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POST-HARVEST PHYSIOLOGY AND STORAGE BEHAVIOUR OF POMEGRANATE FRUITS

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ABSTRACT

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Tested pomegranate fruits had a low respiration rate and a non-climacteric respiratory pattern. They produced trace amounts of C_2H_4 and showed no response to exogenous C_2H_4 treatments as measured by changes in skin colour, and juice colour and composition. Both CO_2 and C_2H_4 production rates increased with temperature. The Q_{10} values for respiration were 3.4 between 0 and 10°C, 3.0 between 10 and 20°C, and 2.3 between 20 and 30°C. Storage at 5°C or lower resulted in chilling injury to the fruits, and the severity of the symptoms increased with time and temperature-decrease below 5°C. Chilling-injury symptoms, which became more visible after transfer to 20°C for 3 days, included brown discoloration of the skin, surface pitting, and increased susceptibility to decay organisms. Internal symptoms were manifested as pale colour of the arils and brown discoloration of the white segments separating the arils (locular septa). Fruits held at 5°C for 8 weeks showed only a slight brown discoloration of the locular septa. Temperature during storage for up to 3 months had little effect on soluble solids content, pH, and titratable acidity of the juice.

Keywords: chilling injury; composition; ethylene; *Punica granatum* L.; respiration.

INTRODUCTION

The pomegranate (*Punica granatum* L.) belongs to the Punicaceae family. The tree is grown in many subtropical countries especially in the Mediterranean region; it is also grown extensively in India, Pakistan, Afghanistan, Iran, Saudi Arabia and in the subtropical areas of South America. All the commercial production in the United States is in California. Pomegranate fruits are mainly used fresh in the Mediterranean countries, but mostly for making juice, jelly, grenadine or wine in the United States (Hodgson, 1917; Chace et al., 1930; LaRue, 1969). In California, harvesting begins in the middle of September and the fruit must meet certain minimum maturity characteristics before harvest. These include titratable acidity (< 1.85% acid content) and colour (red colour must be equal to, or darker than, Munsell

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colour chart 5 R-5/12) of the juice. The fruit should also be free from sunburn, growth cracks, cuts, bruises and decay (Anon., 1975).

Citric acid is the predominant organic acid, and glucose and fructose are the main sugars in pomegranates (Lee et al., 1974). The common anthocyanin in pomegranate juice is delphinidin-3,5-diglucoside (Du et al., 1975). Veres (1976) reported that the juice content amounts to 45—61% of the whole fruit, or 76—85.5% expressed in relation to the weight of the arils. The juice contains 16—17.1% dry matter.

Mukerjee (1958) reported that pomegranates can be stored at 0 or 4.5°C and 80—85% relative humidity for up to 7 months, but no experimental data were presented. However, most subsequent storage recommendations appear to be based on Mukerjee's report. Lutz and Hardenburg (1968) recommended 0°C and 90% relative humidity to keep pomegranates in good condition for up to 4 months. No published data were found on CO_2 and C_2H_4 production rates or pattern, response to ethylene treatments, or response to modified-atmosphere storage of pomegranates.

The objectives of this study were to investigate (1) changes in respiration and C_2H_4 production rates and in composition of pomegranate fruits as influenced by storage temperature and duration, (2) susceptibility of pomegranates to chilling injury, and (3) the response of pomegranates to exogenous ethylene.

MATERIALS AND METHODS

Fruits. — Medium-sized (about 230 g) fruits of the 'Wonderful' cultivar of pomegranate were obtained from a packinghouse in Lindsay, California, and transported to Davis on the day of harvest. Fruits were kept at 0°C until the next morning, when they were sorted to eliminate defects, and then divided into matched lots for each experiment.

Storage conditions. — To study the effect of temperature on CO_2 and C_2H_4 production rates, 3 replicates of 5 fruits each were held at 0, 2.2, 5, 10, 20 or 30°C in jars (one replicate per jar) under a continuous flow of humidified air at flow rates which ensured that CO_2 concentration remained below 0.2%. Respiration and C_2H_4 production rates were monitored every other day using the colorimetric method (Claypool and Keefer, 1942) and a flame-ionization gas chromatograph, respectively.

