taining returns at a low night air temperature (down to 10°). Because of the high capital costs involved in cut rose production, the former strategy might be prefered, in which case energy used per bloom is still reduced due to the increased yield.

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The Maturation and Ripening of the 'Wonderful' Pomegranate

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Abstract. Pomegranate (Punica granatum L. 'Wonderful') fruit reached horticultural maturity for commercial harvest when the soluble solids content (SSC) attained a fairly constant level of 15%. The level of titratable acidity (TA) varied from one location to another and from one year to the next but also generally remained stable at the same time that the SSC reached 15%. After harvest, there was no further change in either SSC or TA at 20°C, but redness of the juice continued to increase in intensity up to and after harvest. The respiration pattern of the mature fruit was of the nonclimacteric type, with only traces of ethylene evolved on occasion. Ethylene treatment of the fruit caused a rapid transient rise in CO₂ evolution but no changes in SSC, TA, and fruit or juice color. A pseudo-climacteric pattern of respiration was found in very young immature fruit. The respiration rate of dehisced arils paralleled that of the intact fruit, but there was no response to exogenous ethylene treatment. Ethylene evidently stimulated the CO₂ output only of the fruit rind.

Although the history of the pomegranate dates to biblical times (4) and the fruit is a well-known orchard crop in Mediterranean countries, it has not been the object of much scientific investigation (8). This is especially true with regard to the physiology of the fruit. The few reviews and studies that deal with pomegranates (3, 5, 8) address mainly such questions as botanical characteristics, cultural techniques, diseases, and cultivars.

Hodgson (5) stated in 1917 that the pomegranate is harvested before it is fully ripe and that it continues to ripen in cold storage, even improving in quality and flavor. Yet he did not present data in support of this statement. Lee et al. (6, 7) described changes in polyphenols, anthocyanins, sugars, and acids and a decline in the respiration rate during fruit development but not thereafter. The objective of the work presented here was to study the maturation and ripening processes of the 'Wonderful' pomegranate and to determine whether its respiratory pattern is climacteric or nonclimacteric.

Materials and Methods

Pomegranate fruits, 'Wonderful', were harvested during 2 seasons from 2 orchards cultivated under different climatic conditions. Location A was an 8-year-old orchard in the Mediterranean coastal plain of Israel, with a temperate to subtropical climate. Location B was a 15-year-old orchard in the Jordan Valley, with a hot and dry, subtropical to tropical climate. In location A fruit were sampled monthly from the time of fruit set until the beginning of the harvest season in September. From then, sampling was weekly until the commercial harvest was terminated in late October. Since fruit set occurs in about 3 distinct waves, fruitlets (17–22 mm in diameter) were tagged on 3 dates (3, 13, and 23 May) for later samplings. This sampling occurred about 2 weeks after the peak of each wave of fruit set, when the chances for fruit drop had decreased notice-

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ably. In location B, fruit were sampled weekly shortly before and during the commercial harvest season. Growth and respiration studies were conducted only with fruit from location A. Compositional analysis was done on fruit from both locations.

Fruit growth for each wave of fruit set was traced by measuring the diameter and weight of 12 of the tagged fruit which were harvested once a month. Eight fruit were used for the respiration studies. The juice from arils of the 4 remaining fruit was extracted and filtered for compositional analysis. Total soluble solids content (SSC) was measured with a hand refractometer. For titratable acidity (TA) determination, 0.5 ml juice was titrated with 0.1 N NaOH to pH 8.2, and TA was calculated as percentage of citric acid. For measuring anthocyanin content as an indication of juice red color, the juice was diluted with 0.1 N HCl (1:50, v/v), and the absorption read at 510 nm. Some of the arils from each fruit were retained intact for taste evaluation. A taste panel of 8–10 persons was asked to rate each sample as inedible, edible, or tasty. Fruit that was rated "edible" by at least 60% of the panel was considered commercially ripe.

The fruit for respiration studies were placed individually, except for the earliest measurement in May when 4 fruitlets were combined, in jars of suitable size to minimize void space. Jars were ventilated continuously with humidified CO_2 -free air at a rate of 60 ml/min, except for the 1 or 2 hr each day when they were sealed hermetically to allow for CO_2 and C_2H_4 accumulation. Ten ppm C_2H_4 were applied to the 4 remaining jars on the day of harvest, at a continuous flow rate of 60 ml/min for

24 hr, and then the jars were ventilated with humidified CO_2 free air for 4 hr before being sealed for CO_2 measurements. The CO_2 concentration was determined with a Packard Model 836 gas chromatograph, equipped with a Poropak Q column and a thermal conductivity detector. Ethylene was measured with a Packard Model 878 gas chromatograph, equipped with an alumina column and a flame ionization detector.

