------------------|-------|-------|-------|---------------------|-------|-------|-------|
| | Age (months) | | | | Age (months) | | | |
| | 2 | 4 | 8 | 10 | 2 | 4 | 8 | 10 |
| Marsh Seedless | 6.00 | 11.33 | 23.67 | 31.67 | 8.50 | 15.50 | 22.50 | 15.83 |
| Little River | 6.17 | 11.17 | 25.50 | 34.17 | 5.33 | 12.66 | 21.50 | 20.83 |
| Davis Seedless | 6.50 | 12.17 | 23.67 | 27.67 | 7.50 | 11.16 | 16.50 | 18.83 |
| Frost March | 6.00 | 13.67 | 22.17 | 29.33 | 6.83 | 12.16 | 18.50 | 18.50 |
| Foster | 6.50 | 11.83 | 30.68 | 32.00 | 6.17 | 12.76 | 22.66 | 22.50 |
| Howell | 6.17 | 12.33 | 22.67 | 30.83 | 5.00 | 9.34 | 20.16 | 19.84 |
| Duncan | 6.33 | 10.50 | 28.33 | 31.67 | 6.67 | 11.17 | 21.67 | 19.83 |
| Carpenter Marsh | 6.00 | 9.17 | 19.17 | 33.50 | 7.33 | 13.66 | 24.50 | 19.67 |
| Shamber | 6.33 | 12.33 | 22.00 | 33.17 | 6.50 | 11.34 | 19.67 | 19.50 |
| Red Blush | 6.05 | 10.83 | 21.50 | 31.67 | 7.83 | 13.83 | 19.63 | 17.16 |
| White | 5.67 | 13.33 | 25.50 | 29.83 | 6.33 | 14.50 | 25.50 | 18.67 |
| Brown | 6.33 | 11.00 | 22.00 | 30.83 | 5.34 | 11.83 | 28.00 | 20.63 |
| Miami | 6.00 | 11.83 | 21.33 | 32.50 | 6.00 | 12.84 | 20.67 | 18.51 |

far above the universally accepted good quality range (Sinclair, 1972; Hamid *et al.*, 1993). In California, Brazil and Israel, sugar to acid ratios of 6.0, 6.5 and 5.3, respectively, were considered satisfactory (Sinclair, 1972; Cruse *et al.*, 1982).

Ascorbic acid (vitamin C)

Apart from sugars and minerals, the nutritional value of a grapefruit is mainly correlated to its vitamin C content. In view of the dietetic value of vitamin C, and that a minimum concentration of 30 to 35 mg per 100 ml is required for processing (Sinclair, 1972), the data presented in Table 4 are of particular interest. The values of vitamin C reported here were higher than those reported for grapefruit in the U.S.A. by Cruse *et al.* (1982). Moreover, all cultivars under study produced higher levels

of vitamin C than that required for processing.

Sugars in the pulp and rind

Fruits in general are considered a rich source of carbohydrates and that reducing and non-reducing (sucrose) sugars are the most important digestible carbohydrates. The level of reducing sugars gradually increased with fruit maturity (Table 5). Two months after fruit set, the concentration of reducing sugars in the pulp varied from 5.6 to 6.5% and increased five-fold (27.67 to 34.17%) at the age of 10 months, with the lowest in Davis seedless, and the highest in Little River. The sucrose content increased with fruit maturity reaching maximum at 8th month stage, after which, the level declined. Apparently, some sucrose was inverted to reducing sugars as the fruit reached prime edibility. The high values

Table 6. Total soluble sugars and starch in fruit rind of different grapefruit cultivars over the maturity period

| Cultivar | Total soluble sugars (% dry wt.) | | | | Starch (% dry wt.) | | | |
|-----------------|----------------------------------|-------|-------|-------|--------------------|------|------|------|
| | Age (months) | | | | Age (months) | | | |
| | 2 | 4 | 8 | 10 | 2 | 4 | 8 | 10 |
| Marsh Seedless | 11.83 | 20.83 | 26.67 | 31.33 | 6.50 | 4.33 | 1.83 | 1.33 |
| Little River | 11.50 | 21.33 | 21.83 | 24.67 | 6.83 | 4.33 | 1.50 | 1.50 |
| Davis Seedless | 8.33 | 19.17 | 23.00 | 27.00 | 6.00 | 3.17 | 1.67 | 1.83 |
| Frost March | 9.17 | 17.00 | 26.00 | 26.67 | 6.33 | 4.17 | 1.83 | 1.33 |
| Foster | 11.00 | 20.50 | 21.17 | 26.37 | 6.17 | 4.00 | 1.17 | 1.83 |
| Howell | 10.17 | 16.67 | 21.33 | 26.50 | 7.67 | 5.00 | 1.83 | 1.17 |
| Duncan | 8.15 | 18.33 | 26.00 | 24.50 | 6.83 | 6.33 | 1.83 | 1.50 |
| Carpenter Marsh | 8.17 | 15.00 | 21.67 | 27.83 | 6.17 | 4.33 | 1.33 | 1.67 |
| Shamber | 9.33 | 18.00 | 25.33 | 26.50 | 6.33 | 4.17 | 1.00 | 1.83 |
| Red Blush | 12.00 | 18.17 | 22.50 | 25.00 | 7.67 | 4.33 | 1.33 | 1.17 |
| White | 8.67 | 21.17 | 24.00 | 30.00 | 7.33 | 6.17 | 1.50 | 1.00 |
| Brown | 7.83 | 14.83 | 23.17 | 26.67 | 7.17 | 3.50 | 1.67 | 1.33 |
| Miami | 11.83 | 14.33 | 19.50 | 27.83 | 6.17 | 4.33 | 1.69 | 1.83 |

of sugars reported in this study were expected since the experimental area is characterized by fairly high temperatures during most of the year and mild winter temperatures, known to be suitable for the production of high quality grapefruits (Siddahmed and Genief, 1984; Khalil, 1985; Hamid *et al.*, 1993).

