Red Color Enhancement of Pimiento Peppers with (2-Chloroethyl)phosphonic Acid

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Abstract. Pimiento peppers from all ethephon treatments had a faster rate and a higher percentage of coloring than peppers receiving the ethylene treatment or the control. The completely green peppers, however, did not color to an acceptable commercial grade within 96 hr.

Ethephon induced a climacteric in the respiration of the treated detached peppers that was not present in the control fruits, indicating that metabolism was affected as the coloring rate was increased.

Red, mature pimiento peppers, Capsicum annuum L., are grown and used for their decorative color and for the flavor they impart to processed foods. Peppers which contain any trace of green color are not acceptable for processing. With hand picking, some partially green fruits are often harvested and discarded or are left to color naturally. This latter procedure prolongs the harvesting period and requires additional labor. With the advent of once-over mechanical harvesting, an even higher percentage of green fruits can be expected to be harvested. Therefore, a rapid method of degreening pimiento peppers should be of economic value to both the grower and the processor.

Ethylene gas has been the commercially accepted degreening agent for citrus (16), bananas (9), muskmelons (20), and other fruit for many years. However, ethylene gas was found to be ineffective in degreening pimiento peppers (Grierson, W., unpublished data). The exact mode of action of ethylene gas in a mature fruit is not known (9, 20). Whether the proposed concept of an interplay between growth hormones and ethylene, which has evolved from experiments with vegetative tissues, will prove useful in interpreting the action of ethylene in mature fruits remains to be determined (9).

Ethephon [(2-chloroethyl)phosphonic acid] is known to have physiological effects on many plants and fruits. It has been shown to be effective in degreening bananas (22), citrus (15, 19), and tomatoes (21). In addition, there are reports that ethephon enhances fruit abscission in cherries and plums (8) and apples (14). Warner and Leopold (25) suggest that the many effects of ethephon on plants is due to a stimulation of ethylene production by plants. Cooke and Randall (11) proposed that ethylene is liberated by the degradation of ethephon in plant cells and that this degradation is related to the pH of the cell cytoplasm. This hypothesis is substantiated by the fact that the evolution of ethylene from ethephon increases with increasing pH (2). Ethephon has a pH of 1.0. At a pH of 4.1, aqueous solutions of ethephon yield small amounts of ethylene. However, since the pH of the cell cytoplasm of plants is generally greater than 4.1, the degradation of ethephon and the liberation of ethylene should be enhanced within the plant.

Preliminary results on the use of ethephon in promoting red color development in pimiento peppers have been reported (17, 23).

The purpose of this study was to evaluate the possibility of using ethephon as a method of promoting rapid degreening of pimiento pepper fruits, to determine whether ethylene gas will produce a similar effect, and to determine the respiratory effects associated with the potential accelerated degreening process of the fruit by either of these chemicals.

Materials and Methods

Initially, a study was conducted with the cv. Truhart, grown in the greenhouse. When the fruit reached the "color-breaking" stage, one group of 50 plants was sprayed to the drip point with an aqueous solution of 2000 ppm ethephon and a 2nd group, water. Both sprays contained 0.05% "Tween 20" as a wetting agent. As compared to the control, ethephon enhanced leaf yellowing after 2 days and color development of the fruit within 3 days following application. Pronounced leaf and fruit abscission accompanied color development of the fruit. Since fruit abscission would cause problems under commercial field conditions, studies were conducted to determine the feasibility of using ethephon as a color enhancement agent on detached fruits.

Fig. 1. Extractable chlorophyll of pimiento peppers as related to measurements of log 1/reflectance on the absorbancy scale at 675 m

0 10 20 30 40 50 60 70 80
Absorbance at 675 m

0 50 100 150 200 250 300
Chlorophyll µg/cm²

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2 This paper is a portion of thesis submitted to Graduate School by the senior author in partial fulfillment of the requirements for M.S. Degree.

3 Graduate Assistant and Professor of Horticulture, respectively.
4 Amchem Products, Inc., Ambler, Penna., under the common name ethephon.

three experiments were subsequently conducted with detached 'Truhart' pimiento fruit grown at the Georgia Experiment Station in Griffin.

**Experiment 1.** Color enhancement was measured at regular time intervals following treatment to determine the effects of several concns of ethephon on color development of pimiento fruit compared to the effect of ethylene gas and to the controls. Fruit were carefully harvested and the commercially unacceptable (any green color present) peppers were separated into 3 groups: 1) The apparently mature but ‘100% green’ group included peppers that had no trace of red or color changing areas; 2) the ‘less than 50% red” group included peppers that had red color in minute amounts to peppers that had 49% red color; 3) the ‘more than 50% red color’ group included peppers which had 50% or more but less than 100% of their surface being red.

