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Developmental changes and postharvest physiology of tomatillo fruits (*Physalis ixocarpa* Brot.)

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ABSTRACT

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The tomatillo or husk tomato (*Physalis ixocarpa* Brot.) is a solanaceous fruit vegetable used to prepare the green sauces of Mexican cooking. Developmental changes were studied from anthesis to yellowing in fruits of cultivar 'Rendidora'. During an 8 week growth period both chlorophyll and carotene contents decreased. Sugar content increased to 7.0% due to accumulation of non-reducing sugars. Titratable acidity also increased with fruit development, reaching 1.3% at 8 weeks. Total pectin content reached a maximum (1.1%) at 6 weeks of development. The ascorbic acid content of tomatillos was low (3–4 mg $100\ g^{-1}$) and did not change during fruit development. Tomatillos may be harvested commercially from about 5 to 8 weeks of development, or when the fruits have filled the calyx (husk). The respiration rate of tomatillos was low (18–25 $\mu l\ CO_2\ g^{-1}\ h^{-1}$ at 20°C) and decreased with time in storage. Respiration rates were higher for immature than for mature and ripening fruits. Rates of ethylene production were also low (0.2–2.0 $nl\ g^{-1}\ h^{-1}$ at 20°C) for immature and mature fruits. Ripening and ripe fruits (horticulturally over-mature) showed much higher rates of ethylene production (20–40 $nl\ g^{-1}\ h^{-1}$) than developing fruits. Storage of fruits at 10°C and 20°C resulted in greater weight loss and color change than storage at lower temperatures. The freshness of the husks was also maintained at lower temperatures. Storage at 2.5°C for 3 weeks resulted in higher decay levels and surface pitting than storage at 5°C. Decay incidence was decreased by a chlorinated water wash before storage.

Keywords: fruit composition; fruit growth; husk tomato; *Physalis* spp.; postharvest physiology.

INTRODUCTION

The tomatillo, or husk tomato, (*Physalis ixocarpa* Brot. syn. *Physalis philadelphica* Lam.) is one of the important solanaceous fruit vegetables of Mex-

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ico and a minor crop in other regions of the Americas (Saray-Meza and Loya-Ramírez, 1974; Heiser, 1975). Tomatillos comprise the major component of the fresh and cooked green chili sauces used in Mexican cooking.

The tomatillo is a vigorous annual plant, spreading or erect in habit (0.3–1 m in height). It is cultivated year-round in Mexico with an estimated 16 000 ha in production (Garzon-Tiznado and Garay-Alvarez, 1979; Anonymous, 1981). Less than 50 ha of tomatillo are produced in California (Anonymous, 1990). Many 'types' and some named varieties are cultivated, producing berries which vary in size, color and flavor (Heiser, 1975; Dremann, 1985). The fruits are considered ready for harvest when they have reached maximum size, filling the husk or calyx (Saray-Meza and Loya-Ramírez, 1974), but fruits from different stages of development may be harvested and marketed together. The intensity of green color of the fruit and the freshness of the husk are quality criteria. Fruits which begin to yellow are considered horticulturally over-mature and are of low culinary quality (Heiser, 1975). Fruits of a related plant, the cape gooseberry (*Physalis pruinosa*), are consumed when the husk has dried and the berry is ripe and sweet (Tindall, 1983).

Most studies on the tomatillo have focused on genetics and breeding (Saray-Meza et al., 1978; Quiros, 1984; M.L. Roose and H. Johnson, Jr., unpublished data, 1986), plant development and cultural practices (Garzon-Tiznado and Garay-Alvarez, 1979; Cartujano-Escobar et al., 1985). We report here a study on changes in growth and composition of developing tomatillo fruits, and the physiology and quality of stored fruits.

