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# Quality Comparisons of Tomatoes Irradiated with Light, Treated with Ethylene, and Stored in Darkness

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**Abstract**: Quality characteristics of tomatoes irradiated with light (red light or far-red light followed two days later with a red light treatment), treated with ethylene, and stored in darkness were evaluated by subjective sensory and objective physical and chemical evaluations. Overall and individual liking evaluations and sensory evaluations were made by an untrained panel of eighteen people. A ranking of treatments for consumer (panelist) acceptability was also conducted by the panel. Physical and chemical evaluations included surface color measurement (L*, a*, and b*), mechanical puncturing (firmness), soluble solids content (SSC), titratable acidity (TA), and tomato juice pH.

Sensory data showed that outside color, inside color, and flavor of tomatoes treated with red light (R) and far-red light/red light (FR/R) were scored significantly higher than those of tomatoes treated with ethylene and those kept in darkness. The L* values for tomatoes treated with R and FR/R were lower (more darkening) than those for tomatoes treated with ethylene and those stored in darkness. Tomatoes treated with FR/R had the highest a* values, followed by those irradiated with R, treated with ethylene, and kept in darkness, respectively. Sensory values for firmness were similar for tomatoes treated with R, FR/R, and ethylene. Treatments had no significantly different effects on sweetness and acidity. There were no significantly different effects between treatments for pH, SSC, TA, and SSC/TA. From observations made during the study, it was suggested that R irradiation stimulated red color development in tomatoes after it had been delayed by FR irradiation. Consumer acceptability for tomatoes with either R or FR/R treatment was significantly higher than that for tomatoes treated with ethylene or stored in darkness. Panelists' overall liking scores correlated well with all sensory variables except acidity, and also correlated highly with inside color, flavor, and sweetness ($P<0.001$). Overall liking versus flavor had the most pronounced relationship ($r = 0.78$, $P<0.001$).

**Keywords:** Tomato, Light, Irradiation, Sensory Evaluation

## Introduction

Tomato is a world-wide cultivated plant, which is the focus of a large agricultural industry. In the United States, fresh tomato consumption has increased from less than 5.0 kg in 1979 to more than 6.8 kg per person in 1989 (How, 1992). Color and appearance, flavor, and texture are key factors affecting consumer purchase preferences when selecting tomatoes (Schutz et al., 1984). Texture or firmness is dependent on structure of the skin, the fruit wall, the amount of locular jelly, and the stage of ripeness (Morris and Kader, 1978). A tomato-like flavor, a sensory attribute that confers a unique fruit flavor, is highly preferred by consumers and is an important factor in the acceptance of the tomato. Flavor of the tomato is established by the relative amounts of various volatile compounds that impart aroma and stimulate the taste sensations such as sweetness and sourness. The red color of tomatoes is due to lycopene, the main red pigment of the tomato, which increases steadily during ripening.

The highest quality of fresh market tomato can be obtained through vine ripening (Bisogni et al., 1976; Watada and Aulenbach, 1979). The flavor is especially high when tomatoes are picked at the table-ripe stage (Kader et al., 1977). However, vine-ripened tomatoes are easily damaged and do not have the shelf life required for transportation and distribution through the market system. Therefore, most fresh market tomatoes sold in supermarkets are harvested at the mature-green or breaker stage of maturity and are ripened during marketing operations. Various postharvest technologies have been applied to control the shelf life of fresh tomatoes. Controlled atmosphere (CA) or modified atmosphere (MA) storage involves the replacement of environmental oxygen with inert gases resulting in low concentration of $O_2$ around the tomatoes in storage. The action of CA or MA is a delay in ripening along with associated biochemical and physical changes involving reduction of respiration and ethylene evolution rates and softening (Bhowmik and Pan, 1992; Yang and Chinnan, 1987). However, when CA or MA

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technology is misused, it can prevent desirable ripening, induce severe physiological disorders, and cause an increase in decay. Such misuse is easily incurred, because even closely related products or even different cultivars of the same fruit have specific and so far unpredictable tolerances for low $O_2$ and/or high $CO_2$ concentrations (Lipton, 1975).