Two hundred twenty-five peppers were selected to represent each color group. Within each color group, subgroups of 45 peppers each were dipped for 10 sec in either water or an aqueous solution of 1000, 3000, or 5000 ppm ethephon. ‘Tween 20’ (0.5%) was added as a wetting agent. During the treatment period, the solution was kept at a temp of 100°F. Three similar color groups of peppers were treated with a continuous flow of 500 ppm ethylene gas for 96 hr. After treatments, all peppers were stored at 80°F and 85% relative humidity.

On each pimiento pepper, five 1 cm diam spots, having the same color reading, as determined with the reflectance unit on the Bausch and Lomb Spectronic 20, were selected in a random manner. The extractable chlorophyll content of the pepper discs was determined by using a modification of the method proposed by Arnon (3). Chlorophyll was extracted in 80% acetone by grinding discs in a Waring blender for 5 min. After centrifugation at 1600 x g for 5 min to remove cell debris, absorbancy was measured at 652 mp using 80% acetone as a blank. Physical measurement of reflectance was made, using a Bausch and Lomb Spectronic 20 with a reflectance unit (18). Log l/reflectance was read at 675 mp directly from the absorbancy scale. This procedure was repeated with a range of pepper colors to obtain a correspondingly wide range in chlorophyll content.

Chlorophyll per cm² from the extractable chlorophyll samples was plotted against log l/reflectance at 675 mp to give a standard curve (Fig. 1). By use of the standard curve it was possible to indirectly determine the chlorophyll content in peppers by making a physical measurement of the reflectance of the intact pimiento pepper on the Bausch and Lomb Spectronic 20 with reflectance unit and then converting the reflectance reading to µg chlorophyll/cm². This method was used to determine the rates of chlorophyll degradation of peppers following treatment with ethephon and ethylene gas.

Due to the inherent uneven coloring properties of pimiento peppers, visual observations of each fruit were also used to determine the time a pepper became completely red or commercially acceptable.

**Experiment 2.** Eight hundred ten peppers were divided into 3 groups of 270 fruit each representing 3 color categories described in Expt. 1. Forty-five peppers were dipped for either 1 or 3 min in either water or 100 or 300 ppm ethephon at 100°F. ‘Tween 20’ (0.5%) was added as a wetting agent.

Treated peppers were stored at 80°F and 85% relative humidity to simulate commercial storage conditions. Color development in the fruit was rated visually at various periods in storage and reported as percent of sample attaining full red color.

**Experiment 3.** The purpose of this experiment was to determine the effects of ethephon on the respiration rate of peppers. Carbon dioxide measurements were made with a Beckman 215A Infrared CO2 analyzer according to the method of Vines et al. (24), and measurements were made for a 20-hr period before treatment was applied, as described in Expt. 1. Peppers were maintained at 77°F during respiration measurements and all data were converted to milligrams CO² per kilogram fruit per hr according to the following equation:

\[
\frac{\text{ppm CO}_2 \times \text{air flow (ml/hr)} \times 1.811}{1,000,000 \times \text{fruit wt (kg)}} = \frac{\text{mg CO}_2}{\text{kg/hr}}
\]

**Results**

**Experiment 1.** The relationship between the absorbance reading (log l/reflectance at 675 mp read directly from the absorbance scale) and chlorophyll content (µg/cm²) was obtained from fruit varying in color from red to green. This curve (Fig. 1) shows that degradation of chlorophyll occurs as the pepper colors or ripens. This nondestructive method of following chlorophyll degradation in pimiento peppers was used.

Data in Fig. 2 show the effects of ethephon dips and ethylene gas treatment on chlorophyll degradation as compared to the control. The chlorophyll content of the treated peppers was in relation to percent chlorophyll content of the control. Values greater than 100% of the control indicate a chlorophyll content greater than the control, as shown in the ethylene treatment. Values less than 100% of the control indicate a chlorophyll content smaller than the control, as shown in all ethephon treatments. Ethylene gas was ineffective in coloring peppers in any color group and was inhibitory in the more than 50% red color group. Concentrations of Ethrel up to 5000 ppm appeared to be equally effective in accelerating chlorophyll degradation.

**Experiment 2.** Ethephon, by accelerating chlorophyll degradation, increased percentage of acceptable red fruit. Comparison of the 1- and 3-min dip of 100% green peppers shows a slight advantage for the 3-min dip, but neither was
Fig. 3. Percent acceptable (completely red) pimiento peppers dipped in 1000 or 3000 ppm ethephon for one (left) or 3 (right) min when peppers were 100% green.

