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The effect of certain chemicals on the rate of respiration, firmness and color change of harvested tomato fruit.

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THE EFFECT OF CERTAIN CHEMICALS ON THE RATE OF RESPIRATION, FIRMNESS AND COLOR CHANGE OF HARVESTED TOMATO FRUIT

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INTRODUCTION

In recent years, much post-harvest physiological research has been done with many vegetables and fruits to extend their marketable life. There are indications that several chemicals may be capable of extending the shelf life of numerous edible crops.

However, adequate information is lacking concerning the influence of many chemicals on the rate of deterioration of harvested fruits because of the difficulty of introducing such materials into the internal tissue of intact fruits without injuring them. There is no assurance that simple dips or sprays of chemical compounds on the surface of harvested fruits result in any appreciable absorption or translocation of the compound into the flesh of the fruit. In any case, such techniques do not provide a quantitative measure of the amount of material absorbed by the fruit.

The fact that harvested tomato fruits will readily absorb small amounts of a given solution through their stem-end, make them an excellent vehicle for testing the action of some chemicals on the rate of ripening and general deterioration of the fruit following harvest.

The objectives of these experiments are to determine the influence of some chemical substances which are suspected

or known to have some senescence inhibiting qualities on the rate of respiration, changes in the surface and interior color and the firmness of harvested tomato fruits (Lycopersicon esculentum Mill.).

The chemicals used in these experiments with harvested mature green tomatoes are: N6-benzyladenine (N6-B), 6-Furfurylamino purine (Kinetin), N-dimethylamino succinamic acid (B-995) and indoleacetic acid (IAA).

REVIEW OF LITERATURE

Physiological Studies of the Tomato Fruit

Untreated Tomato Fruits

Gustafson (30) was the first to report a decrease in the production of carbon dioxide by tomato fruits during growth, by calculating the respiratory rate of detached tomato fruit at several stages of development. Carbon dioxide production decreased to a minimum point at about the time that increase in fruit size ceased. This was followed by an increase in carbon dioxide production until a maximum was attained when the fruits were orange to red in color. Thereafter, the rate of respiration decreased.

Results of others are in agreement with these findings of Gustafson (30). Clendenning (14) discovered that the act of detachment of the fruit from the plant did not interfere with the respiratory sequence which would have been exhibited by the fruit, had it remained on the plant. Furlong (25) found that the flavor and color of tomatoes which ripened after harvest were not quite as good as that of vine ripened tomatoes.

Emmert and Southwick (23), and Workman *et al.* (89) showed that the respiratory rate of green mature, detached tomato fruits dropped from a relatively high level to a pre-

climacteric minimum, then rose to a climacteric peak, then dropped again as the fruit became post-climacteric.

Kattan (41), in objective determination of firmness and color, indicated that tomatoes harvested at the pink stage, upon ripening, were firmer and superior in red color to tomatoes harvested at earlier stages of maturity.

Freeman (27) found that the climacteric peak was higher in vine ripened than in storage-ripened fruits. There was no difference in respiration rates of red ripe fruits ripened on the vine or in storage.

Gustafson (30) showed that tomatoes have a respiratory pattern similar to apples. Emmert (22) made a comparison between the respiratory behavior of apples and tomatoes, and confirmed Gustafson's finding. Biale (6) reviewed the work reported by several investigators concerning the respiration pattern of fleshy fruits, and indicated that during ripening tomatoes show the same climacteric pattern of respiration usually observed with apples, pears, avocados and bananas. The internal concentrations of carbon dioxide, oxygen and ethylene in tomato fruits follow the same general pattern as shown by cantaloupe fruits at various stages of maturity (47, 48).

Effect of low temperature on the ripening of detached tomato fruits

Diehl (18) reported that green mature tomatoes held at 30 to 32° F. for one day, and then held at 70° F. there-

after, ripened normally.

Tomatoes stored at 32° F. for 4 days ripened after removal from cold storage. However, storage at 32° F. for 8 days or longer caused a collapse of the tissue of the outer wall of the fruit, particularly near the stem-end, when removed to higher temperature.

Rosa (68) found that storage of mature green tomatoes for 4 days at 4° C. (39.2° F.) retarded the rate of ripening after removal to 25° C. (77° F.). The longer the period at low temperature, the slower was the rate of ripening after removal from cold storage, and the greater was the percentage of breakdown and decay. Decay was caused by molds, but was preceded by collapse of the fruit. Storage at 8° C. (46.4° F.) and 12° C. (53.6° F.) retarded ripening, also. After 20 days' storage at 12° C. (53.6° F.), 8 days longer were required to bring the fruits to full ripeness in comparison with similar fruits not subjected to cold storage. Rosa (68) showed that temperatures between 12 and 15° C. (53.6° and 59° F.) were best for prolonged storage of ripening tomatoes. Twenty-five degrees C. (77° F.) was the optimum temperature for ripening tomatoes, and 30° C. (86° F.) retards red color development. Similar results have been reported by Furlong (28).

Furlong (28) found that it was possible to procure a supply of ripe tomato fruits over a period of 65, 50 and 29 days by storing green fruits at 50, 55 and 65° F., respectively. El-Shiate et al. (21) reported that green mature

tomato fruits can be stored for 6 weeks at 45° F. and 5 weeks at 65° F.

Dennison (17) showed that temperature is an important factor in lycopene development (a red carotenoid pigment, which is largely responsible for red color in tomatoes). He found that fruits picked when green and ripened off-the-vine showed the optimum ripening temperature and maximum lycopene development to be 18 to 23° C. (64.4 to 73.4° F.). Above 30° C. (86° F.), practically no red coloring develops in tomatoes; they lose their green color and become yellow. When green fruits were ripened at temperatures above 30° C. (86° F.) and placed at moderately lower temperatures, red color developed, indicating that the suppression of lycopene formation at high temperatures did not destroy its capacity for development.

In storage studies of vine-ripened tomatoes, Scott and Hawes (70) held pink, medium ripe, and ripe tomatoes at 32 and 50° F. for 6, 12 and 17 days. Samples were then held at the end of 6 and 12 days at storage temperatures of 72 and 85° F. for 5 days. Their data agrees with the findings of previous workers (18, 68, 28, 21) showing that storage at low temperatures retards the rate of color development exhibited at subsequent exposure to a higher temperature. At 32° F. the retarding effect was more pronounced than at 50° F., and was similar to lots harvested at different stages of ripeness. Prolonging the low temperature storage period from 6 to 12 days increased the amount of red color development.

The physiological collapse or breakdown described as occurring when green mature tomatoes are held at low temperatures by Diehl (18), Rose (68), and Furlong (28) did not occur in the tests of Scott and Hawes (70). They reported (70) "after 6 or 12 days' storage of pink, medium ripe, and ripe tomato fruit at 32° F., there was no evidence of physiological breakdown or chilling injury." They, furthermore, advised "handling vine-ripened tomatoes under conditions of refrigeration (from 32 to 45° F.) in order to prevent loss from over-ripening and to maintain highest quality."

More recent work by Hall (32) indicates that ripened tomatoes held at 35° F. or 40° F. rapidly lose red color during the first four days of storage and the total carotenoid (but not the carotene) content declines. Ripened fruits stored at 50° F. lost some red color occasionally, while red color increased in fruits held at 70° F. He found that all fruits held at 35° F. for 10 days or 12 days decayed or showed breakdown symptoms after 3 days at 70° F. The skin of fruits held at 35° F. for 8 to 12 days was found to be easily ruptured and slipped readily from the flesh.

Effect of controlled atmospheres on the ripening of detached tomato fruits

Decreasing the oxygen and increasing the carbon dioxide concentration of the atmosphere resulted in a marked reduction in the amount of carbon dioxide evolved by tomato fruits, Gustafson (31). Soldatenkov (75) found that the

respiration of tomato fruits increased 50 to 100 percent when subjected to oxygen concentrations above those in air.

Furlong (28) stored mature green tomatoes for 28 days at 55° F. in 5 percent oxygen and 5 percent carbon dioxide and at 50° F. at 5 percent oxygen and 10 percent carbon dioxide. Samples of fruit were allowed to ripen for another 18 days at both 55 and 65° F. in air. His data show that a marked inhibition of ripening resulted in both gas mixtures. The fruits from both mixtures ripened and developed good quality and had a negligible amount of rot at both 55° F. and 65° F. The fruit from the 5 percent oxygen and 5 percent carbon dioxide mixture had better appearance and flavor than those from the other mixtures. Fruits of both treatments compared very favorably with fruits ripened in air, at the same temperatures.

Eaves (19) stored tomato fruits in different mixtures of carbon dioxide and oxygen. Fruits held at 12.7° C. (55° F.) for 12 weeks in an atmosphere of 5 percent carbon dioxide and 2.5 percent oxygen developed better red color and were firmer in comparison with fruits from the other treatments and those held in air. Eaves and Lockart (20) found that high concentrations of carbon dioxide markedly retarded ripening and rotting, irrespective of oxygen concentration. A retardation in the oxygen level without carbon dioxide also retarded ripening.

McArdle and Curwen (51) found that the fresh tomato marketing season could be extended by 2 to 3 weeks by the

storage of mature green (but not pink) fruit in an atmosphere of 10 percent oxygen and 5 percent carbon dioxide at 55° F. Fruit stored in this manner ripened uniformly within 5 days after storage when placed at room temperature in air, whereas, 10 days were required to ripen unstored mature green fruit. Under normal atmospheric conditions at 55° F., mature green fruit had a maximum storage life of 14 days, after which a rapid deterioration in texture occurred on removal from storage.