Modified atmosphere packaging (MAP) has been recognized as a potential method to improve shelf life of fresh fruits and vegetables (Anzueto and Rizvi, 1985; Nakhasi et al., 1991). That is, when commodity and film permeability characteristics are properly matched, an optimum micro-atmosphere for the produce can be passively created within a sealed package through consumption of $O_2$ and production of $CO_2$ by respiration. However, improper packaging materials can cause extreme imbalances in $CO_2$ and $O_2$ resulting in detrimental effects such as off-flavor and off-odor (Shamaila et al., 1992).

Ethylene treatment is another postharvest technology, which has been applied to induce ripening of fruits and vegetables. Generally, ethylene is considered as a plant hormone, which affects the mechanism controlling plant growth and development. It has long been established that ethylene advances the onset of fruit ripening. Currently, a common commercial practice is to apply ethylene in the final marketing stages to promote faster and more uniform ripening of fruits such as green bananas and tomatoes. The use of ethylene for initiating (managing) fruit ripening has provided a capability for tomatoes' recent market advances.

There is, however, significant consumer dissatisfaction with these "supermarket" tomatoes. Many consumers believe that ease of shipping has taken precedence over eating quality both in the development of new plant cultivars and in fruit handling procedures. It appears that quality problems with tomatoes, especially flavor, are related to time of harvest, postharvest treatments, etc. As suggested by Kader et al. (1978) and Paz et al. (1981), the commercial practice of ethylene application to harvested tomatoes at the mature-green or breaker stage of maturity has no effect on the enhancement of fruit flavor or nutritional value compared to room-ripened fruits without supplementary ethylene. Many consumers have indicated that they would pay more for premium-products such as vine-ripened tomatoes (Bruhn et al., 1991). Thus, new postharvest technology, which can improve quality of market tomatoes, is desirable.

During tomato ripening, color change can be enhanced by red wavelengths of light or inhibited by far-red wavelengths of light since carotenoid biosynthesis is meditated by photoreversible phytochrome, a photoreceptor (Khudairi and Arboleda, 1971; Thomas and Jen, 1975). Hence, there is the possibility that light energy applications can be used as an alternative to current postharvest use of ethylene to manage tomato ripening.

Lee et al. (1996) investigated light quality, irradiance, and irradiation time for red and far-red light (R and FR) required to induce or delay color development in tomatoes during ripening. They suggested that even a few minutes of light application affects the phytochrome-mediated carotenoid biosynthesis. This paper is a presentation of the sensory evaluations associated with that study. The objectives of this study were to: (1) Compare sensory characteristics of tomatoes irradiated with R and FR/R, treated with ethylene, and stored in darkness. (2) Determine if tomato ripening delayed by 3 minutes of FR irradiation can be stimulated when followed within two days with 3 minutes of R irradiation. (3) Compare consumer acceptability characteristics of tomatoes irradiated with R and FR/R, treated with ethylene, and stored in darkness. (4) Develop objective relationships between overall liking and individual sensory variables.

## Materials and Methods

### 1. Experimental Procedures

Mature-green tomatoes were hand-picked randomly from 'Mountain Pride' cv. (*Lycopersicon esculentum* Mill.) plants that were grown over plastic mulch by a commercial grower (Robertson Brothers Farm, 707 Pumpkintown Road, Pumpkintown, SC). Fruits were immediately transported to the laboratory and stored in darkness at 22℃ and 70% RH. After two days of storage, tomatoes which had reached the breaker stage of maturity, were selected by comparison with the USDA standard color chart (USDA, 1975). These breaker stage tomatoes were sorted for uniform size with no physical defects. Test tomatoes were removed from dark storage, treated, and immediately placed in an uninterrupted dark storage maintained at 23℃ and 85% RH. Treatments were as follows:

(1) FR/R: far-red light irradiation (3 min) - 2 days of dark storage -red light - irradiation (3 min) - 6 days of dark storage (Note: the FR treatment was applied two days ahead of other treatments so that all samples would be available for sensory evaluation at the same time).

(2) R: red light irradiation (3 min) - 6 days of dark storage.

(3) Ethylene ($C_2H_4$): ethylene exposure for 1 day in darkness - 5 days of dark storage without ethylene.

(4) Dark: dark storage from time of sorting without any other treatment.