MATERIALS AND METHODS

Plants (four rows of 60 plants each) of the cultivar 'Rendidora' were grown during the summer rainy season using normal cultural practices at the National Institute of Agricultural Research (INIA, now called INIFAP) Experiment Station in Zacatepec, Morelos, Mexico. Flowers at anthesis were tagged over an 8 week period (10 flowers on 120 plants week^{-1}), and fruits at all stages of development were harvested randomly from the plot at the same time. Fruits were weighed, husks removed, divided into three replicates of 10 fruits each per developmental stage, and then frozen at $-10°C$. Fruit pulp was subsequently analyzed for pectic components (McCready and McComb, 1952), phenolics (Joslyn and Goldstein, 1964), and sugars and pigments (Grotner, 1965) by colorimetric methods. Reduced ascorbic acid was determined in a metaphosphoric acid–acetic acid extract by indophenol dye reduction (AOAC, 1970). Titratable acid content was calculated as malic acid after titration with 0.1 N NaOH, and nitrogen content was determined colorimetrically after a micro-Kjeldahl digestion (AOAC, 1970).

For the postharvest studies, tomatillos of a purple–green fruit type (hereafter called purple tomatillo) and of 'Rendidora' were harvested in the fall

from commercial fields and experimental plots in California. Fruits were classified into the following categories. Stage (1) immature: fruits were dark green and filled one-half to three-quarters the volume of the husk; Stage (2) mature or developed, green husk: fruits were green and had filled the husk which was turgid and green; Stage (3) mature or developed, dried husk: fruits were green and had filled the husk, which had begun to dry; Stage (4) ripening: fruits were beginning to yellow; and Stage (5) Ripe: fruits were completely yellow or yellow–orange.

For measurements of respiration and ethylene production, samples of three fruits each with husks removed were placed in glass jars through which humidified (approximately 90% relative humidity) air flowed, at a rate to maintain CO_2 below 0.5%. Effluent gas samples were taken with 1 ml plastic syringes, and injected either into an infrared analyzer or into a gas chromatograph with a flame ionization detector for determination of carbon dioxide and ethylene. A static set-up was used for some fruit samples, in which they were placed individually in large plastic syringes (50 ml) and held for 1 h at 20°C before sampling (CO_2 concentration equals 0.25–0.5%). The data reported are the averages of three replicates.

Storage experiments were done with fruits placed in 0.5 ml vented polyethylene bags (approximately eight 0.5 cm holes 600 cm^{-2} area), and evaluated for shrivel, pitting and decay by hedonic scores where 1 equals none, 2 equals slight, 3 equals moderate, 4 equals moderately severe and 5 equals severe. Data are the means of three or four replicates of 10 fruits each per treatment.

RESULTS

Fruit growth and composition. – The tomatillos grew rapidly over the 8 week developmental period studied, increasing from 5 g at 2 weeks to about 60 g at 8 weeks (Fig. 1A). The proportion of fruit weight attributable to the calyx (husk) decreased steadily over the same period (Fig. 1A). Fruit shape was almost constant during development, because increases in length and diameter paralleled each other (Fig. 1B). The water content of the fruit pulp increased only slightly during development (Fig. 1C), and therefore compositional data were expressed solely on a fresh weight basis. The water content of the calyx varied considerably, increasing during the first 4 weeks of fruit development to a maximum of 80%, and then decreasing as the fruit matured and began to ripen or yellow (Fig. 1C).

The total sugar content of the pulp increased rapidly during development from 2.5% at 4 weeks to 7.0% at 8 weeks (Fig. 2A). Reducing sugars remained almost constant during this same period, indicating that the major sugar which accumulates during development is probably sucrose. Titratable acidity increased during the later stages of development and this corresponded to a decrease in pH of the fruit pulp (Fig. 2B).

