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CHARACTERIZATION OF TOMATO RIPENING PROCESS AS INFLUENCED BY INDIVIDUAL SEAL-PACKAGING AND TEMPERATURE

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Accepted for Publication February 2, 1987

ABSTRACT

Tomatoes were individually seal-packaged and ripened at two temperatures, 12 and 21° C. Both the temperature and seal-packaging delayed the tomato ripening process. The delay in ripening due to seal-packaging occurred prior to the 'turning' and 'pink' USDA color maturity stage when stored at 21° C and 12° C, respectively. Lower concentrations of lycopene were associated with lower chroma values in seal-packaged fruits. Both temperature and seal-packaging prolonged the ripening period but did not affect the firmness values at various color stages of tomatoes.

INTRODUCTION

Tomatoes remain living organisms during ripening like other fresh fruits and vegetables. Tomato quality changes continuously during ripening due to transpiration, evaporation and other physiological and chemical reactions. Extending shelf-life of tomatoes by packaging has been observed using sealing tomatoes inside polyethylene films (Duan and Gilbert 1974; Okubo 1975; Saguy and Mannheim 1975; Kawada 1981) and several different types of polymeric films (Ayres and Pierce 1960; Geeson *et al.* 1985). In film packaged tomatoes, respiration causes an increase in carbon dioxide content and a decrease in oxygen content inside the package. These gas composition changes may be beneficial providing the same effect as controlled atmosphere storage or detrimental in terms of the risk of anaerobic respiration and carbon dioxide injury (Parsons *et al.* 1970). Individual packaging (seal-packaging) of tomatoes, another approach for tomato packaging, was suggested by Ben-Yehoshua (1985) to substitute for air transport

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by marine shipment. According to Ben-Yehoshua (1985) the seal-packaging method prevented an increased risk of a phytotoxic atmosphere having excessive ethylene and carbon dioxide and insufficient oxygen.

Lycopene synthesis during ripening of tomatoes has been considered to be the principal factor in formation of surface color (Meredith and Purcell 1966; Thompson *et al.* 1965). Garrett *et al.* (1960) reported surface color to be a major factor in marketing of fresh tomatoes. Different methods to assess the color of tomato fruit has been described by Hobson *et al.* (1983). Recent studies have indicated that the consumer preference for fresh tomatoes is highly correlated to the surface color and firmness of tomatoes (Beattie *et al.* 1983; Jordan *et al.* 1985; Resurreccion and Shewfelt 1985). It has also been demonstrated that firmness of tomatoes is highly correlated to the surface color (Gormley and Egan 1978).

The objective of this study was to determine the effect of physiological maturity on the quality of individually seal-packaged tomatoes.

MATERIALS AND METHODS

Green tomatoes (Ohio cv. 'Flora-Dade') were obtained from Atlanta Terminal Market. The tomatoes were sorted for size, color and physical damage followed by dipping in 100 ppm of 'Benlate' for 30s to reduce the microbial load. The tomatoes were then divided into two groups — control and seal-packaged. The tomatoes in the seal-packaged group were individually sealed in D-955 polymeric film (0.6 mil thick) obtained from Cryovac Division of W.R. Grace & Co., Duncan, SC. Sealing was accomplished with a 1913 GSM Bestronic sealer (Bessler, Florham Park, NJ), by passing through a T14-8-D Bestronic shrink tunnel for 15s at 177° C. The gas transmission rates for oxygen, carbon dioxide, and ethylene for the D-955 film are 6.8, 14.6 and 11.8 1/24h/sq m (@ 73°F and 0% RH, 1 atm), respectively; and 0.94 g/24h/100 sq in (@ 100° F and 100% RH) for water vapor. Tomatoes were subjected to two ripening temperatures of 12 and 21°C (relative humidity in the storage room varied from 60 to 70%). The six USDA color maturity stages for grading fresh tomatoes are 'green', 'breakers', 'turning', 'pink', 'light-red' and 'red'. When a majority of tomatoes in each group met the breaker stage requirements, the breakers fruit were selected for further analysis and the remainder discarded. The same procedure was followed for the other stages. At each color stage five tomatoes were randomly chosen for objective measurements. The Hunter color values (L, a, b) were determined using Gardner XL-845 colorimeter (Pacific Scientific, Bethesda, MD). Color values were obtained by averaging instrument readings at four points on the circumference and four locations on the blossom end.