FR/R test tomatoes were placed with the blossom-end up on a shelf inside the far-red light (700 to 800 nm) irradiation chamber (Lee et al., 1996) so as to receive an irradiance of 38.90 W/m$^2$ for 3 minutes. After irradiation, the tomatoes were returned to dark storage in an environator, which was maintained at 23℃ and 85% RH. Two days later, these FR irradiated tomatoes were withdrawn from dark storage and positioned on a self inside the red light (600 to 700 nm) irradiation chamber (Lee et al., 1996). Red light (R) exposure was for 3 minutes with an irradiance of 15.37 W/m$^2$. After the R treatment, these tomatoes were immediately returned to the environator for six days of storage in darkness.

At the same time of the R irradiation treatment of FR/R samples, other treatments were carried out. Thirty tomatoes from the original field lot, which had reached the breaker stage of maturity, were selected and randomly sorted into three groups of ten each. One group was immediately moved to storage in the environator for 6 days of dark storage. Another group of ten tomatoes was irradiated with red light (600 to 700 nm) for 3 minutes under an irradiance of 15.37 W/m$^2$ and then moved to the environator for six days of storage in darkness.

The remaining ten breaker-stage tomatoes were treated with ethylene. Reid (1992) suggested that an ethylene concentration of 100 ppm is sufficient to speed up the ripening process of fruit. Therefore, the amount of pure ethylene needed for 100 ppm was injected into a 3.8-liter glass jar containing two tomatoes and environmental air. The actual mixture of ethylene and air in the jar was measured by gas chromatography against a 100 ppm standard (Paz et al., 1981). The ethylene was injected into each jar through a septum previously installed in the jar lids. The glass jars were stored in darkness in the environator. After 12 hours of storage, the glass jars were opened under dim light and were ventilated with a fan (Reid, 1992). Pure ethylene was again injected into the glass jars to refresh the ethylene atmosphere to 100 ppm. Jars were again stored for 12 hours in darkness. After ethylene treatment of one day in total, jars were opened, and tomatoes were removed and stored in the environator similar to other test tomatoes.

At the end of the storage period (8 days for the FR/R treated lot and 6 days for the others), six tomatoes were randomly selected from each treatment lot for sensory evaluation, preference testing, and consumer acceptability rating. The remaining four tomatoes in each treatment lot were used for physical and chemical measurements of quality.

### 2. Sensory Evaluation

A quantitative descriptive analysis (Meilgaard et al., 1991; Munoz et al., 1992) was used to evaluate sensory attributes of tomatoes from each treatment. Eighteen panel members were recruited from staff and students of the Food Science Department at Clemson University. Panelists were familiar with the product but had no special technical expertise in sensory evaluation of tomatoes. No formal training program was provided to panelists in this study. Use of untrained panelists was done for the purpose of measuring a response to differences in tomato sensory quality (Hovenden et al., 1979; Paz et al., 1981) and deriving a consumer response for acceptability of tomato quality (Lawless et al., 1993; O'Mahony, 1988) resulting from treatments alone. An orientation program was given for panelists to become acquainted with the scoring system used and to introduce them to the tomato characteristics they were being asked to evaluate.

The six tomatoes taken from each treatment for sensory evaluation were washed and each was cut into 3 wedges. Four wedges of tomato from each treatment were coded by randomly selected three-digit numbers and placed on individual paper plates. Sensory evaluations were carried out in the sensory evaluation laboratory of the Food Science Department, Clemson University, which has separation booths with individually controlled lighting. Panelists were instructed to rinse their mouths with water between samples. Unsalted crackers were also provided along with the rinse water in each individual booth. Panelists received a plate containing four coded wedges of tomato from each treatment and individual score sheets for each sample. Samples were presented simultaneously in random order. Panelists were instructed to sample from left to right in the order presented.

Panelists rated individual sensory terms for each sample by placing a vertical line on each 15-cm unstructured horizontal lines with anchor words at each end of the scale to indicate direction of intensity. Scores were measured as the distance in centimeters from zero to the vertical line. Attributes evaluated for each treatment were: outside color, inside color, firmness, flavor, acidity, sweetness, and overall liking. Panelists also rated preference of each attribute using the 15 cm linear scale. After these evaluations were completed, panelists were asked to rank all samples by treatment 1st to 4th according to consumer (personal) acceptability.