Respiration of separated arils and rinds was measured on sampling dates when the fruit were large enough to contain over 50 g of arils. Ten grams of arils from each fruit were weighed into each of five 100-ml flasks ventilated with air containing 0, 0.1, 1, 10, or 100 ppm C_2H_4 , at a rate of 60 ml/min for 24 hr. The same treatments were applied to whole fruit. In one experiment, the respiration of the rinds and their response to C_2H_4 treatment were measured in the same manner as with the arils. Evolution of CO_2 and C_2H_4 was measured daily. The color, SSC, and TA of the juice extracted from the arils were measured at the beginning and at the end of the experiment.

Results and Discussion

Changes in fruit size and composition during development. The growth rates of fruit from the different setting dates were virtually identical, as measured by the increases in both diameter and weight (Fig. 1). Thus, the size of the fruit on any specific day of harvest is determined to a large degree by the date on which it sets. The measurement of fruit diameter indicated 2 phases of growth; a rapid phase until mid-June and, thereafter,



Fig. 1. The growth pattern of 'Wonderful' pomegranates from 3 setting dates. The linear rate of increase in fruit weight has been calculated for each wave set. The average rate of fruit diameter increase was calculated for all 3 wave sets and the closest estimates showed a change in the linear growth rate around mid-June, as indicated by the 2 formulae on each side of the broken line.



extractable juice of 'Wonderful' pomegranates harvested at various developmental stages from 2 locations during 2 seasons. sE, as percentage of the mean of 8 replicates near the critical values, were: 1% for SCC, 3.6% for TA, 6% for SCC:TA, and 16% for red color.



17

15

13

11

9

4

2

0

%

Fig. 3. The postharvest respiration rates of mature 'Wonderful' pomegranates.

a gradual phase until harvest. Yet there was a constant rate of fresh weight increase throughout the growing season. Calculation of the ratio of weight to diameter increase also showed a break in the linear relationship at a fruit diameter of 52.5 mm (data not presented).

As the fruit grew, there was a gradual decline in TA content and a concomitant increase in SSC until the 2nd half of September (Fig. 2). From this time on, both TA and SSC generally

remained at a fairly constant level. However, whereas the SSC level was similar in both seasons and both locations, there was considerable annual variation in the TA level between locations. When the SSC of the fruit reached 15%, the fruit appeared to be ripe in terms of quality. Due to the variation in acid content, the ratio of SSC: TA also varied noticeably between locations and seasons and did not correlate satisfactorily with taste (Fig. 2C). There were no changes in either TA or SSC of fruit held at 20°C following harvest. Another index of maturity, i.e., juice red color, generally did not reach its maximum values when SSC levelled off, but continued to increase in intensity until the fruit was harvested (Fig. 2D) and thereafter, in storage (data not shown).

Chace et al. (3) attempted to establish a maturity standard for 'Wonderful' pomegranates grown in California and collected a considerable amount of data during three seasons. They concluded that 1.8% TA was the most satisfactory maturity standard. This value is too high for Israeli grown fruit from the point of view of flavor. The SSC of the California fruit generally was above 17%, also higher than we found, and probably explains the feasibility of harvesting fruit with such high acidity. The ratio of SSC to TA in California fruit was, however, similar (7-12) to that found acceptable in mature Israeli fruit (6-13). In fruit defined as "tasty" by the panel, the SSC:TA ratio was 11-16.

Changes in respiration rate during fruit development. The respiration rate of pomegranates harvested in September either remained constant or declined from the day of harvest (Fig. 3).



Fig. 4. The respiration rates of 'Wonderful' pomegranates harvested at various developmental stages. Numbers beside curves indicate average fruit weight at harvest in grams. Arrows indicate harvest dates.

Only a trace of C_2H_4 production could be detected, even when the fruit was sealed in the respiration jars for 4 hr (data not presented). By following the initial respiration rate of the fruit harvested at various stages of development, a gradual decline in respiration was observed during and after May, both on the day of harvest and thereafter (Fig. 4). The same trend was found in the early stages of fruit development, when fruit of different ages were harvested on the same day; that is, young fruit produced more CO₂ than old fruit. As the season progressed, the differences between fruit of different ages harvested on the same day were reduced.

In May, the respiratory pattern following harvest was reminiscent of the climacteric — an initial rise in CO_2 output lasting for one day, followed by a gradual decline. The initial burst of CO_2 evolution became progressively less pronounced as the fruit developed and as the season advanced. In July, only the youngest fruit still showed a small rise in respiration on the day after harvest, and thereafter virtually none was observable (Fig. 5).

Ethylene evolution in measurable amounts was detected only in very young fruit, those which had set around 7 May and were



Fig. 5. The effect of applied ethylene (10 ppm for 24 hr) on the respiration and ethylene evolution of pomegranate fruit (set on 7 May) harvested at various developmental stages. Arrows indicate beginning of ethylene treatment. Upright arrows indicate the beginning of a repeated ethylene application.

Table 1. CO_2 evolution (mg kg⁻¹ h⁻¹) from 'Wonderful' pomegranates at different stages of development following 24 hr of C_2H_4 treatment at 20°C.