Effect of wax treatment on the ripening of detached tomato fruits

Waxing the skin of green mature tomato fruit does not increase the carbon dioxide content of the internal atmosphere of the fruit, Brooks (9). Such treatment has no appreciable influence on the ripening of the fruit. However, waxing the stem-scar increases the internal carbon dioxide content of the fruit, and slows the rate of ripening. Brooks (9) concluded that gas exchange of the tomato fruit takes place almost exclusively through the stem-scar, and the skin is quite impermeable to gases.

Walford (84), Singh and Mathur (72), and Clendenning (13) have not recognized this fact and have waxed the stem-scar of tomato fruit to prevent decay and abnormal respiratory behavior has resulted.

Walford (84) observed two physiological types of tomatoes when fruits were picked at the mature green stage,

waxed at the stem-scar area and stored at 12.5° C. (55° F.). The fruits of late spring and summer showed a distinct rise in their respiratory rate as they ripened in storage, while the late autumn and winter fruits exhibited slow and uneven coloring without any apparent rise in the carbon dioxide output. He designated these contrasting types as "conventional" and "anomalous" respectively, and provisionally concluded that their distribution was related to seasonal factors.

This occurrence of different physiological types of tomato fruit was thoroughly investigated later by Clendenning (14), who discovered that only waxed fruits appeared in the "anomalous" category, and that when the seals of the "anomalous" fruits were removed, the fruits immediately recovered their "conventional" characteristics. Also, a "conventional" type fruit could be converted to an "anomalous" type simply by sealing over the calyx end of the fruit.

Emmert's (22) results, also, show that waxing the stem-scar area of mature green tomatoes reduced the amount of carbon dioxide evolved. Waxing other areas of the fruit had little or no effect on carbon dioxide evolution.

Effect of chemical treatment on the ripening of detached tomato fruits

a. Effect of ethylene

Rose (67) was the first to note that ethylene treatment of 1:4300 or lower to green mature tomato fruits greatly accelerates the development of the red pigment. It also

accelerated other ripening processes such as the destruction of starch and the conversion of insoluble nitrogen to soluble forms.

Work (88) demonstrated the relation between maturity and the rate of response of tomato fruit to ethylene treatment. He found that it was more effective in hastening the ripening of 30-to 40-day-old fruit, than either older or younger fruits. He concluded that ethylene ripened the fruits 3 to 4 days faster than untreated ones. There was no observed difference between the response of the different varieties of tomatoes tested in response to ethylene.

Ethylene at a concentration of 0.1 percent reduced the time needed for completion of ripening of green tomatoes stored at 65° F., and of fruit ripened at 65° F. after a period of storage at 45, 50, and 55° F., Furlong (28). This effect, however, was due to acceleration of the ripening of a comparatively few of the slowest ripening fruits. Furlong (28) concluded that the presence of ethylene tended to make ripening more uniform by its effect on certain fruits only, while the rate of ripening of the sample as a whole was not accelerated to a great extent. Hibbard (36), and Heinze and Craft (35) also found that ethylene hastened the ripening of immature tomato fruits.

Fidler and Nash (24) obtained data from treating mature green tomatoes stored at 65° and 70° F. for 18 to 21 days and exposed to 0.1 percent ethylene for 2 to 12 days which is difficult to interpret. In several experiments,

ethylene appeared to hasten the ripening of tomato fruits, while others showed that ethylene may have no effect. Fidler and Nash (24) concluded that the tomato appears to be a fruit which does not respond to ethylene. They (25) indicated a confirmation of this conclusion by finding that treatments with ethylene at 1 part ethylene to 650 parts of air did not accelerate the rate of ripening of turning tomatoes held at 55° F.

However, Pratt et al. (65) found that at 20° C. (68° F.) ethylene caused mature green tomato fruits to ripen earlier and more uniformly than untreated fruit. Ethylene treatment induced the climacteric rise in respiration. In addition, treated fruit developed a higher maximum respiratory rate than untreated fruit. The R.Q. of ripening fruits showed the same change following ethylene treatment as occurred in the untreated lots.

Lyons et al. (48) obtained similar results following ethylene treatment on immature and mature green tomato fruits. They found that ethylene treatment induces a climacteric rise in fruit at different ages ranging between 38, 49, 64, 74, and 93 percent of their total age calculated as the elapsed percentage of time for their total growth period. It also hastened or induced changes in the fruit which are usually associated with ripening, such as the development of red color, flavor, and aroma. Neither fruits at 38 nor 49 percent maturity developed red color within the 22-day storage period unless they were treated with ethylene.

Untreated immature green fruit of 64 percent and 74 percent maturity developed red color and showed an increase in ethylene production which was associated with their ripening and respiratory climacteric. However, fruits less than 93 percent mature did not ripen to an acceptable edible quality. Lyons et al. (48) concluded that the less mature the fruit is at harvest, the greater the response to ethylene.

Rosa (68), in his studies to determine the influence of propylene on the ripening process of tomato fruits, found that the propylene hastened the ripening of tomato fruit. Propylene hastens tomato ripening in a manner comparable to that observed from ethylene.

Apple emanations were found to hasten the ripening of green mature tomatoes, Emmert and Southwick (23). Only mature green tomatoes and possibly fruits which showed incipient red coloring were stimulated to earlier ripening (by emanations from ripe apples). They suggested that this response is due to the presence of ethylene in ripe apple emanations.

b. Effect of growth regulators

Emmert (22) found that sprays of methyl ester of naphthalene acetic acid did not have a consistent effect on the respiration and ripening behavior of detached green mature tomatoes.

Emmert and Southwick (23) studied the response of mature green tomatoes to post-harvest sprays of 2,4-dichloro-phenoxy-acetic acid, and reported that it did not influence

tomato respiration. Their data is in agreement with Mitchell and Marth (55), who found no stimulating effect of 2,4-dichlorophenoxy-acetic acid on the ripening rate of mature green tomatoes. However, the detached tomato fruits were sprayed with the aforementioned chemicals. Since it has been established that tomato skin is quite impermeable to gases, there is some doubt about the effectiveness of spraying tomato fruits as a method of treatment. Absorption of the compound into the sprayed fruit is open to question in such cases.

Southwick and Lachman (78), being aware of this problem and of evidence provided by Brooks (9), Clendenning (14) and Emmert (22) showing that gas exchange occurs at the stem-end of tomato fruit, developed a new technique for the treatment of tomato fruits with solutions containing chemical compounds, by placing a measured amount of the solution on the stem-end scar of a tomato fruit immediately after fruit harvest and stem removal. They studied the effect of maleic hydrazide on the rate of respiration of harvested tomato fruits, following its absorption through the stem-end of detached fruits. They (78) found that treatment of maleic hydrazide ranging from 100 to 10,000 ppm appears to slightly inhibit the rate of respiration of preclimacteric tomatoes. They found that absorption of similar volumes of distilled water by harvested preclimacteric tomato fruit also tends to hasten their rate of respiration and red color development.

Recently, Hartman (34) studied the effect of several

growth regulating substances on the ripening rate, internal constituents, and carbon dioxide evolution of tomato fruits. He used 11 different compounds at concentrations of 50, 100, 500 and 1,000 ppm. These compounds were: 2,4-dichlorophenoxyacetic acid, 2,4,6-trichlorophenoxyacetic acid, para-chlorophenoxyacetic acid, ortho-chlorophenoxyacetic acid, alpha (ortho-chlorophenoxy) propionic acid, alpha (para-tertiary-butylphenoxy) propionic acid, Alpha naphthaleneacetic acid, 2-naphthoxyacetic acid, 3-indolepropionic acid, and ammonium thiocyanate. In addition, 2,4,6-trichlorophenoxyacetic acid at 100, 500, and 1,000 ppm was used in combination with 1,000 ppm ammonium thiocyanate. Carbowax served as a carrier in the preparation of aqueous solutions of most of these growth regulating substances. In his preliminary experiments, he sprayed the growth regulator solutions on the fruit with an aerosol sprayer. These fruits were then spread out on tables to dry and allowed to ripen under room conditions. In some of his other experiments, tomatoes were treated by immersing them in the growth regulator solutions for a period of three minutes. They were then permitted to drain and dry before being allowed to ripen or placed in a respiration apparatus. Hartman (34) discarded those compounds which failed to hasten fruit ripening, and continued with 2,4,6-trichlorophenoxyacetic acid with 2 percent carbowax as a wetting agent and ammonium thiocyanate, which appeared to be effective in shortening the ripening of green tomato fruits. Five hundred to 1,000

ppm were most effective in accelerating the rate of ripening. Hartman (34) mentioned that one compound, alpha-naphthaleneacetic acid retarded the ripening rate of the tomato, but did not carry on detailed studies with this compound. He found the accelerating substances to be most effective when applied by dipping at least 6 days before the "red" stage of ripening, which is the period before the onset of the climacteric rise in respiration. Carbowax 4000, used as a wetting agent in 2 percent solutions, was observed to retard ripening of tomatoes during the early stages of the experimental period, although the lots treated with this material eventually contained as many ripe fruits as the control lots.