### 3. Physical Measurements

Surface color of four tomatoes from each treatment were determined using a Spectrogard II Color System (BYK - Gardner, Inc., Silver Spring, MD), calibrated with black and white standards. Color measurements were recorded using L*, a*, and b* color space coordinates (CIELAB). L* indicates lightness and a* and b* are chromaticity coordinates on a green-red and blue-yellow axis, respectively. Final chromaticity values for each fruit were computed as the average of four measurements taken by rotating each tomato through 360 degrees with one quarter of a revolution after each measurement.

After determining color, firmness was measured by puncturing each tomato with a Fruit Pressure Tester with 8 mm diameter cylindrical plunger fitted on a drill stand. A handle on the drill stand was slowly moved down toward a tomato held firmly by the left hand until the plunger tip penetrated into the pulp of fruit. Tomato firmness was recorded in Kilograms and converted to Newton (N). Reported values represent the mean of two readings from each tomato taken 90 degree apart.

**4. Chemical Measurements**

Soluble solids content (SSC) was measured using a hand held refractometer(Model ATC-1E, AGTO CO., LTD.) on juice squeezed from the tomato at a rupture site created during firmness measurement. Reported values present the average of two readings measured from each rupture site on an individual tomato. Titratable acidity (TA) and pH were measured on juice extracted from the whole tomato after firmness and SSC evaluations. A whole tomato was ground in an Osterizer blender and filtered through miracloth to remove fibers. A 20 ml sample of tomato juice was prepared. Titratable acidity and pH were determined using a Corning digital pH/Temp Meter 4. An initial pH was recorded, and then titratable acidity was determined by titrating puree to pH 8.1 with 0.1 N NaOH. Percent acidity was calculated as citric acid.

**5. Statistical Analysis**

For the sensory evaluations, preference testings, and consumer acceptability ratings, the randomized block experimental designs in which panelists were considered as blocks were used (Gacula, 1988). An analysis of variance (ANOVA) was performed using the General Linear Model (GLM) and Duncan's multiple range test (SAS, 1991) to determine significant difference among treatment means (Montgomery, 1991). Physical and chemical measurements were analyzed by one-way analysis of variance (ANOVA), and treatment means were compared via Duncan's multiple range test. Correlation coefficients were calculated to determine relationships between individual sensory parameters and overall liking.

## Results and Discussion

Figs. 1 and 2 show mean scores and significance comparisons from Duncan's multiple range test for panelist evaluations of outside color, inside color, firmness, flavor, acidity, and sweetness. Outside color, inside color, and flavor of tomatoes from either of the light treatments (R and FR/R) had significantly higher scores than those of tomatoes treated with ethylene or stored in darkness. High quality tomatoes have often been associated with flavor and visual appeal. The sensory results presented in figs. 1 and 2 show that both light treatments (R and FR/R) resulted in tomatoes with superior visual color and flavor compared with tomatoes treated with ethylene or kept in darkness. The good flavor of light-treated tomatoes may be due to a more desirable balance in individual volatile compounds, sugar, and acid levels. Also, the preferred color may result from an increased lycopene accumulation due to the light treatment. Thus, we would conclude that the quality of light-irradiated tomatoes was better than that of tomatoes treated with ethylene or stored in darkness.

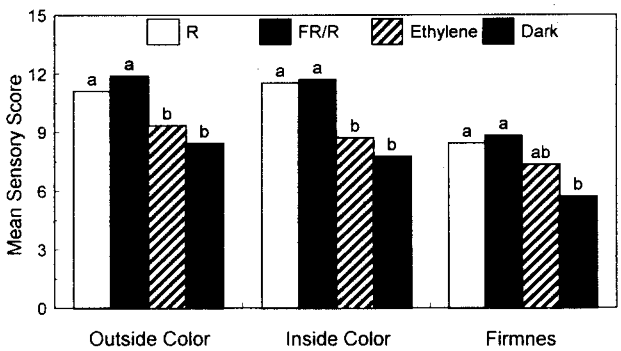


**Fig. 1 Mean sensory scores for outside and inside colors and firmness of tomatoes irradiated with light (R, FR/R), treated with ethylene, and stored in darkness. Bars within a group not labeled with the same letter are significantly different at the 5% level.**