The level of total soluble sugars (Reducing + sucrose) in grapefruit rind increased with fruit maturity (Table 6). However, the amounts of total soluble sugars in the rind were lower than those produced in the pulp. In contrast to total soluble sugars, starch content of the rind declined rapidly with maturity (Table 6). A range of 6.0 and 7.6% starch was obtained when fruits were 2-month-old and it decreased with fruit maturity to less than 2% in the rinds of all cultivars under test by 8 month

stage (Table 6). The decline in starch could be attributed to the loss of chlorophyll content of the rind with fruit maturity.

During maturation of citrus fruits, there is a loss of chlorophyll and an increase in carotenoids (Erickson, 1968). Since the flavedo of young citrus fruit contains chlorophyll which functions photosynthetically and contributes to the fixation of carbon dioxide (Erickson, 1968), increased development of carotenoids with fruit maturity will reduce the photosynthetic efficiency of the rind. Bean *et al.* (1963) found fully colored oranges and lemons to have small amounts of chlorophyll which showed a proportional photosynthetic activity as measured by fixation of $^{14}\text{CO}_2$. The decrease in starch content of the rind with fruit maturation reported in this study may, therefore, be attributed to reduced photo-

synthetic activity as chlorophyll, the major photosynthetic pigment, had been masked by carotenoids. Hydrolysis of starch to simple sugars with fruit maturity cannot be excluded.

The acceptable quality parameters of grapefruit reported (Erickson, 1968; Sinclair, 1972; Cruse *et al.*, 1982) for the U.S.A. were: juice content (35%), total soluble solids (11.0%), sugar:acid ratio (6.0 to 7.69) and ascorbic acid content (30 to 35 mg per 100 ml). The fruit quality data as indicated by the juice content (34.1 to 41.7%), total soluble solids (10.5 to 11.5%), sugar:acid ratio (6.0 to 8.1) and ascorbic acid content (37.0 to 43.75 mg per 100 ml) in the present study compared well with those cited for the U.S.A., the world's major citrus producing country, reflecting the potentiality of the ecological conditions of central Sudan to produce grapefruit of acceptable quality that can compete well in the international markets.

References

- Asatoor, A. and King, E.J. 1954. Simplified colorimetric sugar method. *Biochemical Journal* 56:
- Bean, R.C., Porter, G.G. and Barr, B.K. 1963. Photosynthesis and respiration in developing fruits 111. Variation in photosynthetic capacities during color change in citrus. *Plant Physiology* 38: 285-290.
- Cruse, R.R., Lime, B.J., Weigand, C. and Swanson, W.A. 1982. Effect of rainfall and irrigation management on citrus juice quality in Texas. *Journal of the American Society for Horticultural Science* 107(5): 767-770.
- Dinnar, H.M. and Osman, A.M. 1984. Performance of several citrus cultivars in the arid region of northern Sudan. *Acta Horticulture* 143: 239-243.
- Erickson, L.C. 1968. The general physiology of citrus. In *The Citrus Industry* (Ed. W. Reuther). Vol. 2, pp. 86-126. University of California, U.S.A..
- Hamid, G.A., Sidahmed, O.A. and Genief, A.A. 1993. Performance of grapefruit in central Sudan. *Annual Report*, Gezira Research Station, Sudan.
- Khalil, M.I. 1985. Yield potential of different grapefruit cultivars in the heavy clay soils of central Sudan. *M.Sc. Thesis*, Faculty of Agriculture, University of Gezira, Sudan.
- Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. *Journal of Biological Chemistry* 153: 375-380.
- Reuther, W. 1977. Citrus. In *Ecophysiology of Tropical Crops*, pp. 409-439. Academic Press, Inc., New York.
- Shikhamany, S.D., Saroj, P.L. and Parakash, G.S. 1993. Comparison of ripening of Thompson Seedless and Arkavati grapes on different training systems. *Crop Research* 6(2): 276-283.
- Sidahmed, O.A. and Kliewer, W.M. 1980. Effects of defoliation, gibberellic acid and 4-chlorophenoxyacetic acid on growth and composition of Thompson Seedless grape berries. *American Journal of Enology and Viticulture* 31(2): 149-153.
- Sidahmed, O.A. and Genief, A.A. 1984. Performance of citrus in the irrigated heavy clay soils of central Sudan. III. Grapefruit. *Acta Horticulture* 143: 265-270.
- Sinclair, W.B. 1972. *The Grapefruit: Its Composition, Physiology and Products*. University of California, Berkeley, USA.
- Soule, J., Grierson, W. and Blair, J.G. 1967. Quality tests for citrus fruits. *Florida Agriculture Extensive Service Circular* 315-27.
- Wutscher, H.K. and Shull, A.V. 1992. Performance of 13 citrus cultivars as rootstocks for grapefruit. *Journal of the American Society for Horticultural Science* 97(6): 778-781.