To study the effect of temperature on compositional changes during storage, fruits were kept at 0, 5, 10, 20 or 30°C in jars ventilated with humidified air. At weekly intervals, 6 fruits from each treatment were divided into 3 replicates of 2 fruits each, and evaluated for external colour, juice colour, soluble solids content (SSC), pH and titratable acidity. For weight loss determinations, 10 fruits were numbered and placed in jars ventilated with a humidified (bubbled in water) air stream (relative humidity of about

95%) at 0, 5, 10, 20 or 30°C. Five additional fruits were placed in open boxes at the same temperatures to provide lower relative humidity conditions (about 85, 80, 75 and 60%, respectively). Individual fruit weight was recorded every week until the fruits were discarded.

Chilling injury studies. — To check the susceptibility of pomegranates to chilling injury, fruits were kept at -1 and 10°C in jars ventilated with humidified air for 1, 2, 3 or 4 weeks, then transferred to 20°C for 3 days to permit the development of the chilling-injury symptoms. Three replicates of 6 fruit each were used per treatment. In another test, fruits were kept at 0°C for 3, 4 or 5 weeks, then transferred to 20°C for 3 days before evaluation of the chilling-injury symptoms. In addition, fruits were evaluated for external colour, juice colour and composition (SSC, pH and titratable acidity). In a third test, 3 replicates of 6 fruits each were kept at -1, 2.2, 5 or 10°C in jars ventilated with humidified air for 8 weeks, then transferred to 20°C for 3 days. Respiration and C_2H_4 production rates were monitored during the storage period and after transfer. Quality evaluations were done at the end of the holding period at 20°C, and included external colour of the fruits as well as colour, SSC, pH and titratable acidity of the juice.

Ethylene effects. — In one test, fruits were exposed to 0, 10, 100 or 1000 p.p.m. C_2H_4 for 48 h at 20°C. Three replicates of 12 fruits each were used per treatment. Fruit quality evaluations were performed immediately following the C_2H_4 treatment and also after holding the fruits for an additional 7 days in air at 20°C. In a second test, fruits picked at different stages of maturity were subjected to 100 p.p.m. C_2H_4 at 20°C for 2, 4 or 7 days. Fruit analysis was done following the termination of each C_2H_4 treatment. Three replicates of 6 fruits each were used per treatment. The desired C_2H_4 concentration was obtained by mixing pure C_2H_4 with air using capillary tubes as flow meters (Claypool and Keefer, 1942). Fruits were held in jars under a continuous flow of air or air plus C_2H_4. Ethylene concentrations were determined using a flame-ionization gas chromatograph.

Quality evaluation. — External colour readings were taken for each individual fruit in a given lot. Two readings were taken per fruit on 2 sides using a Gardner Colour Difference Meter Model XL-23. The arils from the fruits in each replication were separated from other tissues and their juice was extracted using a hand-operated citrus squeezer. The juice was filtered through cheesecloth, and then used for measuring colour by the above-mentioned Gardner colorimeter, and for determination of SSC, pH and titratable acidity. SSC was measured with a temperature-compensated refractometer; pH with a pH meter. The diluted juice (6 g juice plus 50 ml distilled water) was titrated with 0.1 N NaOH and the titratable acidity was expressed as percent citric acid.

RESULTS

Effect of storage temperature on respiration and ethylene production rates. — Respiration rates of pomegranates stored at 0—10°C remained low (less than 8 ml CO_2/kg-h) during the 3-month storage period (Fig. 1). Respiration rate increased with temperature, except that fruits kept at 0°C exhibited a higher rate than those held at 2.2°C. At 20°C, respiration rate fluctuated during the first 20 days of storage, then increased to 18 ml CO_2/kg-h before they were discarded because of the incidence of decay after 26 days in storage (Fig. 2). Fruits stored at 30°C showed a decrease in respiration rate with time until discarded after 7 days due to decay incidence. Based on respiration rates after 1 day in storage, the Q_{10} values were about 3.4 between 0 and 10°C, 3.0 between 10 and 20°C, and 2.3 between 20 and 30°C.