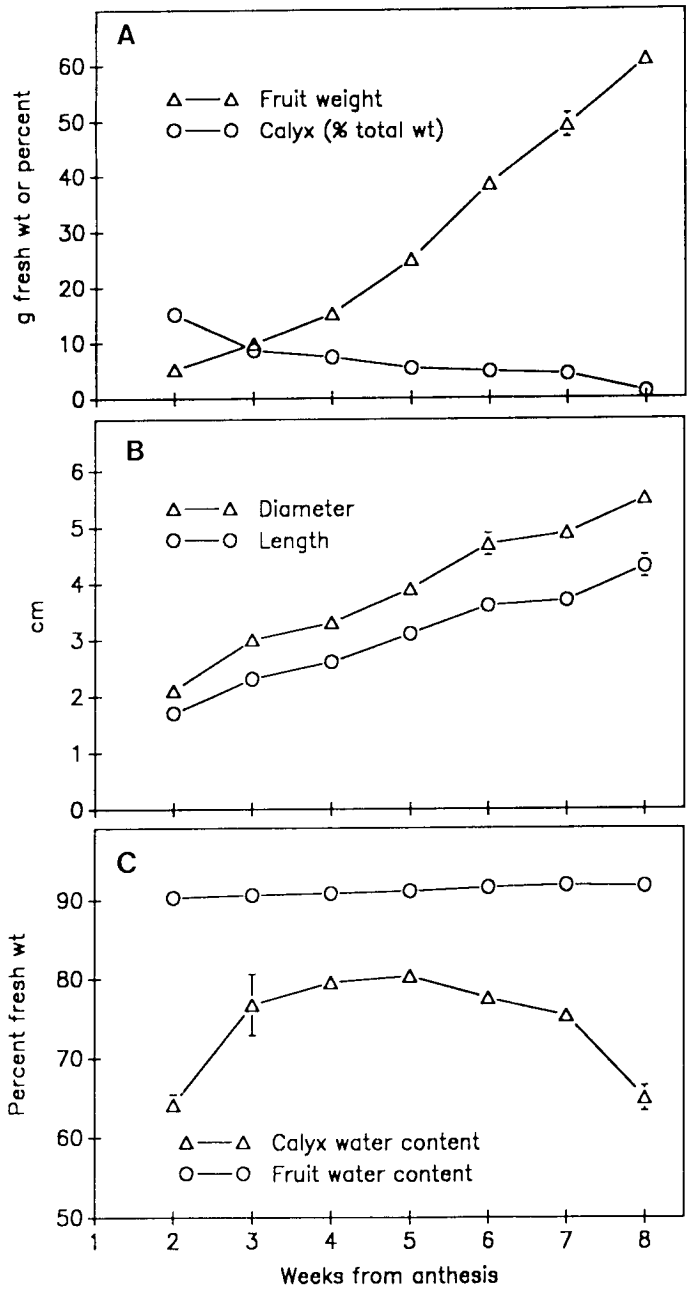

Fig. 1. Changes in fruit weight (A), dimensions (B), water content (C), and in calyx proportion (A) and water content (C) during the development of the tomatillo 'Rendidora'. Data are the averages and SD of three replicates.

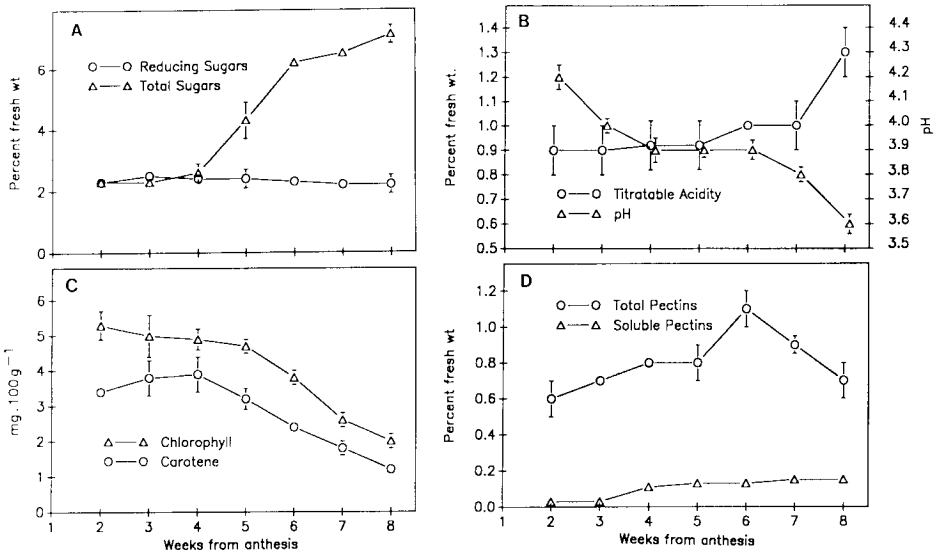

Fig. 2. Changes in sugars (A), acidity (B), pigments (C) and pectins (D) of tomatillo fruit 'Rendidora' during development. Data are the means and SD of three replicates.