A summary histogram of percent red fruit from the treatment 1-min dip after 96 hr storage (Fig. 7) shows that ethylene retards color development when compared to the control. Fruit in the “less than 50% color” group was most effectively colored by ethephon.

Discussion

Ethylene gas was not effective in accelerating the degreening of pimiento peppers under the conditions of these experiments, but ethephon, which releases ethylene (2, 11), was effective in the promotion of the degreening process (Figs. 2-5). Also, ethylene gas inhibited degreening of pimiento fruit in all color groupings. The reasons for this action are unknown. Perhaps the thick cuticle of pepper fruit prevents entry of ethylene gas, whereas ethephon in aqueous solution is absorbed. Ethephon has been reported to penetrate the cuticle of a tomato, even though the effects were only localized (21).

No consistent differences in degreening rates of peppers could be observed among any of the ethephon concn or dipping times used. This work and the work of other researchers (15) indicate that thorough wetting of the fruit with an ethephon solution appears to be all that is needed to obtain color enhancement. California studies (23) indicate that ethephon concn in the range of 500 ppm or less applied postharvest may be as effective in degreening pimiento fruit as the higher postharvest concn used in this study. The abscission properties as well as the color enhancing properties of ethephon may adapt very well to the mechanical harvesting of pimiento peppers. It may be possible to spray the plant with low concn of ethephon to promote leaf abscission, color development of the fruit and to loosen the fruit, all of which facilitate the harvesting process.

Therefore, ethephon, under the conditions of these experiments, did promote more rapid degreening of detached pimiento pepper fruits than was observed in the control groups.


satisfactory (Fig. 3). The greatest enhancement effect occurred on peppers that were less than 50% red (Fig. 4). There was no advantage in the 3-min dip over the 1-min treatment, but the peppers from 3000 ppm dip colored quicker and to a greater percentage acceptability than those from the 1000 ppm dip or the control. Both concn of ethephon colored the peppers in the “over 50% red” group to acceptability within 48 hr (Fig. 5).

Ethyphon-treated peppers in all color groups colored to an acceptable point faster and attained a higher final percentage of acceptability than the controls. These data would indicate that ethephon does promote chlorophyll degradation in peppers similar to that which has been reported in other crops (15, 19, 22, and 23). Also, it has been reported (6, 12, and 13) that during chlorophyll degradation in peppers, there is also a marked increase in the carotene content. Capsanthin (C40H56O3) has been shown to be the major carotenoid in pimiento pepper fruits (7, 10). What effect ethephon has on capsanthin or other carotenoid development is unknown. Since ethephon accelerates the coloring process, it may be true that ethephon also increases the rate of capsanthin formation.

Experiment 3. Color development is a metabolic process, as is respiration. Therefore, any treatment that affects rate of color development should also affect respiration rate. Ethephon increased respiration rates of both color groups of pimiento peppers, similar to an induced climacteric, which began within 10 to 15 hr after treatment (Fig. 6).

The respiration peak was reached within 24 to 36 hr after treatment. Fruits showing less than 50% red color at harvest responded more quickly than those having more than 50% red color at harvest. These results are similar to those reported by Aharoni et al. (1) for oranges.

An increase in respiration rates shortly after treatment of both the “less than 50% red” and the “more than 50% red color” groups of peppers would, according to Biale (4, 5), satisfy one of the important criteria in determining a non-climacteric fruit. That is, a non-climacteric fruit will respond to ethylene treatments with an increase in respiration rate at any stage of ripeness.

A summary histogram of percent red fruit from the treatment 1-min dip after 96 hr storage (Fig. 7) shows that ethylene retards color development when compared to the control. Fruit in the “less than 50% color” group was most effectively colored by ethephon.
Fig. 4. Percent acceptable (completely red) pimiento peppers dipped in 1000 or 3000 ppm ethephon for 1 (left) or 3 (right) min when peppers were less than 50% red.

Fig. 5. Percent acceptable (completely red) pimiento peppers dipped in 1000 or 3000 ppm ethephon for 1 (left) or 3 (right) min when peppers were over 50% red.
Fig. 6. Respiration rate of pimiento peppers dipped in 3000 ppm ethephon for 1 min. Stages of color development were less than 50% red (predominantly green) and more than 50% red (predominantly red).

Fig. 7. Percent acceptable (completely red) pimiento peppers in three initial color groups recorded 96 hr after treatment with water (control), ethylene gas, or ethephon, (1-min dip).

Literature Cited