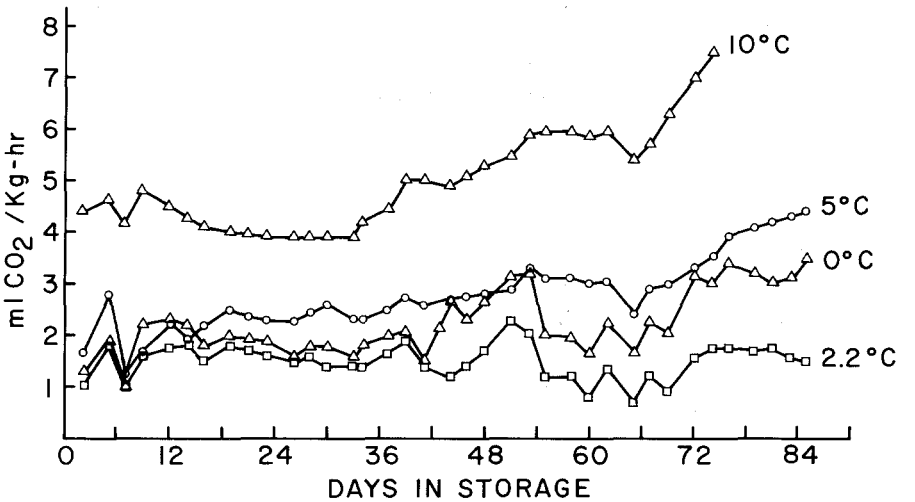

Fig. 1. Effect of storage temperatures (0, 2.2, 5 or 10°C) on respiration rate of pomegranate fruits.

Pomegranate fruits produced small amounts of C_2H_4 and the rate of production fluctuated throughout the storage period, but remained mostly below 0.1 μl C_2H_4/kg-h at temperatures of 10°C or lower (Fig. 3). Ethylene production rates were about the same for fruits held at 0, 2.2, 5 or 10°C during the first month of storage, then the rate was proportional to temperature except that fruits held at 0°C had a higher C_2H_4 production rate than those held at 2.2°C (Fig. 3). Ethylene production rates did not exceed 0.5 and 2 μl/kg-h for fruits held at 20 or 30°C, respectively, before the fruits were discarded because of decay.

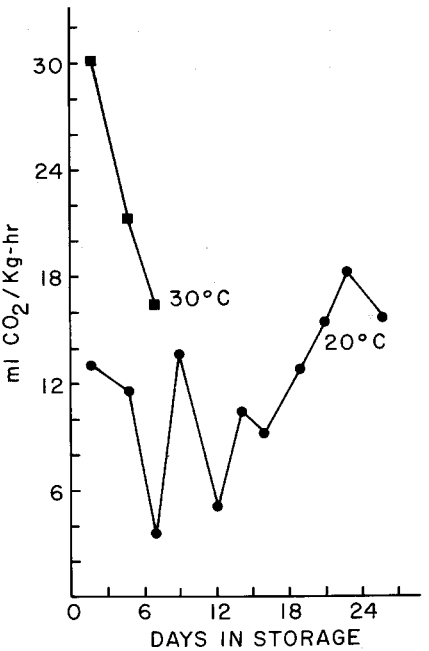

Fig. 2. Effect of storage temperatures (20 or 30°C) on respiration rate of pomegranate fruits.