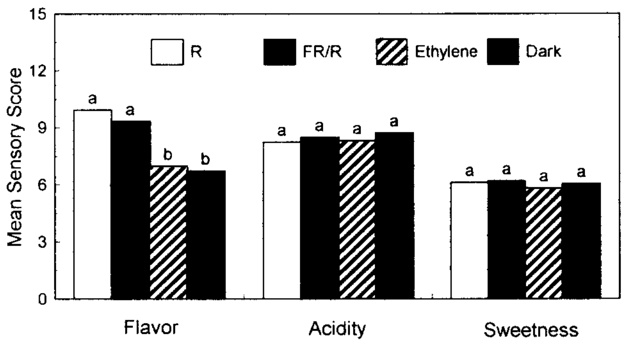


**Fig. 2 Mean sensory scores for flavor, acidity, and sweetness of tomatoes irradiated with light (R, FR/R), treated with ethylene, and stored in darkness. Bars within a group not labeled with the same letter are significantly different at the 5% level.**

A trend in firmness values is indicated in fig. 1. The firmness of ethylene-treated tomatoes was not significantly different from the firmness of tomatoes treated with light (R and FR/R) or those stored in darkness. Also, panelists' sensory values for acidity and sweetness showed no significant differences between treatments (fig. 2). But, comparing results presented in fig. 2 and table 1 show that sensory evaluation results for acidity and sweetness correspond well with titratable acidity and soluble solids content. This was also reported by Bisogni et al. (1976) in that they found that titratable acidity and soluble solids content had significant correlations with sensory panel scores for acidity and sweetness, respectively. There was no significant difference between treatments for pH, TA, SSC, and SSC/TA (table 1).

Lycopene, the main red pigment of tomatoes, is steadily accumulated throughout ripening and may be evaluated by chromaticity measurements of the red color value, a*, and the lightness color value, L* (D'Souza et al., 1992). Chromaticity values presented in table 1 indicate that tomatoes treated with ethylene and those stored in darkness were lighter than those receiving either light treatment (R and FR/R). Tomatoes treated with far-red light and followed two days later with a red light treatment (FR/R) had the highest a* values, indicating the most intense red color. R irradiated tomatoes had the next most intense red color followed by ethylene-treated tomatoes and untreated tomatoes. Panelists' color evaluations, presented in fig. 1, correspond well with the physically measured a* and L* color values, presented in table 1. Color values of b* (yellowness) were similar among treatments.

The purpose of the FR/R treatment was to investigate whether far-red light irradiation could inhibit or delay tomato ripening and if it did, could red irradiation again accelerate the ripening process. The interval between FR and R irradiations was selected as two days to correspond to a reasonable shipping period from field harvest to market terminals. Observations made during the study suggest that R irradiation stimulated red color development in tomato after it had been delayed by FR irradiation.

Firmness value measured from puncture tests was the lowest (20.6 N) in FR/R treated tomatoes. This value was significantly different from that of tomatoes receiving other treatments. There was no significant difference in firmness values for tomatoes irradiated with R (21.8 N), treated with ethylene (22.3 N), or kept in darkness (22.3 N).

ANOVA revealed significant treatment differences (table 2) for panelists' overall liking as well as individual likings for outside color, inside color, firmness, flavor, and acidity, but not for sweetness. Liking scores for outside color, inside color, and flavor

**Table 1 Objective quality measurements for tomatoes irradiated with light, treated with ethylene, and stored in darkness[H]**

| Treatment | Color | | | Firmness (N) | SSC (%) | TA (%) | SSC/TA | pH |
|---|---|---|---|---|---|---|---|---|
| | L* | a* | b* | | | | | |
| R | 51.27 b | 32.28 b | 31.03 | 21.81 a | 4.1 | 0.36 | 11.5 | 4.23 |
| FR/R | 49.37 c | 33.56 a | 30.76 | 20.58 b | 4.1 | 0.35 | 11.7 | 4.27 |
| $C_2H_4$ | 53.07 a | 31.30 bc | 31.06 | 22.30 a | 4.0 | 0.36 | 11.1 | 4.22 |
| Dark | 53.79 a | 31.02 c | 31.04 | 22.30 a | 4.0 | 0.38 | 10.6 | 4.22 |

[H] Mean separation within columns by Duncan's multiple range test. 5% level. Data are means of five observations. Lack of letters = differences nonsignificant.