Hartman's (34) respiration studies of green tomato fruits involved measurement of carbon dioxide output from individual tomato fruits. He reported that the majority of the fruits followed the "conventional" respiration pattern as defined by Walford (84). A few fruits failed to show the climacteric rise during the color changes of ripening. Hartmen (34) suggested that these fruits appeared to follow the type of respiration pattern designated by Walford (84) as "anomalous," and supported this idea of the existence of "anomalous" tomatoes by the early findings of Clendenning (13) that there are "anomalous" and "conventional" tomatoes. However, later work of Clendenning (14) clearly refutes the existence of "anomalous" tomatoes. The "anomalous" type of tomato discussed by Walford (84), Singh and Mathur (72) and Clendenning (13) owes its characteristics to treatments that

restrict the gas exchange in the tomato fruit. Removal of this restriction causes immediate disappearance of the "anomalous" behavior, and the fruit follows the usual respiratory pattern which Walford (84) described as a "conventional" tomato. Probably the different respiratory behavior of a few tomato fruits reported by Hartman (34) can be explained on the basis of differences in the maturity stage of the green fruits which were used. Hartman (34) selected green tomato fruits for his tests by their general appearance as indicated by size and color. This is not a reliable method to select a uniform population of tomatoes at the same physiological age, Sando (69), Rosa (68), Fidler (25), Melvin (53), and McCollum (57). The selection of a population of tomato fruits of uniform physiological age is discussed in another part of this paper.

Miscellaneous effects

Ethylene chloride used at the rate of 0.1 cc of a 40 percent solution per liter, and ethylene dichloride .057 cc per liter did not hasten the ripening process of detached green tomato fruits held at 16-18° C. (60.8-64.4° F.) and 25° C. (77° F.). Ethylene chlohydrin was very toxic to tomatoes at these concentrations, Rosa (68).

Soldatenkov and Kubli (76) injected undetached, green developing, tomato fruits with different concentrations of ethyl alcohol, and found that they accelerated the ripening of these fruits to a marked degree. Ethyl alcohol vapors were also tested and found to have a stimulatory effect

although their effect was not as marked as those resulting from injection treatments. Nestrova (57) found ethyl alcohol injections to be much less effective than ethylene.

Jones (40) found that exposure of the tomato fruit to fumes of methyl-bromide led to a delay of from three to six days in the development of detached fruits. Opposing results were presented by Knott and Claypool (44). They found that fumigation with 1 or 2 compounds methylbromide per 1,000 cubic feet space for 24 hours, accelerated the respiratory rate of mature green tomatoes.

Furlong (28) observed the ripening of green fruits left on the cluster. Selected trusses carrying green tomatoes were cut with a portion of the main stem attached. Such fruits held at 65° F., and at 50° F., following a period at 55° F., took 5 or 6 days longer to ripen than similar detached fruits without stems. Those kept at 50° F. for a period before transfer to 65° F. took from 9 to 13 days longer to ripen. These data indicate that green tomato fruits left on the trusses with a portion of the main stem attached ripened at a slower rate than detached fruits kept at the same temperature. The lower temperature was a factor in extending the ripening period, also.

El-Shiate et al. (21) noted that disinfection by dipping tomato fruits in calcium hypochlorite or borax-boric acid solutions appeared to have little effect on decay, quality or composition of the fruit.

The Effect of Kinin, Kinetin, and Auxin on Plant Material

There is considerable evidence that kinins are involved in all phases of plant growth and development. Skoog, as cited by Steward (80), has designated the substances that promote cell division in plants as "kinins" of which kinetin is one.

Miller (54) presents an excellent review concerned with kinetin where he cited and discussed more than 300 papers dealing with its biological effects on plant material. His review shows that kinetin accelerates cell division and influences cell enlargement as well. It also increases shoot initiation, bud elongation, and development. He presents the evidence pro and con concerning its effect on root inhibition. Kinetin breaks dormancy, and promotes seed germination.

Miller's (54) review contains evidence that an intact purine ring in the kinetin (its chemical structure indicates that it is 6-Furfurylamino purine) is required for activity. He finds all research workers are in agreement that, "the furfuryl group attached to the amino group on the sixth position of the purine ring may be replaced by a rather wide variety of substitutions. If the furane ring is replaced by a benzene ring, it gives 6-benzylaminopurine" (known also as N6-benzyladenine and referred to hereafter as N6-B).

Miller (54) states that "N6-B shows activity comparable to kinetin in regard to cell division of tobacco callus tissue, germination in lettuce seeds and cell enlarge-

ment in leaf disks of radish." Actually, N6-B may have a greater effect on these processes than kinetin.

N6-B, a senescence inhibitor produced by Shell Chemical Company, has been used in the past few years on several vegetables, fruits, and cut flowers, in attempts to extend their marketable life. Bessey (5) was the first worker to report on the effect of N6-B on horticultural products by spraying heads of lettuce with N6-B prior to harvest. He used concentrations of N6-B ranging from 10 to 100 gallons per acre in an attempt to evaluate relative effectiveness of different concentrations and dosages applied. The heads were sprayed with all their field wrapper leaves on, then they were cut back and trimmed to five or six wrapper leaves, packed and held at 60° F. After 7 days the evaluation began and continued until the 13th day after treatment. Bessey (5) found that heads treated with N6-B retained their fresh green condition for 3 to 4 days longer than similar untreated heads. An application rate of 100 gallons per acre was more effective than 50 gallons per acre of the same concentration, indicating that heavy coverage of the heads was essential in obtaining a response to treatments.

Kaufman et al. (43) found that freshly harvested cauliflower sprayed with 10 ppm N6-B, and stored at 38° F. were still saleable after 18 days. Most of the leaves on the treated heads were still fresh and green and the curds were white and compact, in contrast to the yellow spotted leaves

of the untreated heads which were unsaleable. N6-B at 10 ppm combined with 50 ppm of 2,4-dichlorophenoxyacetic acid gave similar results.

Asparagus spears held in the dark for 5 days at 21° C. (69.8° F.) had a lower respiration rate when treated with 10 ppm of N6-B, Dedolph et al. (16).

Wittwer et al. (85) studied the effect of post-harvest treatments of N6-B applied as a dip to freshly harvested stalks of green and golden celery (Apium graveolens L.). Their preliminary experiments, using concentrations of 5, 10, 15, and 20 ppm of N6-B plus 40 days at 40° F., indicated that all concentrations from 5 to 20 ppm of N6-B were able to lengthen the shelf life of the treated celery in comparison to the controls (dipped in water). Treatments of 10, 15, and 20 ppm of N6-B significantly reduced the weight loss of the treated stalks. In another experiment, to determine the influence of N6-B, variety, temperature, and storage duration, they applied N6-B at a concentration of 10 ppm. The treated samples were wrapped in heavy wax paper and stored at 40, 50, 60, and 70° F., for 2, 4, 6, and 8 weeks. Weight loss during storage at 50 and 60° F. was significantly reduced, but not at 40 or 70° F. Their data show that "N6-B applied as a post-harvest dip at 10 ppm to celery extended the period of visual freshness, green coloration and market acceptability."

Dedolph et al. (16) dipped freshly harvested broccoli (Brassica oleracea var. italica) into an aqueous solution of

N6-B at 10 and 20 ppm containing a wetting agent, wrapped it in waxed paper and stored samples at 4, 10, 15, and 21° C. The samples were visually examined and evaluated at 2-day intervals. N6-B was effective in slowing the rate of degradation of the marketable appearance of broccoli at all the employed temperatures. However, they found that the weight loss was significantly less from samples treated with N6-B, than from the controls, when held at 4° C. (39.2° F.). Measurements of carbon dioxide production from treated heads of broccoli kept at 21° C. (59.8° F.) were taken at 4-hour intervals for 92 hours. Bud clusters of broccoli were removed from the head and treated with N6-B. After 24 hours at 21° C. (69.8° F.), their respiratory quotient was determined by measuring the oxygen uptake and carbon dioxide evolution. Their data show that broccoli heads treated with N6-B respired less than the control, as indicated by the carbon dioxide evolved. N6-B treated broccoli buds 24 to 26.5 hours after treatment have lower rates of oxygen uptake, and lower rates of carbon dioxide evolution than similar control samples. Observations (16) show that broccoli treated with post-harvest dips at 10, 20, 30, 40, and 50 ppm of N6-B and kinetin (6-furfurylamino purine) and held at 21° C. (69.8° F.) for 48 hours had increased its chlorophyll retention. The effects of N6-B were more pronounced than those of kinetin. Dedolph et al. (16) summarized their results by stating that N6-B applied as a post-harvest dip to freshly harvested broccoli, extended the duration of visual market acceptability and re-

duced weight loss, carbon dioxide evolution, oxygen uptake, and retention of green color.

MacLean et al. (50) in similar work with N6-B as pre- and post-harvest applications to broccoli, reported similar results in reducing respiration rates and extending the storage life of broccoli at 15° C. (59° F.).

Lipton et al. (45)indicate that N6-B effectively retarded yellowing of lettuce (Lactuca sativa var. capitata) in holding and transit tests. N6-B at 10 ppm was sprayed in the field at the rate of 100 and 115 gallons per acre 2 hours before harvest. The lettuce was cut, packed, and vacuum cooled. In the transit tests, the heads were shipped from California to New York and after 8 days of transit at 3 to 5° C. (37.4 to 41.0° F.) were examined and re-examined after 3 additional days at 21° C. (69.8° F.). Also, heads stored in California were examined after 8 days at 3° C. (37.4° F.) and re-examined after another 4 days at 21° C. (69.8° F.). Lipton et al. (45) report a striking retardation of yellowing in lettuce leaves treated with N6-B. This is in agreement with Zink's (91) observation with the same compound on tobacco leaves. Measurements (45) of oxygen uptake of leaf segments for heads of lettuce sprayed in the field with concentrations of 0, 5, 10 and 20 ppm of N6-B and held 7 days at 3° C. (37.4° F.), or 7 days at 5° C. (41° F.) indicates that the rate of oxygen uptake increased as the concentration of the treating solution rose.