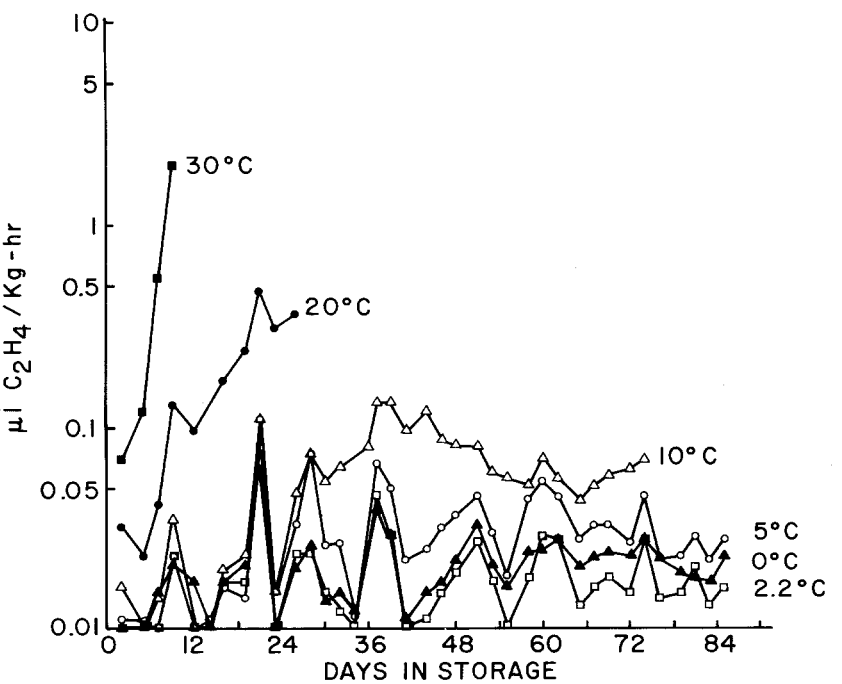

Fig. 3. Effect of storage temperatures on ethylene production rates by pomegranate fruits.

Effect of storage temperature on fruit quality. — No significant differences were found in skin or juice colour of fruits held at 0 or 5°C for up to 10 weeks, or at 10°C for up to 6 weeks, or at 20°C for up to 4 weeks (data not shown). Changes in SSC during storage at 0, 10 or 30°C for up to 10, 6 or 1 week(s), respectively, were not significantly different (Table I). Fruits stored at 5°C for 2, 3 or 5 weeks had a slightly higher SSC than non-stored fruits (evaluated at harvest), but after 10 weeks the SSC was lower. After 2 weeks at 20°C, fruits had a higher SSC than non-stored fruits. The pH values in fruits held at 0 or 5°C for 1, 2, 5, 6, 8 or 9 weeks, and at 10°C for 1, 2, 4 or 5 weeks, were significantly higher than in non-

TABLE I

Effect of storage temperature and duration on soluble solids content (SSC, %) of pomegranates

Storage time (weeks)	Temperature (°C)				
	0	5	10	20	30
0	17.5	17.5	17.5	17.5	17.5
1	17.4	17.4	17.8	17.3	17.3
2	17.8	17.9	17.9	18.1	—
3	17.6	18.0	18.1	17.5	—
4	17.2	17.7	17.9	17.5	—
5	17.4	18.0	18.1	—	—
6	17.5	17.2	17.0	—	—
8	17.4	17.6	—	—	—
9	17.2	17.3	—	—	—
10	17.4	16.7	—	—	—
LSD at 5%	NS	0.3	NS	0.3	NS

TABLE II

Effect of storage temperature and duration on pH of pomegranates

Storage time (weeks)	Temperature (°C)				
	0	5	10	20	30
0	3.72	3.72	3.72	3.72	3.72
1	4.08	4.13	4.17	4.10	3.90
2	4.03	4.08	3.92	3.87	—
3	3.80	3.75	3.77	3.82	—
4	3.77	3.85	3.93	3.98	—
5	4.10	4.23	4.00	—	—
6	3.93	3.83	3.77	—	—
8	4.02	4.17	—	—	—
9	4.07	3.97	—	—	—
10	3.60	3.60	—	—	—
LSD at 5%	0.13	0.07	0.07	0.04	0.12

stored fruits (Table II). Most pH values of stored fruits were higher than non-stored fruits. Titratable acidity (expressed as % citric acid) in stored fruits was slightly higher than in non-stored fruits throughout most of the storage period at all temperatures (Table III).

TABLE III

Effect of storage temperature and duration on titratable acidity (TA, expressed as % citric acid) of pomegranates

Storage time (weeks)	Temperature (°C)				
	0	5	10	20	30
0	1.5	1.5	1.5	1.5	1.5
1	1.4	1.6	1.8	1.9	1.6
2	1.6	1.6	1.7	1.7	—
3	1.6	1.8	1.8	1.9	—
4	1.6	1.8	1.6	1.7	—
5	1.5	1.4	1.6	—	—
6	1.6	1.5	1.5	—	—
8	1.7	1.5	—	—	—
9	1.5	1.5	—	—	—
10	1.6	1.6	—	—	—
LSD at 5%	0.1	0.1	0.1	0.1	NS

Effect of storage temperature on weight loss. — At a relative humidity of about 95%, weight loss by pomegranates stored at 0, 5, 10 or 20°C for 5 weeks was 1.0, 1.4, 1.6 and 2.7%, respectively. Weight loss reached 1.3, 2.3 and 5.8% in fruits held for 10 weeks at 0, 5 and 10°C, respectively. At 5°C, weight loss was 1.4 and 6.1% for fruits held in 95 and 75% relative humidity, respectively, for 5 weeks. Shriveling became noticeable on fruits which lost 5% or more of their weight.