Huge angle, chroma (ΔC) and total color difference (ΔE) values were calculated from L, a, b measurements as follows:

$$\text{Hue angle} = \tan^{-1}(b/a)$$

$$\Delta C = [(a - a_0)^2 + (b - b_0)^2]^{1/2}$$

$$\Delta E = [(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2]^{1/2}$$

where, subscript $_0$ corresponds to Hunter color values of a standard color plate.

Firmness of each tomato was measured with a puncture probe (11.1 mm) penetrating to a depth of 7.9 mm using an Instron Universal Testing Machine (Model 1122, Canton, MA) operated at cross head speed of 10 mm/min, chart speed of 20 mm/min and 10 kg full scale load. Average of two maximum force recordings were.taken at two diametrically opposite positions on the circumference of each tomato. The weight of tomatoes was measured with accuracy of ±0.01g using Sartorius Balance (Model 1264 MP, Brinkmann, Westbury, CT). The carotenoid and lycopene contents were measured by Hewlett Packard 8451A Diode Array spectrophotometer (Avondale, PA) using the method described by Zscheilė and Porter (1947). Ethylene evolution rate was detected by placing a 2 gram disk (10 mm in diameter) of tomato pericarp tissue in a 15 mL air tight vial and after six hours the ethylene content was measured using a Hewlett-Packard gas chromatograph (Model 5790A, Avondale, PA) with hydrogen flame ionization detector and aluminum column packed with aluminum oxide and operated at 90°C oven temperature with He as the carrier gas.

Statistical analyses on data were performed using GLM and Duncan's Multiple Range Test procedures of Statistical Analysis System (SAS 1982).

RESULTS AND DISCUSSION

Delay in Ripening Rate

Both the temperature and the packaging treatment significantly affected the time required to reach each USDA color maturity stage (Table 1). Seal-packaged tomatoes stored at 12°C required the longest time to reach each maturity stage (Fig. 1). Seal-packaging delayed the ripening from the breaker to the red stage by three days, at both 12°C and 21°C. At 12°C the delay in ripening due to seal-packaging occurred prior to the pink stage, whereas at 21°C it occurred prior to the turning stage. No delay in ripening was observed at either temperature beyond the pink stage of maturity. Shewfelt *et al.* (1986) suggested that individual seal-packaging might provide a means of delaying ripening at the pink stage or beyond to allow harvest of fruit at a later stage of flavor development. These data suggest that individual seal-packaging will not delay ripening of tomatoes packaged after

Table 1. Significant effect of main factors (storage temperature, TEMP; packaging methods, PACK; USDA color classifications, COLOR) and their interactions on various quality and physical parameters associated with storage of tomatoes

Source	Hunter color parameters				Lycopene	Ethylene	Firmness	Percent Weight Loss	ß-Carotene	Days[a]
	Lightness L	Hue Angle A	Color Difference ΔE	Chroma ΔC						
TEMP	–	–	–	**	–	*	–	–	*	**
PACK	–	–	*	*	**	**	–	**	–	**
COLOR	**	**	**	**	**	**	**	**	**	**
TEMP*PACK	–	–	*	*	–	*	–	–	**	–
TEMP*COLOR	–	–	–	–	**	**	–	–	**	**
COLOR*PACK	*	–	*	**	*	**	–	**	**	*
COLOR*TEMP*PACK	–	–	–	–	–	*	–	–	*	–

– Not significant
* Significant at 5% level ($P < 0.05$)
**Significant at 1% level ($P < 0.01$)

[a]The time (days) required to reach each USDA color maturity stage

the turning stage. In addition, Kavanagh *et al.* (1986) has shown that flavor development in 'Flora-Dade' tomatoes is highest in fruit harvested at the breaker stage. Ben-Yehoshua *et al.* (1985) reported that in oranges the resistance to mass transport of oxygen increased about three fold due to seal-packaging. Delay in ripening of seal-packaged tomatoes may be attributed to the increase in oxygen resistance.