This finding of Lipton et al. (45) of higher rates

of oxygen consumption by segments from leaves sprayed with N6-B agrees with those of Osborne (59), who observed a delay in senescence, accompanied by relatively high rates of respiration in leaves of "Prunus serrulata" treated with 2,4-dichlorophenoxyacetic acid and 2,4, 6-trichlorophenoxy-acetic acid. Lipton et al. mention that Bushnell (report at the AIBS meetings, 1961) obtained similar results with wheat leaves treated with kinetin. Their explanation for higher than normal rate of respiration is consistent with retention of cell vigor and prevention of protein decline in detached leaves as a result of these chemical treatments.

This information is not in agreement with the explanation offered by Wittwer et al. (85), and Dedolph et al. (15). They concluded that senescence inhibition in detached fresh explants treated with N6-B is a result of respiration inhibition. However, Lipton et al. (45) suggested that these two conclusions may not be conflicting because of the great morphological and physiological differences between the experimental plant parts used.

Tuli et al. (82) applied N6-B, as a post-harvest dip at 10 ppm with a wetting agent, to market-ripe sweet cherries (Prunus avium L.) and freshly harvested strawberries (Fragaria vesca L.). The fruits were held at 70° F. for 7 days. Weight measurements were reported, the pedicels were oven dried for 24 hours at 140° F. and then the chlorophyll content was determined. They (82) reported that, "although N6-B maintained a higher chlorophyll content in treated sweet

cherry fruit pedicels, which reflected more green color and reduced the loss of fresh weight of the stored fruits, it had no effect on the retention of chlorophyll in strawberry fruit calyxes or cops."

Smock et al. (74) investigated the effect of N6-B on apples when applied as pre-harvest sprays and as post-harvest injections and dips. Their results indicate that this compound accelerated respiration rates of preclimacteric apples and depressed respiration rates in the post-climacteric apples. They consider N6-B to be a "senescence inhibitor" for apples, but doubt that its use will be beneficial to apple producers. Their results with N6-B in several tests in New York, Tasmanian and New Zealand show no beneficial effects on the storage life of apples.

In studies on the effect of N6-B on the post-harvest respiratory rates of cut flowers, MacLean et al. (49) suggest that carnation (Dianthus caryophyllus) and chrysanthemum (Chrysanthemum morifolium) treated with N6-B and held for 7 days at 21.1° C. (70° F.) respired less than control flower stalks as indicated by carbon dioxide evolution. N6-B concentrations ranged from 0, 10, and 20 ppm (with a wetting agent) and was applied by dipping entire flower stalks into the solutions. Carnations responded more to such treatments than the chrysanthemums.

Oyer (62) studied the effect of N6-B on the set of tomatoes. He obtained no marked effect of N6-B on final frost set when used singly or in combination with indolacetic

acid, naphthalene acetic acid or gibberellic acid.

Jones (40), in his preliminary work, found that M6-B seems to be effective in increasing fruit set of muskmelons and watermelons.

Several studies have been made concerning senescence of plant material. The fact that several chemical compounds have an inhibiting effect on the rate of senescence of plant material, and especially with leaves, has stimulated some investigations of the basic factors which control and regulate senescence. The chemical changes that occur in leaves as they grow older has been characterized for many species. A normal future of the aging leaf blade is a continuous decline in the protein level, Chibnall and Wiltshire (12). The most rapid fall occurs during senescence and is associated with irreversible yellowing, loss of chlorophyll, and the eventual death of the organ. The factors responsible for senescence and decline of total protein in the leaf are not fully understood, Osborne (61). He reviews other workers' reports and finds that, "the decrease in protein content of the blade of excised leaves is not necessarily due to the lack of carbohydrate or nitrogen, or to an inability of the cells themselves to synthesize amino acids, but due rather, to a failing ability to incorporate these amino acids into protein." Osborne (61) adds that, "if the leaf has a growing root system, the incorporation of amino acids proceeds normally. This indicates that the roots metabolize and supply the blade with certain factors necessary for the continued synthesis of

protein."

During the past few years, several chemical substances have been shown to retard senescence of leaf blades, and in this respect the compounds would appear to substitute either directly or indirectly for an unknown "root factor."

Person et al. (64) show that floating detached wheat leaves on a solution of benzimidazol at 50 mg. per liter retarded both chlorophyll degradation and protein loss. Similar results were obtained by keeping the petioles of excised leaves of Xanthium dipped into solutions of kinetin at 5 mg. per liter, Richmond and Lang (66). Osborne's (61) presentation of Mothes and Engelbrecht's (56) work in Canada shows that, "they sprayed solution of kinetin directly onto leaves of Nicotiana and reported in (1959) that the retention of chlorophyll is localized to the areas of the blade to which kinetin is supplied. They found that labeled amino acids migrate to, and accumulate in, the treated parts of tobacco leaves, and they suggested that kinetin retarded leaf senescence by causing the treated areas to act as loci for the accumulation of metabolites. Extensive investigations have shown that both protein synthesis and ribonucleic acid synthesis are stimulated in kinetin treated parts of tobacco leaves, Wollgiehn (86)."

In 1959, Osborne (59) demonstrated that indolacetic acid and other auxins are markedly effective in retarding the senescence of detached autumn leaves of Prunus serrulata-sen-riko. In more recent work, Osborne (60, 61) studied effects

of the kinin, kinetin, upon the metabolism of protein and nucleic acids during the senescence of excised leaves of Xanthium pensylvanicum. "Certain changes in the tissue may be correlated with the progress of senescence. These include a fall in the level of extractable chlorophyll, a decrease in the level of nucleic acid, both RNA and DNA, and a reduction in the total content of protein." He found that treatment with kinetin to detached leaves and excised discs, retained chlorophyll, and DNA, and in certain cases caused a small net synthesis of DNA. Both RNA and protein synthesis were stimulated by kinetin treatments as indicated by the observed increase in, incorporation of 14-C-Leucin into protein and 14-C-orolic into RNA. Osborne (61) suggests that, "the effect of kinetin in retarding senescence in Xanthium leaf cells is medicated through its action in sustaining nucleic acid and protein synethesis.

This work is in agreement with the explanation offered by (1) concerning the mode of action of N6-B, a kinin, on plant materials. "After harvest, several processes go on in the plant resulting in destruction of soluble ribonucleic acid (S-RNA), the nucleic acid which catalyzes protein formation. This slows down protein synthesis, the protein in the plant rapidly disintegrates, and amino acids accumulate, thus providing a medium for microorganisms. As the protein of the chloroplasts disintegrates, off-colors in the crop become evident, other breakdown products cause off-flavors."

The first step in degradation of S-RNA is the loss of

the end group which is adenine, and (1) suggests that N6-B reverses this process by providing adenine in an active form to restore the S-RNA molecule. As a result, protein synthesis is maintained. "N6-B, thus, functions as a maintenance hormone stimulating protein synthesis after the plant has been cut off from its normal source of supply," presumably the roots.

Galston and Purves (29) in an excellent review of work done with auxins, present a discussion of the high points of more than 300 articles dealing with auxins. Until now, and regardless of the extensive, careful work done with auxins, their mechanism of action is not known. Auxins were discovered about 40 years ago. The American Society of Plant Physiologists define the term "auxin" as follows: "Auxin is a generic term for compounds characterized by their ability to induce elongation in shoot cells. They resemble indole-3-acetic acid in physiological action. Auxins may, and generally do, effect other processes besides elongation, but elongation is considered critical. Auxins are generally acids with an unsaturated cyclic nucleus or their derivatives," Tukey et al. (81).

Galston and Purves (29) found that auxins promote root initiation, inhibit root elongation, delay leaf abscission, inhibit lateral buds, and induce callus formation. However, auxins do not promote growth of intact plants, especially of the dwarf type, nor promote seed germination and the breaking of dormancy, nor promote

flowering in nonvernalized biennials and in long-day plants.

Although there are numerous reports about the effect of several auxins on horticultural products, especially in relation to fruit thinning, fruit set, fruit abscission, respiration and ripening behavior of several fruits, very little is known concerning the effect of indolacetic acid on these processes.

Smock et al. (73) were the first to report on the use of IAA on intact organs of the plant. They found that the application of IAA as a pre-harvest spray with a wetting agent, to apple fruits delayed their maturity for a few days when applied at 100 ppm. However, the treated fruits respired at about the same rate as the controls.

Woodruff and Crandall (87) conducted a study to determine the influence of several inhibitors on the respiratory rate of apple tissue slices and whole apples. A Warburg manometric procedure was used for measuring oxygen uptake. The total microliters of oxygen taken up per gram of tissue (fresh weight) during the three hours after the addition of IAA, at .005 M, to the tissue in the Warburg flasks was found to be 39 percent (with a range of 24-45) of the volume of oxygen uptake by check sample. They found IAA at .005 M caused severe injury to the tested material. They injected apple fruits, weighing approximately 200 grams each, with 2.5 ml of a distilled water solution of IAA at .0005 M and .001 M. Apples used as check samples were injected with 2.5 ml of distilled water. The apples were kept at room

temperature for two days after injection and then held at 32° F. until their respiratory rates were measured. Lots were removed from storage and held at 70° F. for ten days. During these 10 days, respiratory rates were determined as milligrams of carbon dioxide produced per kilogram fruit per hour. Fruits treated with .0005 M and .001 M IAA respired 130 percent and 154 percent, respectively, more than comparable fruit treated with distilled water, only. Respiration measurements were completed within four months after treating the fruits. Indolacetic acid treated fruits at .001 M were severely injured.