**Table 2 Mean liking scores for overall and sensory variables of tomatoes irradiated with light, treated with ethylene, and stored in darkness***

| Terms in liking scale | Treatment | | | |
|---|---|---|---|---|
| | R | FR/R | $C_2H_4$ | Dark |
| Outside color | 11.83 a | 11.91 a | 9.31 b | 8.21 b |
| Inside color | 11.80 a | 11.88 a | 8.60 b | 7.65 b |
| Firmness | 9.79 a | 9.17 a | 8.37 ab | 7.11 b |
| Flavor | 10.02 a | 9.42 a | 7.23 b | 6.34 b |
| Acidity | 9.79 a | 8.83 ab | 8.45 ab | 7.84 b |
| Sweetness | 7.91 a | 7.16 a | 7.07 a | 7.63 a |
| Overall | 10.22 a | 9.14 ab | 7.57 bc | 6.58 c |

* Values in the same line not followed by a common letter are significantly different at the 5% level according to Duncan's multiple range test.

of tomatoes treated with light (R and FR/R) were higher than those of tomatoes treated with ethylene or held in darkness. Acidity and firmness of tomatoes treated with light (R and FR/R) had liking scores similar to those of tomatoes treated with ethylene. Overall liking scores for tomatoes treated with light (R and FR/R) were more pronounced in comparison with tomatoes stored in darkness.

Consumer acceptability evaluations showed that light-irradiated tomatoes were ranked significantly higher than those of tomatoes treated with ethylene or stored in darkness (table 3).

**Table 3 Mean acceptability rank for tomatoes irradiated with light, treated with ethylene, and stored in darkness***

| Treatment | Rank |
|---|---|
| R | 1.8 b |
| FR/R | 2.0 b |
| $C_2H_4$ | 2.8 a |
| Dark | 3.3 a |

* A rank of 1 was given to the sample with most acceptability and a rank of 4 for the sample with least acceptability. Mean separation within column by Duncan's multiple range test, 5% level.

Similarly, Bisesi and Gregory (1992) found that light-irradiated tomatoes were preferred in taste tests over tomatoes treated with ethylene or those stored in darkness.

Correlation coefficients were computed between overall liking values (on hedonic rating scale) and individual sensory attributes (table 4). All sensory attributes except acidity were correlated with overall liking values. However, inside color, flavor, and sweetness were correlated most highly ($P<0.001$). Overall liking values had a high correlation coefficient

**Table 4 Correlation of individual sensory attributes with overall liking**

| Sensory attribute | Correlation coefficient |
|---|---|
| Outside color | 0.33* |
| Inside color | 0.42H |
| Firmness | 0.34* |
| Flavor | 0.78H |
| Acidity | -0.06 |
| Sweetness | 0.42H |

* Significant at 1% level of probability.
H Significant at 0.1% level of probability.

($r = 0.78$, $P<0.001$) with flavor attribute and a low correlation coefficient ($r = -0.06$) with acidity. These results are similar to the reported results of Bruhn et al. (1991) that consumer dissatisfaction with "supermarket tomatoes" centers around a lack of flavor as the primary criticism. Also, Watada and Aulenbach (1979) indicated that desirability of tomatoes was highly correlated with fruity- floral flavor, and poorly with acidity. Hence, it is suggested that the flavor attribute should be considered strongly in assessing quality of tomatoes.

## Conclusions

Based on the results and general observations made during this study, the following conclusions were reached: (1) Three minutes of red light irradiation for tomatoes enhanced red color and preferred flavor developments compared to similar tomatoes receiving an ethylene treatment or storage in darkness. (2) Three minutes of far-red light irradiation delayed tomato ripening; a process which was changed when followed within two days with three minutes of red light irradiation. (3) Consumer acceptability had a significant preference for tomatoes irradiated with light compared to tomatoes treated with ethylene and stored in darkness. (4) Panelists' preference (overall liking) was correlated most highly with inside color, flavor, and sweetness.

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