TABLE I

Composition of tomatillo fruits

Constituent	Content (% fresh weight)	
	Hernández et al. (1980)[1]	Present study
Water	–	91.5
Protein ($N \times 6.25$)	1.0	< 1.0
Lipids	0.7	–
Carbohydrates	4.5	6.9
Organic acids	–	1.0
Minerals (mg %)		
Calcium	18	–
Iron	2.3	–
Vitamins (mg %)		
Carotenes	4	2.2
Ascorbic acid	2	3.5
Thiamine	0.08	–
Riboflavin	0.04	–
Niacin	1.7	–

[1]Unspecified fruit type and stage of development.
[2]Average composition of fruits of 'Rendidora' from 5 to 8 weeks of development.

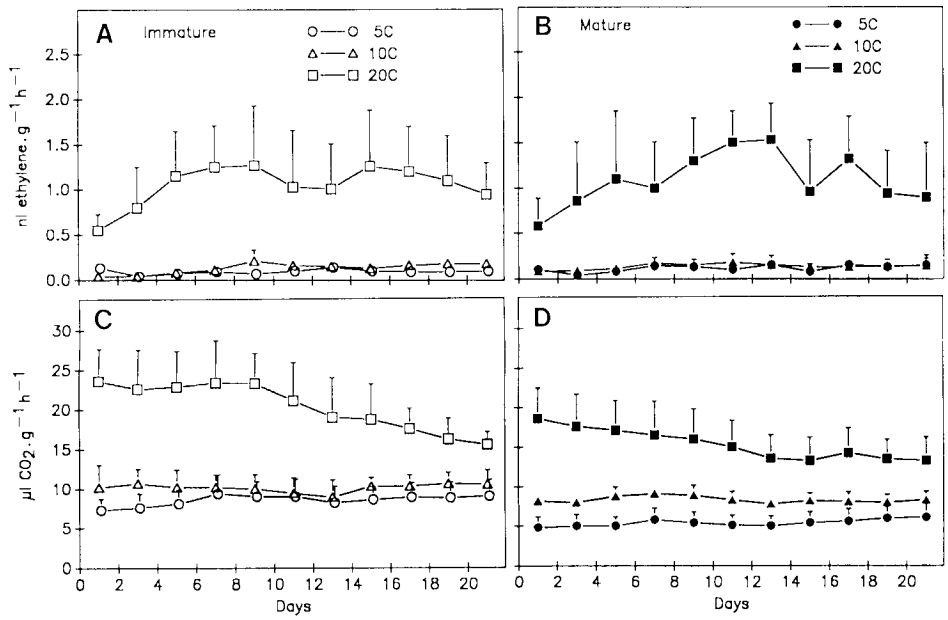

Fig. 3. Ethylene (A and B) and carbon dioxide (C and D) production rates of immature (open symbols) and mature (filled symbols) purple tomatillos stored at 5, 10 and 20°C for 21 days. Data are the means and half SD of three replicates.

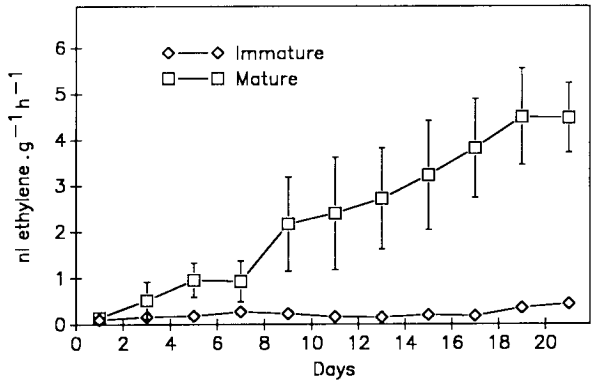

Fig. 4. Ethylene production rates of immature and mature 'Rendidora' tomatillos stored at 10°C for 21 days. Data are the means and half SD of three replicates.

The chlorophyll and carotene contents of the fruit decreased with development (Fig. 2C). Yellowing of the fruits at 8 weeks of development coincided with the lowest levels of chlorophyll and carotene, approximately 2 mg 100 g^{-1} and 1.5 mg 100 g^{-1} fresh weight, having decreased from a maximum of 5.3 mg 100 g^{-1} and 3.9 mg 100 g^{-1}, respectively.