N-dimethylaminosuccinamic acid (B-995) is a plant growth retarding compound produced by the Naugatuck Chemical Division of the United States Rubber Company. In studies with numerous plant species, B-995 has effectively reduced vegetative growth. It, also, has promoted bud initiation in certain other species. Other beneficial effects resulting from the chemical treatment include darker green foliage, stronger stems, and increased drought resistance (3).

Suggested uses (2) of this compound on several vegetables, fruits, and cut flowers are, "In preliminary tests, B-995 sprayed at 1250-2500 ppm on tomato plants during the seedling stage (3rd true leaf ½-1 inch long), increased the yield of marketable fruit in a single maximum harvesting. The same treatment also induced frost resistance in transplants and young seedlings." Spraying tomato plants bearing green fruit with 5000-7500 ppm B-995 is claimed to prevent

blossom-end rot.

In experimental work with this compound on fruit trees, it is reported (2) that, "three applications of B-995 at 2000 ppm commencing in late May through mid-June on various pear, cherry, and apple varieties greatly retarded growth and a greater foliar density was apparent."

Preliminary studies (2) on grapes indicate that "one spray of B-995 applied after fruit reaches full size, but prior to maturity, may increase sugar content. It may be, also, of benefit in controlling vine growth when applied at earlier stages of growth." Greenhouse studies with mint indicated that low concentrations of B-995 will prevent excessive growth and lodging. It also may increase the leaf stem ratio (2).

Information supplied by the Naugatuck Chemical Company (2, 3) suggests that B-995 applied as a spray at a 0.25 percent concentration 7 to 8 weeks after potting controls the height of chrysanthemums, when sprayed once at concentrations of 0.25-0.5 percent in early July, B-995 promotes early and multiple flower buds of azaleas. The growth of single stem plants of poinsettias is retarded when sprayed twice with a 0.5-0.75 percent solution of B-995. The first spray is applied to the rooted cuttings prior to the time they resume active growth, and the second spray is applied five weeks later. Spraying once with a 0.25 percent B-995 solution six to eight weeks after the seeds are sown induces basal branching and controls height of petunias. It is possible to grow

asters as a compact plant by spraying once with a 0.25 percent B-995 when plants start to elongate. Sprays of 1.0 percent or higher of B-995 are claimed to increase the stem strength of carnations grown for cut flowers.

The fact that B-995 is a relatively new compound, being introduced for experimental use, less than three years ago, is reflected in the lack of published work about its effect on plant material.

Jaffe and Isenberg (38) reported that, "B-995 when applied at an early stage, was found to decrease the rate of root and shoot elongation of a variety of horticultural plants. The earlier the application and the greater the number of treatments, the greater was the inhibition to growth. In both field and greenhouse experiments, an increase in the dose of B-995 decreases shoot length of all varieties tested, although the treated plants tended to catch up with the untreated controls eventually. In all cases, flower and fruit yield was decreased with increasing dosage."

Buxton and Culbert (10) sprayed B-995 at concentrations of 2500 ppm and 5000 ppm on Yellow Delaware Chrysanthemums grown as single stem plants in 4-inch pots. The plants were sprayed from 1 to 5 times at 2-week intervals to give 15 different treatments at each concentration. Length of keeping was measured as elapsed time between first pollen and last disc floret to show pollen. Their preliminary work indicates that B-995 significantly lengthens the marketable life of chrysanthemums.

Shanks and Link (71), studying the use of the growth retardant B-995 on Hydrangea macrophylla for greenhouse production, "gave three weekly sprays of a 1 percent solution of B-995 to three varieties of hydrangea at different times during the summer growing period. Shorter internodes were produced on the sprayed plants but the most pronounced effects were evident on the growth made in the greenhouse following eight weeks of storage at 42° F. Among these influences were reduction of internode length, large inflorescences, increased number of flowering stems and a retardation in the rate of development. Sprays of B-995 made during the forcing period in the range of 0.2-0.8 percent were also effective in reducing internodal length."

Cathey et al. (11) found that foliar applications of B-995 were effective on bachelor button, China aster, oleome, cosmos, marigold, petunia, salvia, and zinnia for producing compact plants on any day length. They found B-995 to be effective and non-toxic in the range of 0.08 to 1.0 percent. On plants that were rapidly elongating and initiating flowers, foliar applications of B-995 delayed flowering 3 to 4 weeks.

Other unpublished experimental work (83) with B-995 presently being carried on with apple trees includes that of Edgerton. He suggests that B-995 may increase frost resistance of apple flowers and delays the time of flowering. Bajter, in Washington, is working with B-995 on apple trees to determine its effect on the fruit production, vigor, and

floral initiation. Shutak, in Rhode Island, is investigating its effect on scald of apples.

MATERIALS AND METHODS

Suitable maturity indices for determining the physiological or horticultural maturity of tomato fruits have been sought by many people. Sando (69), Rosa (68), and Fidler (25) found that size of the fruit is not a reliable indicator of tomato maturity. Melvin (53) found that the rate of respiration in tomatoes varies with the size of the fruit. Specific gravity, as a maturity index, was studied by Lutz (46), Nettles (58), and Sorensen (77) and was also found not to be a reliable indicator. Elapsed time after flowering was considered by Sando (69), Work (88), Gustafson (30), Wright et al. (90), Lutz (46), and Sorensen (77). Although time after flowering appeared to provide the best index of maturity, Work (88) and Beadle (4) have shown that competition between fruits in a cluster, and between clusters on a plant lead to differences in fruit growth rate, ultimate size, and rate of respiration. Hood (37), also, has shown that the first fruit in a cluster has a faster maturation and ripening rate than the following fruits on the same cluster. McCollum's (52) work suggests that uniform maturity in mature green tomatoes cannot be determined accurately by age, size, or other apparent characteristics.

In the absence of a precise method for judging the

maturity stage of tomato fruit, fruits of uniform color, size and general appearance were used as maturity indices in the selection of mature green, pre-climacteric, (before the degradation of the green color and development of any red color) tomatoes for use in the summer experiments. Fruits were taken to the laboratory immediately after harvest. They were then washed with tap water, dried individually and selected for size, color, and general appearance. These fruits were then randomly divided into equal lots for the different treatments. The number of fruits used in each lot in each experiment are indicated later in the text. This procedure was not completely satisfactory and at the end of some experiments, there were occasional fruits which remained green throughout the test period because they were apparently harvested in an excessively immature condition. However, this problem existed to a similar degree within almost every lot of fruit used in any given experiment. Consequently, the relative influence of chemical treatment on respiration and ripening on similar lots of fruit was possible.

Lyons (48) recently reported that tomato fruits of uniform physiological maturity could be produced by the following procedure: "On a given day, when 1 to 4 clusters on a plant showed open flowers with the petals fully reflexed, either the first or second flower in each cluster was pollinated with a mechanical shaker, the flower was identified with a dated tag, and the remaining flowers in each cluster

were removed. Any additional flower clusters were removed if they contained well-developed flowers that appeared about to open. Immature flower clusters were left on the plant. This procedure was repeated at weekly intervals until the total number of fruits on each plant reached 10 to 12, each from a separate original flower cluster.

To further limit the population, the individual fruits were measured when they were 7 to 10 days old. Fruits within the range 2.5 to 3.5 cm. were retained. Fruits falling outside this size range were removed, so that each plant finally supported 5 to 7 fruits with an age difference of up to 3 weeks between the youngest and the oldest and with no more than 2 of the fruits set on any one date of pollination and tagging. Subsequently, all other flower clusters were removed, so that only the selected fruits developed." Lyon found that fruits pollinated on the same day and meeting the above size limitation were of the same physiological age. A system very similar to that suggested by Lyon was used to produce uniform lots for the fall greenhouse experiments. The only difference between the system used and that suggested by Lyon was that the fruits were not thinned and every plant carried from 10-12 fruits instead of from 5 to 7 as he suggests. This modification was employed because of the need for a larger number of tomato fruits for the respiration and color tests than would have been available using Lyon's method.

Fruits used in each experiment from greenhouse

tomatoes were pollinated on the same day and were of similar size and color. Fruits in the mature green stage were carried to the laboratory immediately after harvest. Here they were divided at random into lots of equal numbers for the different treatments. All of the treatments were applied within a few hours after harvesting the fruit. Light transmittance of these mature green fruits was measured at different wave lengths by the "Biospect."[1] The readings recorded as discussed later in the text, show these tomatoes were of very similar color, indicating that all fruits used in these experiments were initially of uniform maturity.

That Lyon's (48) method of selection of fruit of the same physiological age is a reliable one was evident as indicated by eventual red color development. Surface color measurements by the "Triplett"[2] meter and interior color development by the "Biospect" showed these fruits to ripen uniformly and behave similarly. In all the experiments, there were no fruits that did not ripen to full color and appreciable softness at the end of each test.

The influence of N6-benzyladenine (N6-B),[3] N-dimethylamino succinam acid (B-995),[4] indolacetic acid (IAA),

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[1]Biospect is a trade name for a single beam spectrophotometer capable of measuring optical densities from 0 to 10, manufactured by Agricultural Specialties Co., Inc., Hyattsville, Maryland.

[2]Triplett is a trade name for a surface color meter manufactured by Agricultural Instrument Co., and described later in this text.

[3]N6-B supplied by Shell Chemical Company.

[4]B-995 supplied by Naugatuck Chemical Company.

and 6-furfurylamino purine (Kinetin) on the respiration, surface and interior color, and firmness of pre-climacteric tomato fruits was determined.