Susceptibility to chilling injury. — The rates of respiration and C_2H_4 production by fruits held at -1 or 10°C for 1, 2, 3 or 4 weeks then transferred to 20°C for 3 days are shown in Figs. 4 and 5. The rates of respiration were very low (0.1—1 ml CO_2/kg-h) at -1°C and low (4—8 ml CO_2/kg-h) at 10°C. Following transfer to 20°C after 1, 2, 3 or 4 weeks of storage, an increase in respiration rate was observed, but was much larger for fruits previously held at -1°C than for those held at 10°C. For fruits transferred after 1 week, the rate of respiration increased from 0.14 to 29 ml CO_2/kg-h (about a 200-fold increase) for fruits previously held at -1°C, and from 7 to 19 ml CO_2/kg-h (about a 2.5-fold increase) for those previously stored at 10°C. Similar differences were observed for fruits held for 2, 3 or 4 weeks (Fig. 4). The increase in C_2H_4 production rates was more noticeable following transfer from -1°C than after transfer from 10°C (Fig. 5). After 3 weeks, C_2H_4

production rate increased from 0.013 to 0.095 μl/kg-h upon transfer from -1 to 20°C, and it did not change upon transfer from 10 to 20°C. Fruits stored at 10°C retained higher intensity of red skin colour than those kept at -1°C. Fruits from the -1°C treatments maintained their red juice colour better than those stored at 10°C. No significant differences were found between fruits held at -1 and 10°C for 4 weeks in their SSC, pH and titratable acidity (data not shown).

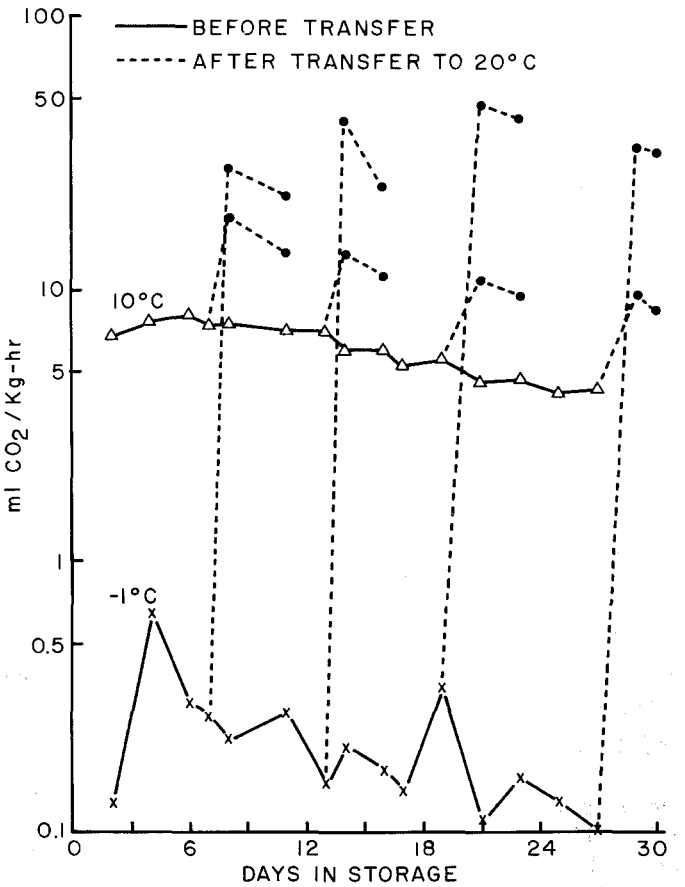

Fig. 4. Respiration rate of pomegranate fruits kept at -1 or 10°C for 1, 2, 3 or 4 weeks before transfer to 20°C.