TABLE 2

Respiration and ethylene production rates of fruits of purple tomatillo and 'Rendidora' harvested at different stages of development

	Stage of development					
	Immature (Stage 1)		Ripening (Stage 4)		Ripe (Stage 5)	
	1 day	4 days	1 day	4 days	1 day	4 days
Respiration rate (μl CO_2 g^{-1} h^{-1})						
Purple tomatillo	44±18	47±8	29±5	31±4	28±6	30±3
'Rendidora'	36±4	26±4	27±6	26±6	21±5	22±8
Ethylene production (nl g^{-1} h^{-1})						
Purple tomatillo	2±2	1±1	3±1	2±1	23±16	17±8
'Rendidora'	3±2	8±6	19±9	16±8	43±15	45±17

Measurements were made at 20°C 1 and 4 days after harvest. Data are the means and standard deviations of three replicates.

Total pectin content of tomatillos was relatively high, reaching a maximum of 1.1% at 6 weeks (Fig. 2D). Soluble pectin increased slightly during fruit development, although the percentage was still low at harvest (about 0.15%) and did not correspond quantitatively to the loss of total pectin.

Nitrogen content was analyzed and converted to protein with a 6.25 conversion factor. Estimated protein content was low and declined from 1.4% to 1.0% at 8 weeks. Phenolic compounds were present at low levels (less than 0.005%) and decreased during fruit development. The ascorbic acid content of tomatillos was low, remaining constant throughout the developmental period at 3–4 mg 100 g^{-1}.

A complete compositional analysis of the tomatillo does not exist, but from the present study and the data reported by Hernández et al. (1980) it is possible to approximate the composition of 'typical' fruits (Table 1).

Respiration and ethylene production. – Changes in the postharvest behavior of tomatillo fruits were studied at three temperatures. The respiration rates of fruits of 'Rendidora' did not differ significantly from those of purple tomatillo and data for the latter only are presented. Tomatillos had low respiration rates which remained relatively constant at 5°C and 10°C (Figs. 3C and 3D) and decreased with time at 20°C. A few of the mature fruits (Stages 2 and 3) stored at 20°C began to yellow after 3 weeks. Immature fruits (Stage 1) had higher respiration rates than mature fruits (Fig. 3). There were no significant differences in respiration rates between mature fruits with green husks and mature fruits with dried husks. Treatment of mature purple toma-