There are several different methods of applying chemicals to detached, fleshy fruits. It may be done by dipping, spraying or injection procedures. As discussed previously, it has been shown that the skin of the tomato fruit is impermeable to gas exchange, and that gas exchange takes place through the stem-scar (9, 14, 22). Therefore, spraying such tomato fruits with chemical compounds probably does not result in any appreciable chemical absorption. Dipping the fruit in a chemical solution does not insure absorption either, although some of the solution may enter the intact fruit through its stem-end scar, depending upon the length of dipping time and other factors. However, such methods are incapable of providing one with an exact means of introducing a known amount of chemical into a fruit of a given weight. In addition, "injections" are not satisfactory because of injury to the fruit. Such injury may influence the rate of ripening and respiration and provide a point of entrance for decay organisms.

Southwick and Lachman (78) developed a method whereby a known amount of chemical solution can be introduced into detached tomato fruit through the stem-end scar. Immediately after removal of the fruit stem-pedicel, one milliliter of solution per 100 grams of fruit weight was applied to the scar area. They found that some tomato fruits would absorb the

liquid in one hour or less, but the remainder would not. The addition of a wetting agent had no effect on this behavior.

This is a reliable method for treating intact detached tomato fruit with chemical compounds in solution, but only about 50 percent of the treated fruits absorbed the test liquid. Considering the difficulty of obtaining uniform tomato fruits in sufficient quantity this procedure is quite wasteful of sample material. Consequently, a modification of this technique, suggested by Dr. F. J. Francis, was employed which resulted in a 100 percent intake of chemical solutions into detached fruits.

This method involves cutting the fruit from clusters, with the stem-pedicels attached to the fruit. They are then brought immediately to the laboratory where the attached stem parts are removed. A small volume (0.5 ml per 100 grams of fruit weight) of a given concentration of the test material is placed on the stem-end scar of the tomato. The fruits are then placed in a gas tight container (Figures 1 and 2). By means of a vacuum pump, a known negative pressure is created within the container. Creation of this slight negative pressure around the tomato fruits results in the loss of some of the fruit's internal gases, (this was observed by small bubbles passing through the liquid placed on the stem-end scar). Release of the negative pressure is followed immediately by the absorption of the material into all of the fruits. No apparent injury to the fruit occurred

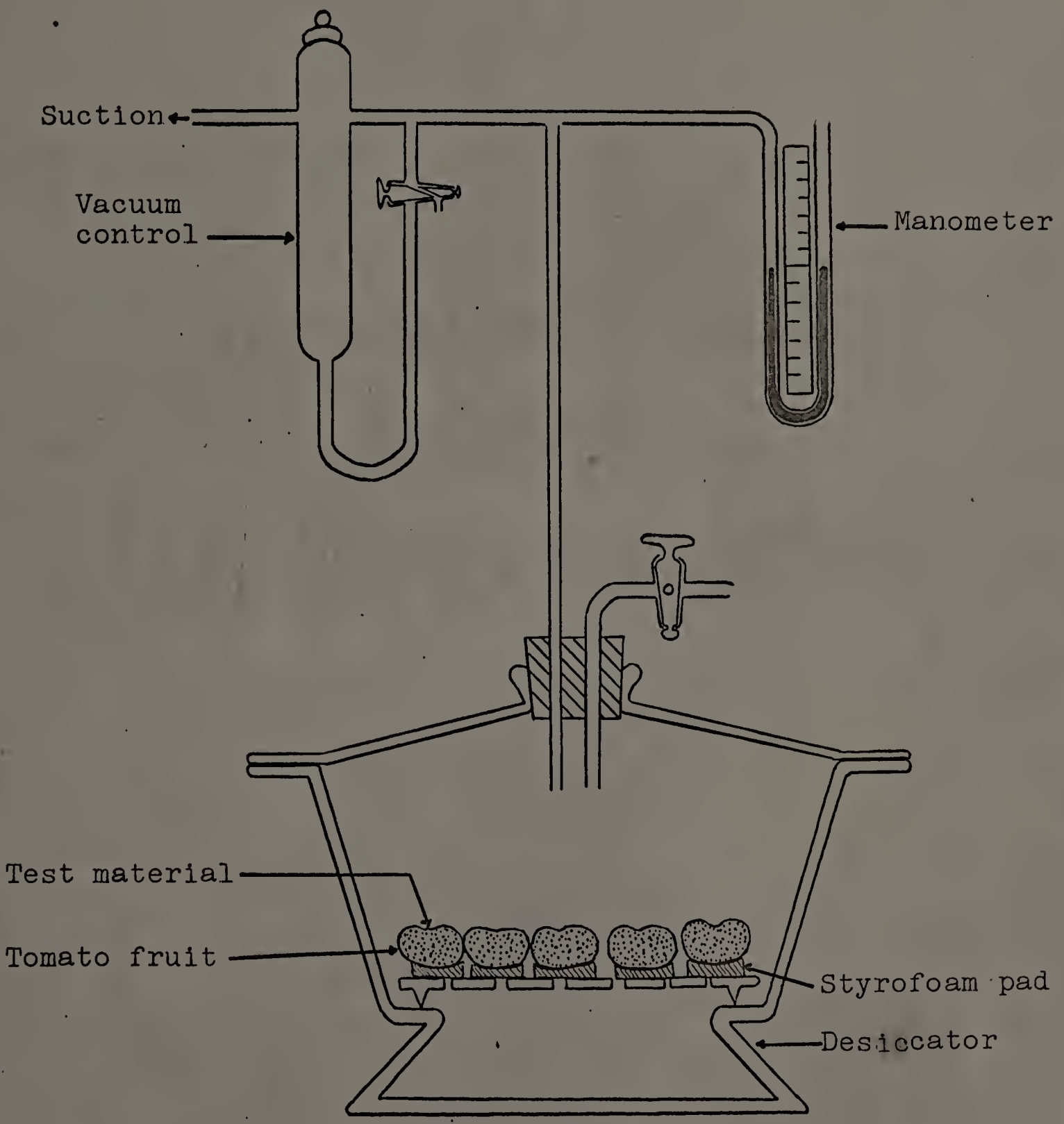


Fig. 1. Vacuum Apparatus

Fig. 2. Vacuum Apparatus

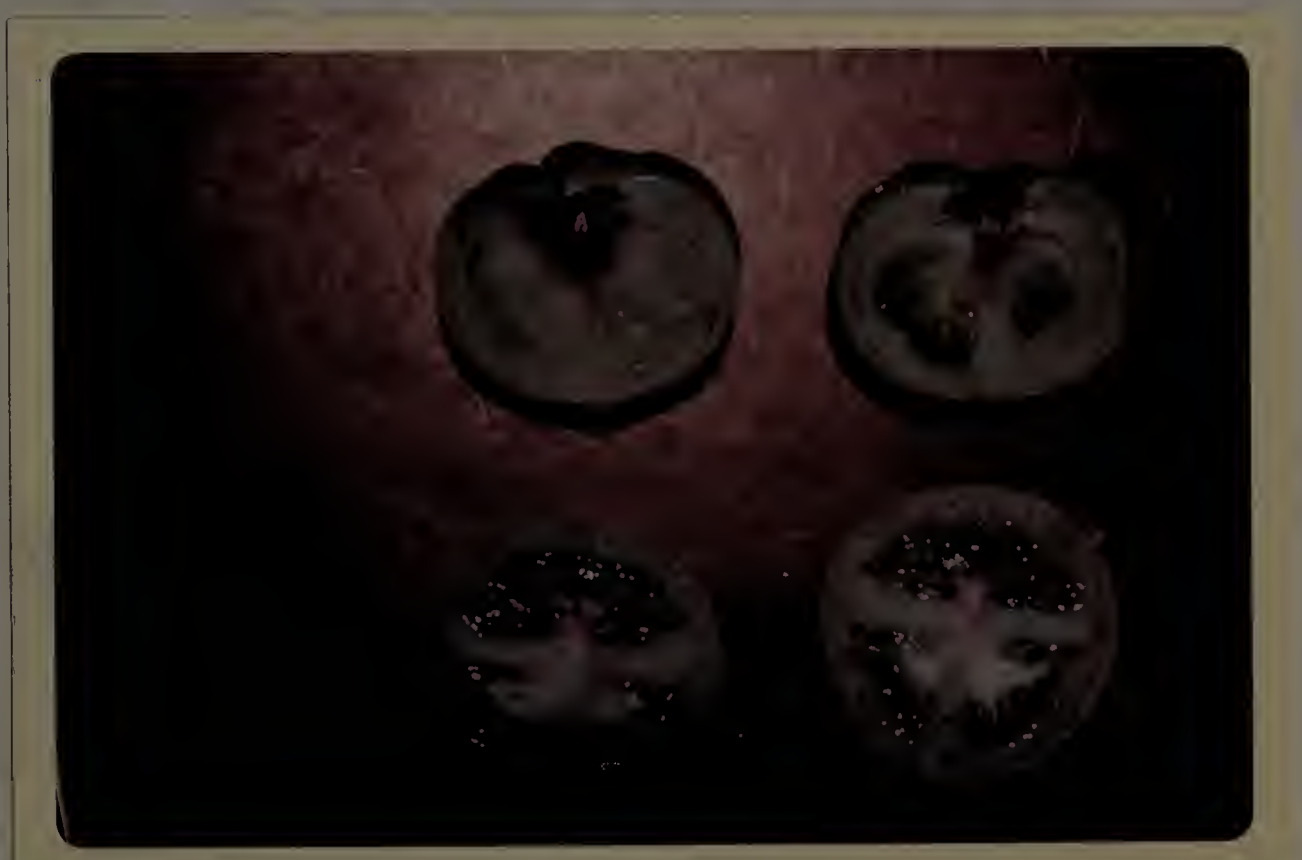


Fig. 3. Tomato fruits showing the distribution of red dye applied by the vacuum method.

in these tests.