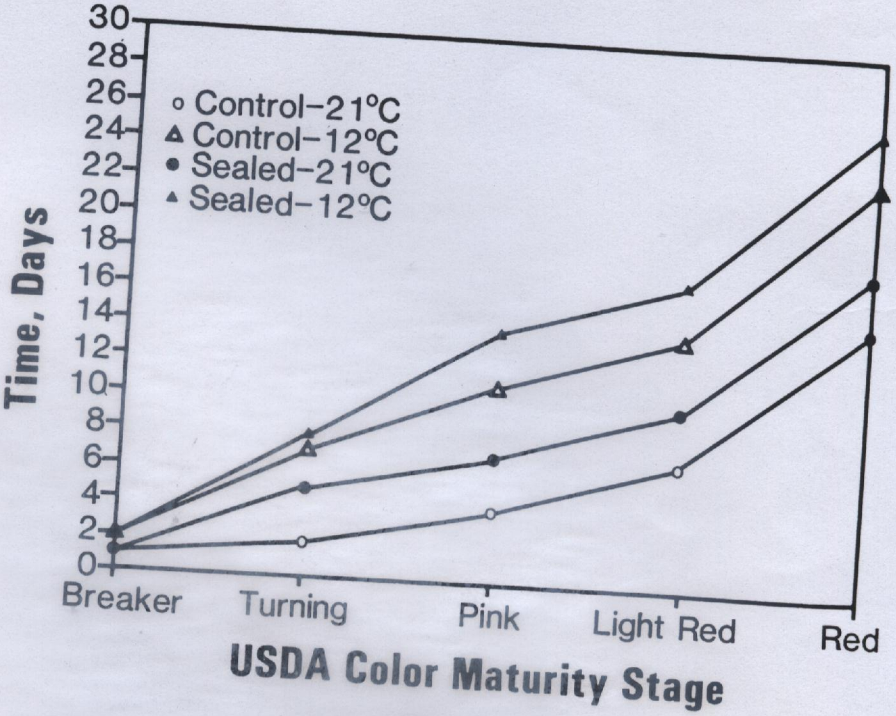

FIG. 1.
EFFECT OF SEAL-PACKAGING ON THE RIPENING PROCESS OF TOMATOES STORED AT 12°C and 21°C

Hunter Color Values, β-Carotene and Lycopene

The Hunter color values of the surface of tomatoes corresponding to the five USDA classifications are listed in Table 2. The interaction effect of storage temperature and packaging treatment on chroma values is significant (Table 1). Seal-packaged tomatoes exhibited lower chroma development than the control samples (Table 3). The higher storage temperature resulted in more chroma development as expected. Temperature did not have significant effect either on lycopene content or color difference values but the effect of packaging treatment on lycopene content was found to be significant (Table 1). Seal-packaged tomatoes

Table 2. Hunter color parameters* for tomatoes at various USDA color stages

Color Stage	L	a	b	Hue Angle	a/b Ratio	Chroma	Color Difference
Breaker (≤10% red)	46.5 ±2.7	-3.5 ±2.5	17.3 ±2.1	101.1 ± 7.9	-0.2 ±0.1	17.8 ±2.2	5.5 ±2.1
Turning (10-30% red)	44.9 ±2.4	5.4 ±4.0	17.5 ±1.9	72.9 ±12.7	0.3 ±0.2	18.7 ±1.7	16.9 ±4.1
Pink (30-60% red)	40.7 ±2.8	16.5 ±4.1	15.3 ±1.9	43.4 ± 8.6	1.1 ±0.3	22.7 ±3.0	28.7 ±4.5
Light-Red (60-90% red)	38.4 ±2.4	21.2 ±4.7	14.4 ±1.9	34.9 ±6.9	1.49±0.4	25.8 ±4.1	34.3 ±5.1
Red (≥90% red)	32.4 ±1.9	28.2 ±2.6	11.6 ±1.5	22.5 ±3.1	2.45±0.4	30.5 ±2.5	43.1 ±4.1

*Mean values for 20 tomatoes

accumulated less lycopene with lower chroma values than the control (Table 4). At the light-red stage, seal-packaged tomatoes were found to have particularly lower lycopene and chroma values than the control compared to the corresponding values at other color stages.

Table 3. Effect of storage temperature and packaging on the chroma values*

Temperature	Control	Seal-Packaged
12°C	23.4	20.7
21°C	25.2	24.1

*Mean of 25 tomatoes from Breaker to Red color stage

Table 4. Comparison of lycopene, color difference, chroma and percent weight loss values of control (C) and seal-packaged (S) tomatoes at various USDA color stages

Color Stage	Lycopene µ/g tomato		Color Difference		Chroma		Weight Loss %	
	C	S	C	S	C	S	C	S
Breaker	1.0	0.9	5.8	5.2	18.0	17.6	0.93	0.29
Turning	3.1	2.5	17.8	16.0	18.8	18.6	1.70	0.44
Pink	8.4	7.0	27.4	30.4	21.9	23.9	2.88	0.48
Light Red	13.2	7.3	36.9	32.2	27.9	24.3	3.57	0.60
Red	26.1	23.1	44.4	40.8	31.4	28.9	7.10	0.96

Each value here is a mean of 10 tomatoes stored at two temperatures (12°C and 21°C)

The correlation coefficients between various objective color parameters and lycopene content are given in Table 6. The tomato color values presented by a/b ratio had the highest correlation (0.92) with lycopene.