Pomegranates held at 0°C for 5 weeks and those kept at -1 or 2.2°C for 8 weeks and then transferred to 20°C for 3 days exhibited external and internal chilling injury symptoms. External symptoms were surface pitting, skin discoloration, scald, dead skin tissues and accelerated fungal growth; *Penicillium* spp. and *Cladosporium* spp. which grow on dead tissues

were identified. Internal symptoms of chilling injury included dead tissues, brown discoloration of the white segments separating the arils (locular septa), and pale colour of the arils. Fruits kept at 5°C for 8 weeks plus 3 days at 20°C exhibited only a slight brown discoloration of the placental tissues separating the arils. No chilling-injury symptoms were noted in fruits stored at 10°C for 8 weeks. No significant differences were found among fruits held for 8 weeks at -1, 2.2, 5 or 10°C in their juice content, SSC, pH or titratable acidity (data not shown). A decrease in acidity and red colour of the juice was noted in fruits from all treatments after 8 weeks relative to the initial values. Differences in juice colour among fruits kept at -1, 2.2 and 5°C were not significant, while the juice colour of fruits held at 10°C was slightly less red after 8 weeks in storage. The external red colour of fruits stored at 5 and 10° C was maintained better than those kept at -1 and 2.2°C.

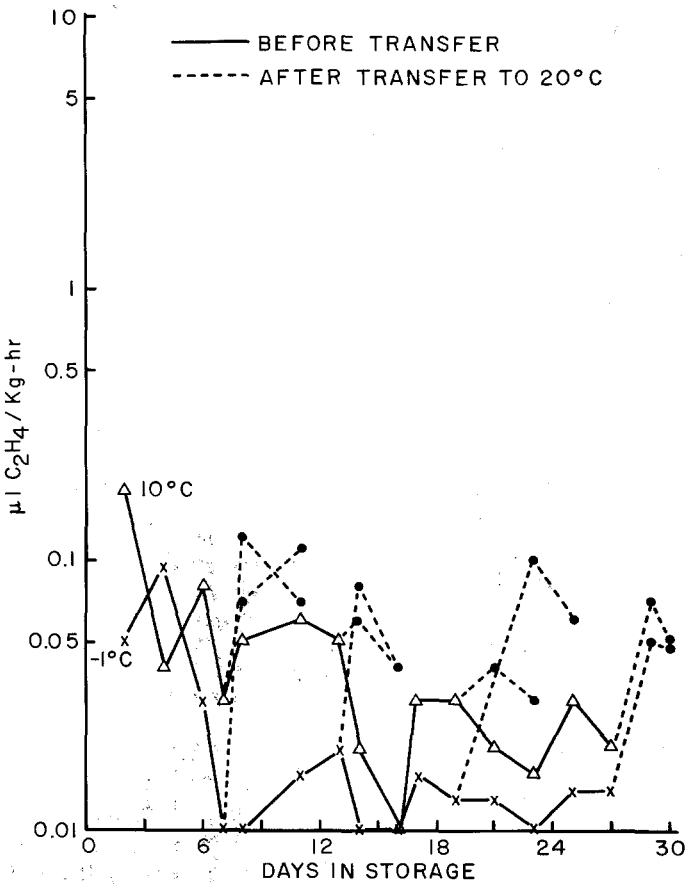

Fig. 5. Ethylene production rates by pomegranate fruits kept at -1 or 10°C for 1, 2, 3 or 4 weeks before transfer to 20°C.

Response to ethylene treatments. — Subjecting pomegranates to 10, 100 or 1000 p.p.m. C_2H_4 for 48 h at 20°C had little or no effect on their skin colour, juice colour and composition when evaluated immediately following the treatment or after an additional 7 days at 20°C in air (data not shown). Treatments with 100 p.p.m. C_2H_4 for 2, 4 or 7 days at 20°C did not significantly affect external colour, juice colour, SSC, pH or titratable acidity of pomegranates relative to those held in air for 7 days (Table IV).