Preliminary work shows that subjecting detached mature green tomato fruits to a negative pressure of 18 centimeters of mercury for 60 seconds is sufficient to induce the fruit to absorb 0.5 millimeters of liquid for every 100 grams of fresh fruit weight (Figure 3). This ratio of volume of solution to fruit weight was used throughout these experiments. A comparable volume of distilled water was introduced into the control fruit. Southwick and Lachman (78) showed that distilled water applied to pre-climacteric tomato fruit hastens the rate of respiration and red color development.

The respiration of detached tomato fruits at 74° F. was measured by determining the amount of carbon dioxide liberated from a known weight of fruit over a given period of time. The apparatus (23) used is shown in Figure 4. The respiratory rate is expressed as the milligrams of carbon dioxide produced per kilogram of fruit per hour. The rate of air flow, in the respiration apparatus, was maintained at levels above 0.03 cubic feet per minute with a mercury pump. Emmert (23) found the critical air flow level to be between 0.01 to 0.03 cubic feet per minute. A flow rate somewhat above this critical level had little or no effect upon the amount of carbon dioxide produced by the tomato fruits. Therefore, the flow of air through the apparatus was maintained well above this threshold level.

In preliminary experiments, more than one layer of fruit was placed in the respiration jars. Tomatoes in the

1. CO_2 absorption tower.
2. Glass-Sintered disc.
3. Wash solution (Sodium hydroxide).
4. Respiration chamber.
5. Test fruits.
6. Constant temperature water bath.
7. Humidifier.
8. Wash bottle (Sodium hydroxide).

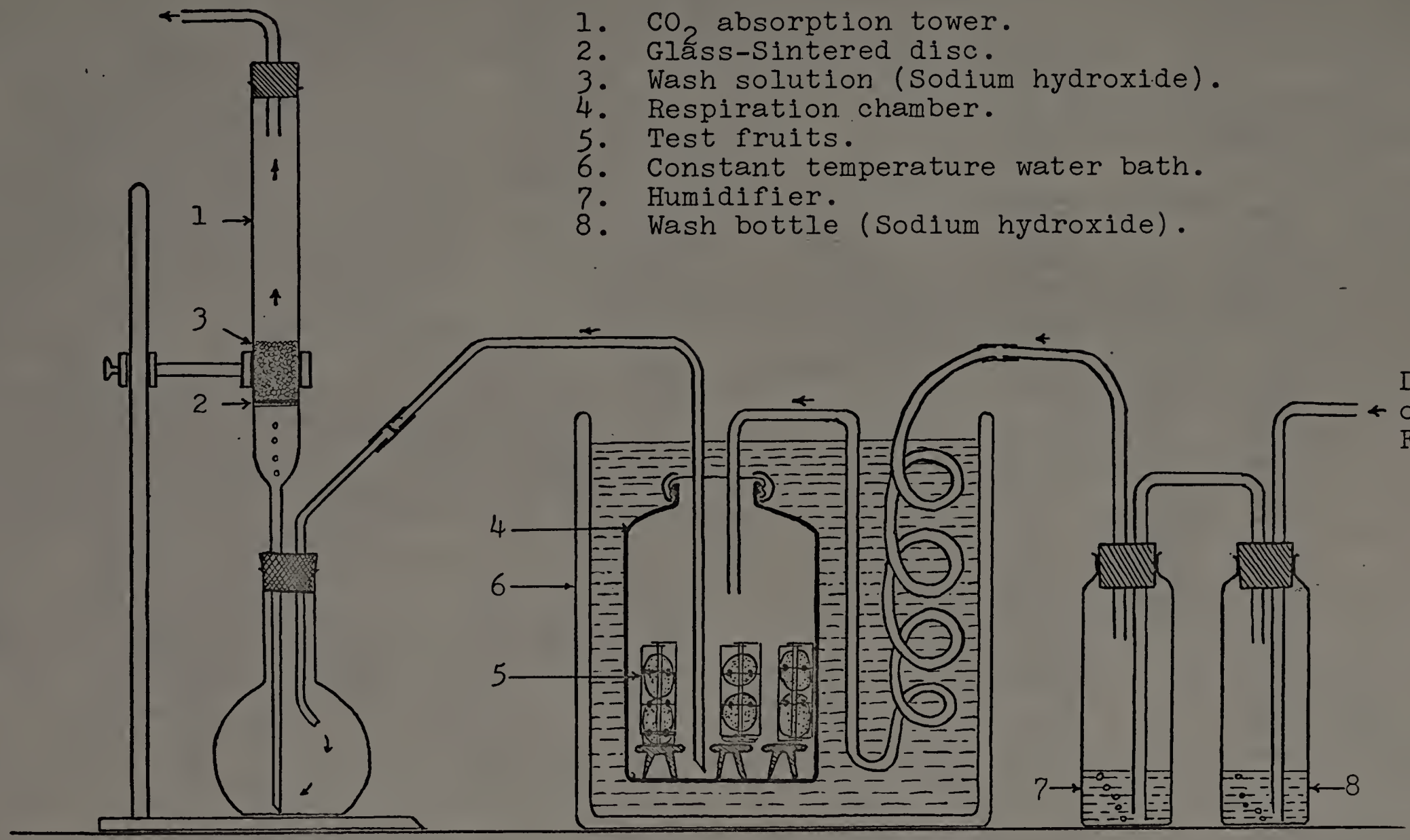


Fig. 4. Respiration Apparatus.

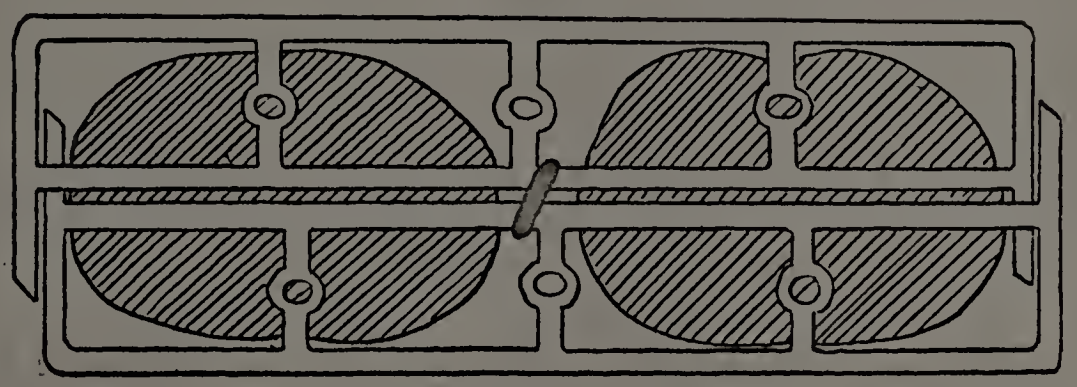


Fig. 5. Compartmented cage for tomatoes.

lower layers became soft because of the pressure created by the weight of fruit in the upper layers. To avoid this effect, two to three tomatoes were placed in a compartmented cage made of two plastic trays (Figure 5). Several of these open, plastic, cage-like containers, with tomatoes in them, were placed in the respiration jars.

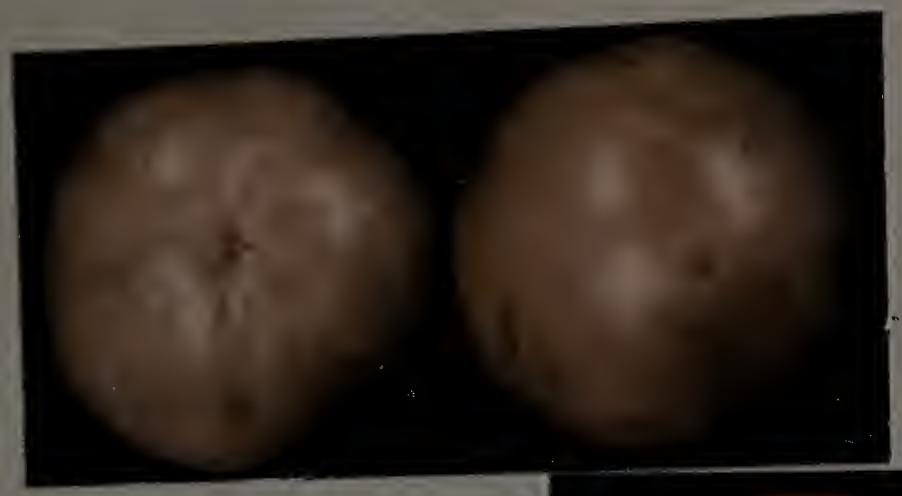
The color change in the tomato fruits was measured objectively by the "Triplett" and the "Biospect." Triplett, Model 420, was used to evaluate the surface red color development in the fruits. It measured the amount of light reflected by a rotating object. A Sylvania bulb, 32 W Cool white standard was the source of light. A red cylinder was used as a standard to give a reading of 100. The color of the tomato fruit was evaluated in comparison with this red standard. Table 1 and Figure 6 show the different classes that describe the color development of the fruits.