C ₂ H ₄ (ppm)	May	June	July	August	Septembe
0	248 a ^z	166 a	101 a	40 a	31 a
0.1	228 a	171 a	101 a	72 b	38 a
1	261 a	166 a	152 b	101 b	89 c
10	304 b	201 b	171 b	104 b	77 c
100	328 b	193 b	164 b	101 b	75 b

²Mean separation in columns by Duncan's multiple range test, 5% level used to establish thresholds.

harvested on 23 May (no samples were taken before this date) (Fig. 5). Treatment of fruit with 10 ppm C_2H_4 for 24 hr increased the rate of C_2H_4 evolution from this early-harvested fruit but did not influence C_2H_4 production in older fruit. The main effect of exogenous C_2H_4 treatment was to cause an immediate burst in CO₂ evolution. The response to C_2H_4 increased as the fruit matured; in young fruit picked in May, CO₂ evolution was stimulated by about 30%, whereas in mature fruit harvested in September, the increase was about 100%. A repeated C_2H_4 treatment of fruit harvested in August, one week after the initial postharvest treatment (Fig. 5 - upright arrow), again doubled the rate of CO₂ output which had been attained on the same day by both untreated and previously treated fruit. The immediate rise in CO₂ evolution was followed by a similarly rapid decline on the next day and thereafter.

The threshold for response to C_2H_4 was one ppm for fruit harvested from, during, and after July (Table 1). Fruit harvested in May and June required 10 ppm C_2H_4 to stimulate a response in CO₂ output. For all fruit, irrespective of the harvest date, an increase in C_2H_4 above the threshold concentration did not in-



Fig. 6. The respiration rates of pomegranate rind and arils from fruit harvested in August, as affected by ethylene treatment at 1 ppm for 24 hr.

duce increased CO_2 output. Aside from the increased CO_2 evolution induced by C_2H_4 treatment, no other changes were observed in the appearance or composition of the treated fruit (data not presented).

Most of the these data indicate that the pomegranate is a nonclimacteric fruit as described and defined by Biale (2). A pseudo-climacteric respiratory pattern of immature fruit also has been described for citrus fruit (1). The pattern of pomegranate respiration is reminiscent of, but not identical to, that of citrus. The initial rise in respiration of immature citrus is gradual, lasting a few days, and the pseudo-climacteric pattern at declining levels is observed during a few months of development. These differences could be the result of the 12-month growth period required for citrus fruit maturation, however, compared with 6 months for the pomegranate. The respiratory behavior of the 2 types of fruit might be considered similar; however, in their response to C₂H₄ treatment, they again differ. Whereas CO₂ evolution by citrus increased with increasing C₂H₄ concentrations (2), the threshold concentration for response by the pomegranate also was the concentration for maximal response to C₂H₄ treatment. Probably the most decisive factor in determining the pomegranate to be nonclimacteric is the return of C₂H₄-treated fruit to the level of CO₂ production measured for nontreated fruit and the reproducible response with repeated C_2H_4 treatments.

A comparison of the respiration rates of the separated arils and the fruit rinds showed that the latter respired at double the rate of the former (Fig. 6). The respiration rate of the dehisced arils was about the same as that of the intact fruit harvested at the same time (Figs. 4 and 5). Similar results also were obtained for mature fruit, but, as the fruit ripened, the arils became increasingly susceptible to fungal attack and the experiment could not be extended beyond 3 days. It is possible that the relatively high values of CO₂ evolution measured for the rinds could result from cutting the tissue during their preparation. Great care was taken to cause no injury to the dehisced arils, as evidenced by the fact that they produced no detectable levels of C₂H₄. This care, however, was impossible with the rinds, and the amounts of C₂H₄ they evolved were easily measurable $(1-2 \mu l/kg/hr)$. Because intact fruit at this stage of development did not evolve more than traces of C₂H₄, we concluded that the high rates of both CO₂ and C₂H₄ produced by the rinds resulted from wounding the tissue. Based on the similar rates of CO₂ evolution from intact fruit and dehisced arils, we assume that the rind tissue in situ respires at a similar rate. When rinds and arils were subjected to C₂H₄ treatment, only the rinds responded with increased CO₂ production. The respiration of the arils was unaffected by this treatment. It is therefore probable that the increased CO_2 production of intact fruit in response to C_2H_4 treatment is the result of increased respiration of the rind tissue only. That the arils were physiologically unaffected by C₂H₄ treatment also was supported by the lack of any compositional changes occurring in the juice of both intact fruit and separated arils which were treated with C_2H_4 .

The conclusion that the intact pomegranate seems to be a nonclimacteric fruit is therefore based on the following facts: 1) the mature harvested fruit depicted a continuous decline in its respiration rate; 2) little to no C_2H_4 was evolved during maturation and ripening; 3) exogenous application of C_2H_4 did not induce any observable changes in composition, although it transiently enhanced CO_2 evolution; and 4) no ripening (as indicated by compositional changes) occurred after harvest.

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