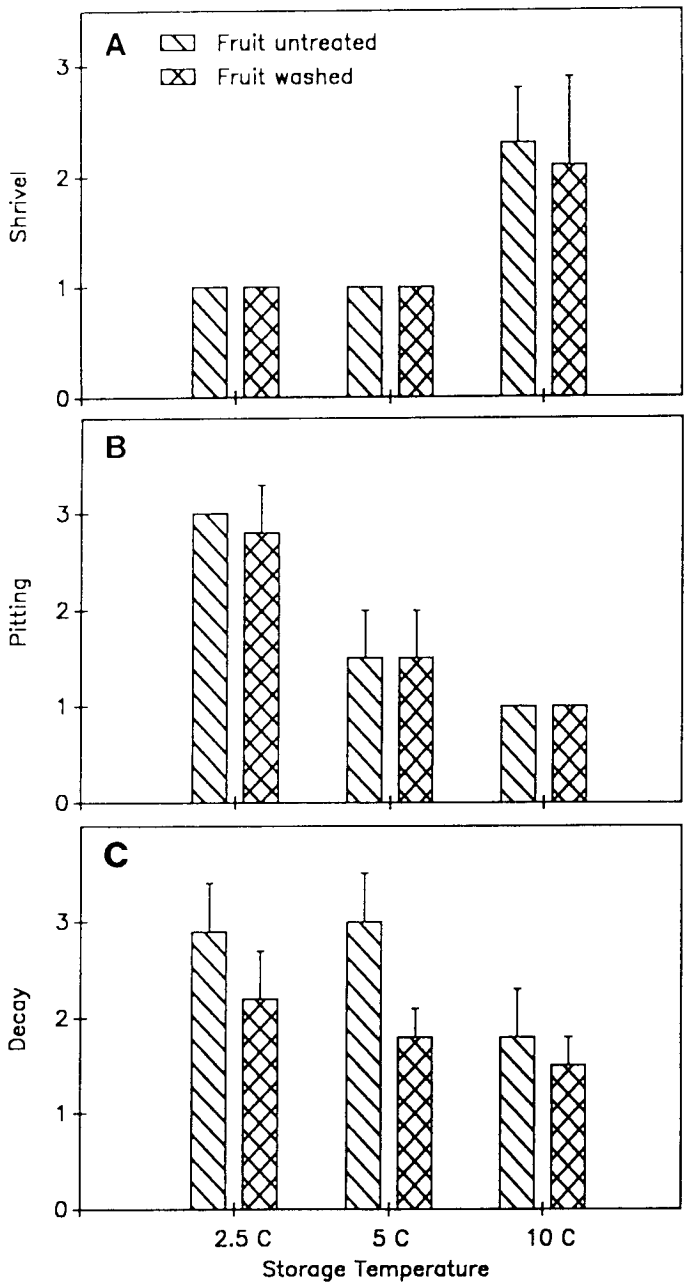

Fig. 5. Shrivel, pitting and decay scores of 'Rendidora' tomatillos stored at 2.5, 5 or 10°C for 3 weeks followed by 2 days at 20°C. Fruits were stored in vented polyethylene bags untreated or after washing with 200 ppm chlorinated water. Data are the means and half SD of four replicates. Evaluations based on hedonic scores where 1 equals none, 2 equals slight, 3 equals moderate, 4 equals moderately severe, and 5 equals severe.

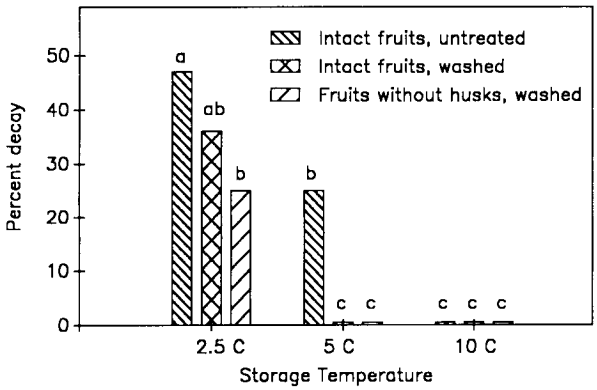

Fig. 6. Decay incidence of purple tomatillo fruits after storage at 2.5, 5 and 10°C for 1 month followed by 6 days at 20°C. Fruits were treated as described in Fig. 5. Data with different letters are significantly different at the 5% level.

tillo with 5 ppm ethylene at 10°C did not induce color change or significantly increase the respiration rate over that of fruits stored in air.

Ethylene production rates for the purple tomatillos were low and remained constant with time at 5°C (<0.1 nl g^{-1} h^{-1}) and 10°C (<0.2 nl g^{-1} h^{-1}). The production rates were similar in immature and mature fruits (Figs. 3A and 3B). The behavior of purple tomatillo may be contrasted with that of 'Rendidora' fruits in which ethylene production by the mature fruits increased with time at 10°C (Fig. 4). This increase was associated with yellowing of some of the 'Rendidora' fruits.

Table 2 compares the postharvest behavior of individual fruits of the two types studied. Respiration rates were similar and decreased as the fruits developed and ripened. Fruits of 'Rendidora' produced more ethylene at an earlier stage of development and at higher rates than fruits of purple tomatillo. Ripe (Stage 5) fruits of purple tomatillo were only partially yellow and did not lose the purple pigmentation, whereas ripe fruits of 'Rendidora' were a bright yellow color.

Quality of stored fruits. – Fruits of 'Rendidora' (late season harvest) were stored for 3 weeks in vented polyethylene bags at 2.5, 5 and 10°C. A storage temperature of 10°C plus 2 days at 20°C resulted in slight but significant fruit shrivel (Fig. 5A). Pitting was highest in fruits stored at 2.5°C (Fig. 5B). Storage at 2.5 or 5°C resulted in more decay than storage at 10°C (Fig. 5C), and washing the fruits with chlorinated water before storage reduced the decay levels. The occurrence of more decay and surface pitting at 2.5°C and 5°C than at 10°C illustrate the chilling sensitivity of the fruits.