TABLE IV

Effect of ethylene treatments at 20°C on colour and composition of pomegranates

Treatment duration (days)		External colour[1]			Juice colour[1]			Soluble solids	pH	Titratable acid as citric
Air + 100 p.p.m. C_2H_4	Air	Rd	a	b	Rd	a	b	(%)		(%)
0	0	26.1	38.0	17.7	1.2	18.6	1.4	16.8	3.70	1.6
2	0	27.0	33.4	19.5	1.2	15.4	1.0	16.3	3.50	2.0
2	5	28.3	29.8	18.6	1.1	16.7	1.3	16.5	3.70	1.8
4	0	29.2	32.6	20.1	1.0	12.6	0.8	16.6	3.50	1.9
4	3	32.1	24.9	20.0	0.7	10.5	0.7	16.8	3.70	1.8
7	0	27.4	33.3	19.2	0.9	11.2	0.8	16.4	3.70	1.8
0	7	27.0	32.1	20.0	1.1	11.2	0.6	16.2	3.50	2.2
LSD at 5%		4.4	7.2	NS	NS	2.9	0.3	0.2	0.04	NS

[1]Determined by a Gardner Color Difference Meter: Rd = lightness; a = redness; b = yellowness.

DISCUSSION

Based on the pattern of CO_2 and C_2H_4 production rates, pomegranate fruits are judged to be non-climacteric fruits. Both CO_2 and C_2H_4 production rates increased with storage temperature, except that the rates at 0°C were higher than 2.2°C, indicating physiological damage due to chilling injury at 0°C. The increase in respiration rate at 10 and 20°C towards the end of the storage period was probably due to the incidence of decay. Fruits held at 10 or 20°C were discarded because of decay after 75 and 26 days, respectively.

Visual and compositional quality attributes were maintained in pomegranates kept at 0 or 5°C for 10 weeks, while fruits stored at 10, 20 or 30°C were discarded after 6, 4 and 1 week(s), respectively, because of the incidence of decay. We found differences in storage life at 10°C which ranged between 6 and 12 weeks among experiments. These differences may be related to level of infection by pathogens at harvest, since these fruits were not treated with post-harvest fungicides.

Weight loss during storage increased with temperature increase and relative humidity decrease and was largely due to water loss, since the calculated dry weight loss due to respiration represented only about 9—26% (depending on temperature) of the total weight loss after 10 weeks of storage. Pomegranates are susceptible to water loss and should be kept under 95% or higher relative humidity to minimize this problem. Their apparently tough skin has numerous openings which permit free water vapour movement. The porosity of the skin was demonstrated by injecting air into fruits held under water and observing air bubbles escaping throughout their surface.

Based on the data presented here and in contrast to published information (Mukerjee, 1958), it is clear that pomegranate fruits are susceptible to chilling injury. The incidence and severity of chilling injury depend upon storage temperature and duration, as has been reported for other commodities (Lyons, 1973). The observed physiological injury, as indicated by CO_2 and C_2H_4 production at -1°C and following transfer to 20°C, is similar to that reported for chilling-sensitive cucumbers (Eaks and Morris, 1956). The minimum safe temperature appears to be 5°C if fruits are stored for up to 8 weeks. Fruits should not be held at -1°C, since symptoms of chilling injury develop at that temperature, and if kept at 0 or 2.2°C, they should be consumed immediately after removal from storage. Although no chilling injury occurred on fruits held at 10°C, the fruits decayed more rapidly at that temperature than at 5°C after 6 weeks of storage. It may be possible to store pomegranates at 10°C for longer than 6 weeks if they were treated with post-harvest fungicides for decay control. Segal (1981) reported that the peel of 'Wonderful' pomegranate fruits undergoes browning during storage at temperatures below 14°C. The difference in the minimum safe temperature between his study and ours may be related to differences in pre-harvest temperatures and cultural practices. Further studies should be aimed at identifying pre- and post-harvest factors which may aggravate or reduce incidence and severity of chilling injury on pomegranates.

Data reported here indicate that ethylene treatments have no, or very little, effect on colour and composition of pomegranate fruits. These observations are similar to those reported on other non-climacteric fruits such as strawberries and grapes. In these fruits, maturation and ripening must occur on the plant before harvest if the fruit is to attain good quality. Fruits harvested prior to ripening do not continue ripening and are of inferior eating quality.

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