The β-carotene content during ripening of tomatoes at various color stages for control and seal-packaged tomatoes stored at 12 and 21°C are illustrated in Fig. 2. β-carotene content reached peak concentration prior to full ripeness for both sealed and control tomatoes (Fig. 2). Similar findings have been reported in the literature (Meredith and Purcell 1966; Rabinowitch *et al.* 1975 and Watada *et al.* 1976). A decline of β-carotene concentration was noted at the light-red color stage for tomatoes stored in 21°C. For tomatoes stored at 12°C, the decline of β-carotene concentration occurred at the pink color stage (Fig. 2).

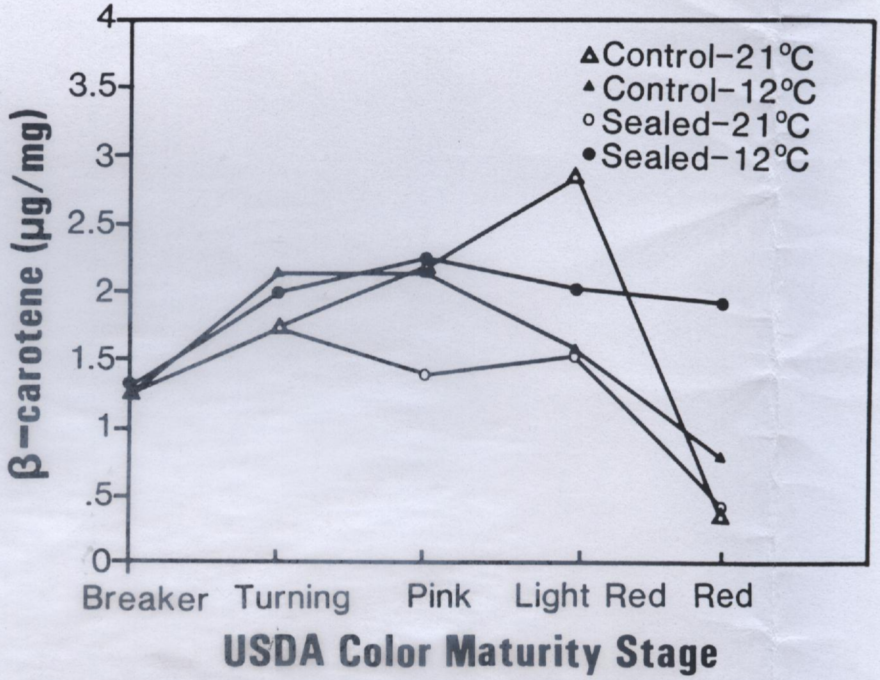

FIG. 2.
CHANGES IN β-CAROTENE CONCENTRATIONS IN CONSTANT AND SEAL-PACKAGED TOMATOES DURING RIPENING WHEN STORED UNDER TWO TEMPERATURES (12 AND 21°C)

Weight Loss

Ripening temperature had no significant effect on weight loss (Table 1), however, seal-packaging significantly reduced weight loss due to transpiration during storage (Table 4). The loss of moisture in seal-packaged tomatoes was negligible ($<$ 1%) during the whole ripening process (i.e., through all color stages) whereas the control lost more than 7% of moisture. Similar results have been documented in other fresh commodities (Ben-Yehoshua *et al.* 1979; Ben-Yehoshua *et al.* 1983; Anzueto and Rizvi 1985 and Purvis 1983). Loss of water from tomatoes not only affects the appearance but also impairs their juicy quality. It was observed (data not presented) that tomatoes did not show a noticeable shrinkage until weight loss greater than 5% had occurred. In spite of prevention of moisture loss by seal-packaging, the high relative humidity in the micro-atmosphere of the seal-packaged tomatoes may encourage fungal spoilage (Geeson *et al.* 1985). Ben-Yehoshua (1983) suggested that the effect of seal-packaging on keeping quality of fresh commodities was due to the water saturated atmosphere in the sealed enclosure around the commodity. Reducing the microbial load on tomatoes prior to seal-packaging can significantly improve their keeping quality.