In a similar experiment conducted with summer-harvested purple tomatillos (Fig. 6) increased decay was observed at the lower storage temperatures

after 4 weeks plus 6 days at 20°C. Improved sanitation of intact fruits or fruits without husks significantly reduced decay. The intact fruits lost 0.4, 0.8 and 2.0% of their fresh weight week^{-1} during storage at 2.5, 5 and 10°C, respectively. Fruits began to appear shrivelled with a weight loss of 7–10%. The visual appearance of the husks was maintained best when fruits were stored at 2.5 and 5°C. There were few compositional changes (soluble solids and titratable acidity) during storage at 2.5 and 5°C; some fruits stored at 10°C had increased acid levels (data not shown).

DISCUSSION

The husk tomato or tomatillo may be harvested commercially (horticultural maturity) when the fruits are well formed and have substantially filled the calyx but are still green in color, which for 'Rendidora' may be from 5 to 8 weeks after anthesis (Flores-Minutti, 1977). It is apparent that fruits harvested at different developmental stages will differ significantly in composition (especially sugar, titratable acid and pigment contents). This can be expected to affect the flavor of the tomatillos. Tomatillos contain higher levels of sugars and acids but lower amounts of carotene and ascorbic acid when compared with tomato fruits (Davies and Hobson, 1981).

The physiological activity of tomatillo fruits is relatively low and uniform. Respiration rates are higher for the more immature fruits and decrease as the fruits mature and ripen. Ethylene production rates are low for fruits during the horticulturally important stages of development. When the fruits ripen and begin to yellow (horticulturally over-mature), they may produce substantial levels of ethylene. The higher ethylene production rates and undesirable color changes associated with storage of 'Rendidora' fruits at 10°C are important commercially, since this cultivar is widely grown for its large-size fruits and high yields (Saray-Meza et al., 1978; M.L. Roose and H. Johnson, Jr., unpublished data, 1986).

The physiological behavior of solanaceous fruits is variable. The tomato (*Lycopersicon esculentum*) is a climacteric fruit although ripening mutants are non-climacteric in their behavior (Tigchelaar et al., 1978). Ripening pepino fruits (*Solanum muricatum*) were reported to have a climacteric respiratory pattern (Lizano and Levano, 1977) but non-climacteric respiratory and ethylene production patterns were found in cultivar 'Toma' (M. Cantwell, unpublished data, 1987). Bell pepper (*Capsicum annuum*) and tamarillo (*Cyphomandra betacea*) fruits have been classified as non-climacteric fruits (Pratt and Reid, 1976; Saltveit, 1977). The respiratory pattern of tomatillo fruits harvested at different stages of development was typical of non-climacteric fruits, decreasing with time in storage. Tomatillos produced high levels of ethylene at late stages of development (coincident with external color change), similar to the behavior of tamarillo (Pratt and Reid, 1976) and cape

gooseberry fruits (*Physalis pruinosa*) (M. Cantwell, unpublished, 1987). During storage, ethylene production rates of mature 'Rendidora' fruits increased, whereas those of purple tomatillo did not. The overall behavior of tomatillos is consistent with that of non-climacteric fruits (Rhodes, 1980).

Tomatillos are frequently handled and marketed under ambient conditions, and the husks are often dried and broken, adhering to the sticky fruit surface. The recommendation for postharvest handling of tomatillos is storage from 13 to 15°C (McGregor, 1987). Under such conditions, the fruits may change in composition, and the visual quality of the fruit and husk will decrease due to dehydration. Low temperature storage (5–10°C) maintains the fresh appearance of the calyx, but probably needs to be combined with improved sanitation since molds may develop on the surfaces of the fruit and husk under higher humidity conditions. Increased decay and pitting after storage at 2.5°C and 5°C for 3 weeks indicate the chilling-sensitive nature of tomatillos (Jackman et al., 1988; Saltveit and Morris, 1990).

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