Firmness

Lower temperature and seal-packaging prolonged the ripening period but did not alter significantly the firmness values at various color stages of tomatoes. Firmness decreased with ripening (color development) of tomatoes (Table 5). The firmness of tomatoes has been demonstrated to highly correlate with a/b ratio (Gormley and Egan 1978). The correlation coefficients between the firmness values and Hunter color parameters L, a/b and hue angle were found to be 0.87, −0.87 and 0.85, respectively (Table 6). The correlation coefficient between firmness and lycopene content was −0.83 (Table 5). In a previous preference study Resurreccion and Shewfelt (1985) noted that firmness was one of the principal factors associated with quality of tomatoes.

Table 5. Firmness values of tomatoes at various USDA color stages

Color Stage	Firmness (kg force)
Breaker	6.01^{a*}
Turning	4.99^{b}
Pink	4.29^{c}
Light Red	3.75^{d}
Red	2.68^{e}

*Values within column followed by different letters are significantly different at 5% level using Duncan Multiple Range Test

Table 6. Correlation coefficient values between L (Lightness), lycopene, a/b ratio, hue angle, firmness and chroma

	L	Lycopene	a/b Ratio	Hue Angle	Firmness	Chroma
L	1.00	-0.91	-0.94	0.87	0.87	-0.86
Lycopene		1.00	0.92	-0.80	-0.83	0.86
a/b Ratio			1.00	-0.95	-0.87	0.90
Hue Angle				1.00	0.85	-0.83
Firmness					1.00	-0.83
Chroma						1.00

All coefficients were significant at 1% level

Ethylene Evolution

The ethylene evolution rate at various stages during ripening of tomatoes is shown in Fig. 3. Ethylene evolution reached maximum value much earlier at higher storage temperature (21°C). Seal-packaged tomatoes had lower ethylene evolution rate than the control. For the control, tomatoes stored at 12°C, the ethylene evolution rate increased and reached the maximum at light-red color stage while the similar tomatoes stored at 21°C rapidly reached the maximum evolution rate at the turning stage. Since ethylene is involved in ripening of fruits and vegetables, the ethylene evolution rate in tomato pericarp could be regarded as a ripening rate indicator (Edwards *et al.* 1983). The ripening rate after light-red color stage reduced considerably as the ethylene evolution rate declined beyond the light-red color stage.

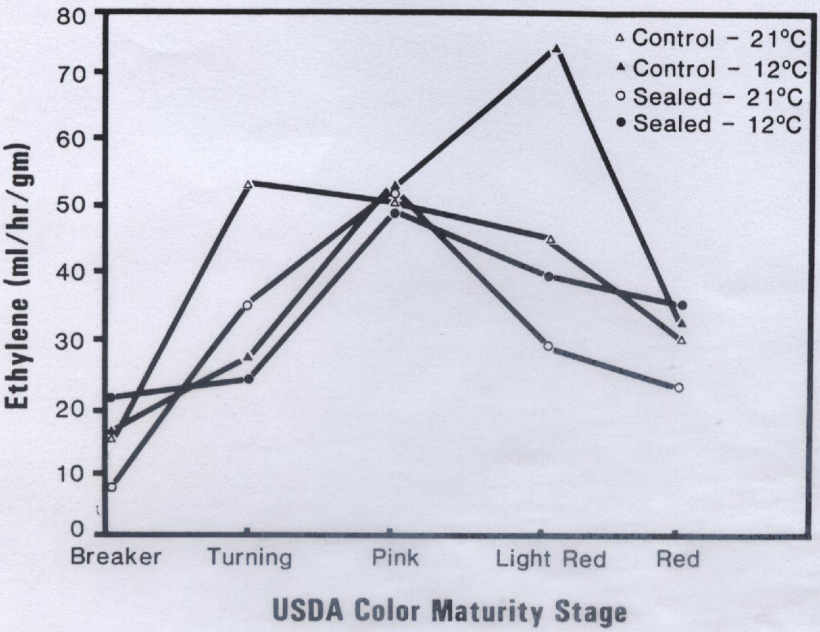

FIG. 3.
CHANGES IN ETHYLENE EVOLUTION RATE OF CONTROL AND SEAL-PACKAGED TOMATOES DURING RIPENING WHEN STORED UNDER TWO TEMPERATURES (12 AND 21° C)

SUMMARY AND CONCLUSIONS

To delay ripening rate during tomato storage, the results imply that tomatoes must be sealed prior to turning and pink stages of maturity when stored at 21° C and 12° C, respectively. No delay in ripening was observed at either temperature beyond the turning color stage. Seal-packaging of tomatoes will result in a lower accumulation of lycopene during ripening.

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