Table 1

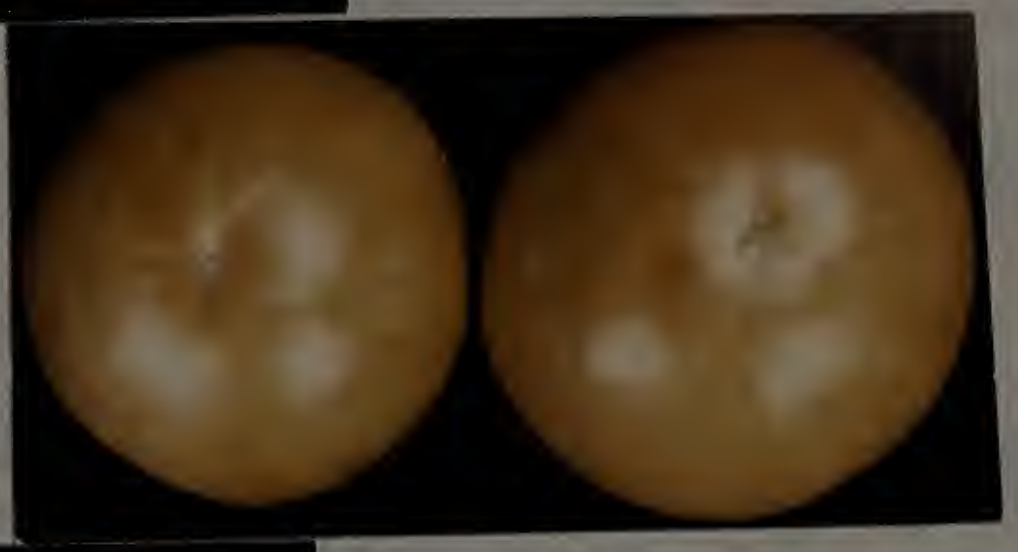
Class	Surface Color[a]	Description
Green (G)	45-55	Entirely green
Pink (P)	56-85	Entirely pink, very little, if any green
Red (R)	86-105	Entirely red

[a]Values are reported in arbitrary units.

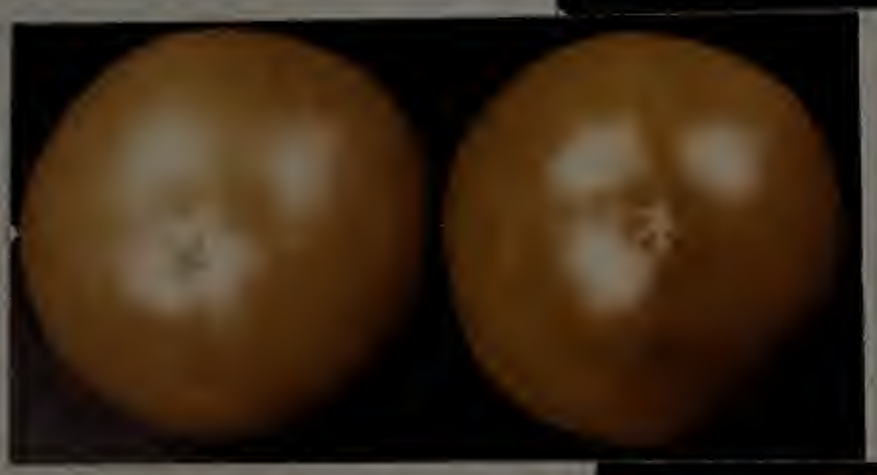
The Biospect No. 60 is used to measure the interior



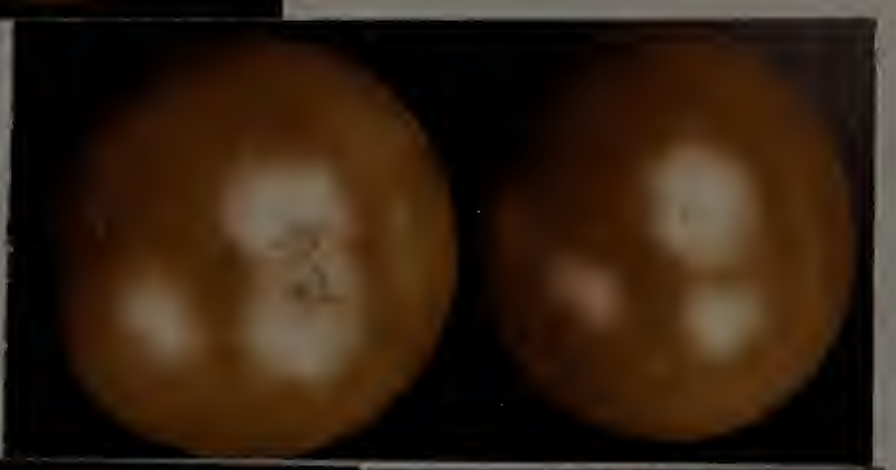
Green "45-55"



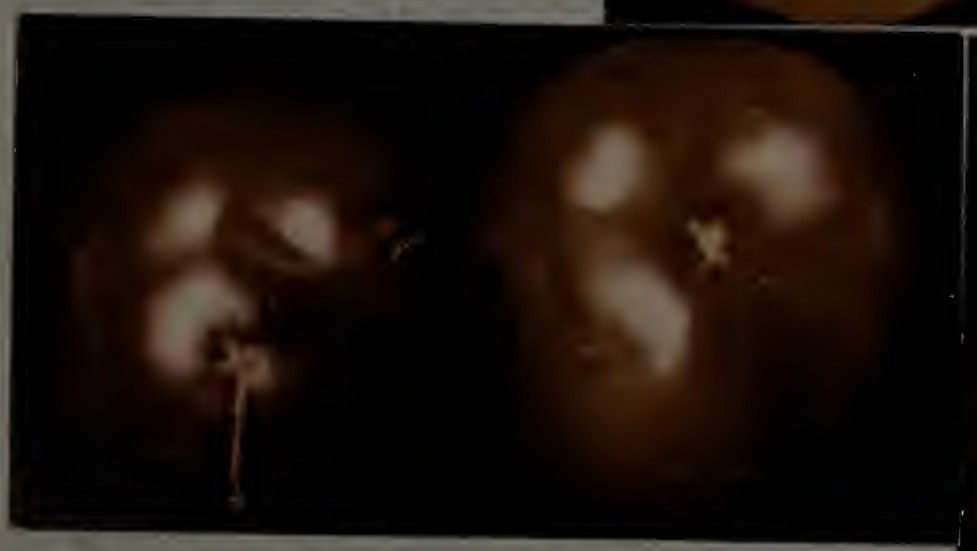
Pink "65"



Pink "75"



Red "90"



Red "105"

Standard "100"

Fig. 6. Stages of red color development of tomato fruits.

color changes in the test fruits. The Biospect is a non-destructive instrument which measures the interior color of tomatoes by spectral transmission. The instrument was equipped with an RCA 6217 photomultiplier tube, and a Bausch and Lomb[1] high intensity grating monochrometer as the light source. The monochrometer was equipped with entrance and exit slits of 1.34 and 0.75 mm, respectively (Pair "A"). The instrument was set to measure 10 optical density units. This method was described by Birth (7) and Birth et al. (8). The data were calculated by measuring the difference in optical density between wave lengths 620 mμ and 670 mμ.

Generally, within a given variety, firmer fruit is less mature than comparable softer fruit. Therefore, firmness measurements were made in these experiments as an aid in evaluating the effect of the different chemicals on the rate of tomato fruit ripening.

A number of pressure or firmness testers have been developed to measure firmness of fruit as it relates to maturity, especially on apples, pears, peaches, and plums.

Several pressure testers were suggested by Fisher and Sengbush (26), Lutz (46), and Paech (63), and Hamson (33) to measure firmness of tomatoes. Hamson (33) discussed these testers and reported that, Fisher and Sengbush measured firmness by placing a tomato under a cork attached

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[1] Bausch and Lomb, Rochester, N. Y.

to a fulcrum along which a weight was shifted until the tomato was split. They found that different diameters of fruits affected firmness readings, and it was difficult to tell just when the fruit had split. Lutz (46) measured firmness as the extent of spring compression on a weight scale. Pasch (63) determined firmness of tomatoes by forcing a plunger against the fruit until it was punctured. This latter method required a gradual increase of pressure until the fruit was punctured. Hamson (33) commented that these methods of measuring firmness in tomatoes were either insufficiently accurate or readings of firmness could not be obtained quickly enough. Consequently, Hamson developed another pressure tester for measuring the firmness of tomato fruits. This "Cornell Pressure Tester" involves the measurement of the compression of the fruit by a plunger of a given diameter exerted by a given weight. Hamson, however, reported that there are significant differences in the tomato firmness depending upon the position of the plunger on the surface of the fruit. This is especially true for a variety with large locules. Such a problem might be expected to exist whenever firmness is determined from a single-point compression.

Kattan (41, 42) felt that a method of measuring firmness employing a multi-point-compression principle might overcome this difficulty and developed the "firm-o-meter" which employs this principle. The fact that the "Cornell pressure tester" was available accounts for its

use in the following experiments (see Figure 7). Readings were made by placing the tomatoes on the specimen platform of the pressure tester so that a straight line extending through the fruit from the stem scar to the styler-scar would be parallel to the surface of the platform and the plunger would contact the fruit at its greatest diameter. Hamson found that the difference in the diameter of the fruit does not have any significant effect on the compression of the fruit. Hamson (33) compared the use of weights of 500, 1000, 1500, and 2000 grams with a one-inch plunger to determine which weight showed the greatest separation of readings of firmness between soft and firm fruits. He showed that greater differences in readings of firmness were evident by using a 2 kilogram weight, for 5 seconds. This latter method was used throughout all the following experiments to determine fruit firmness.

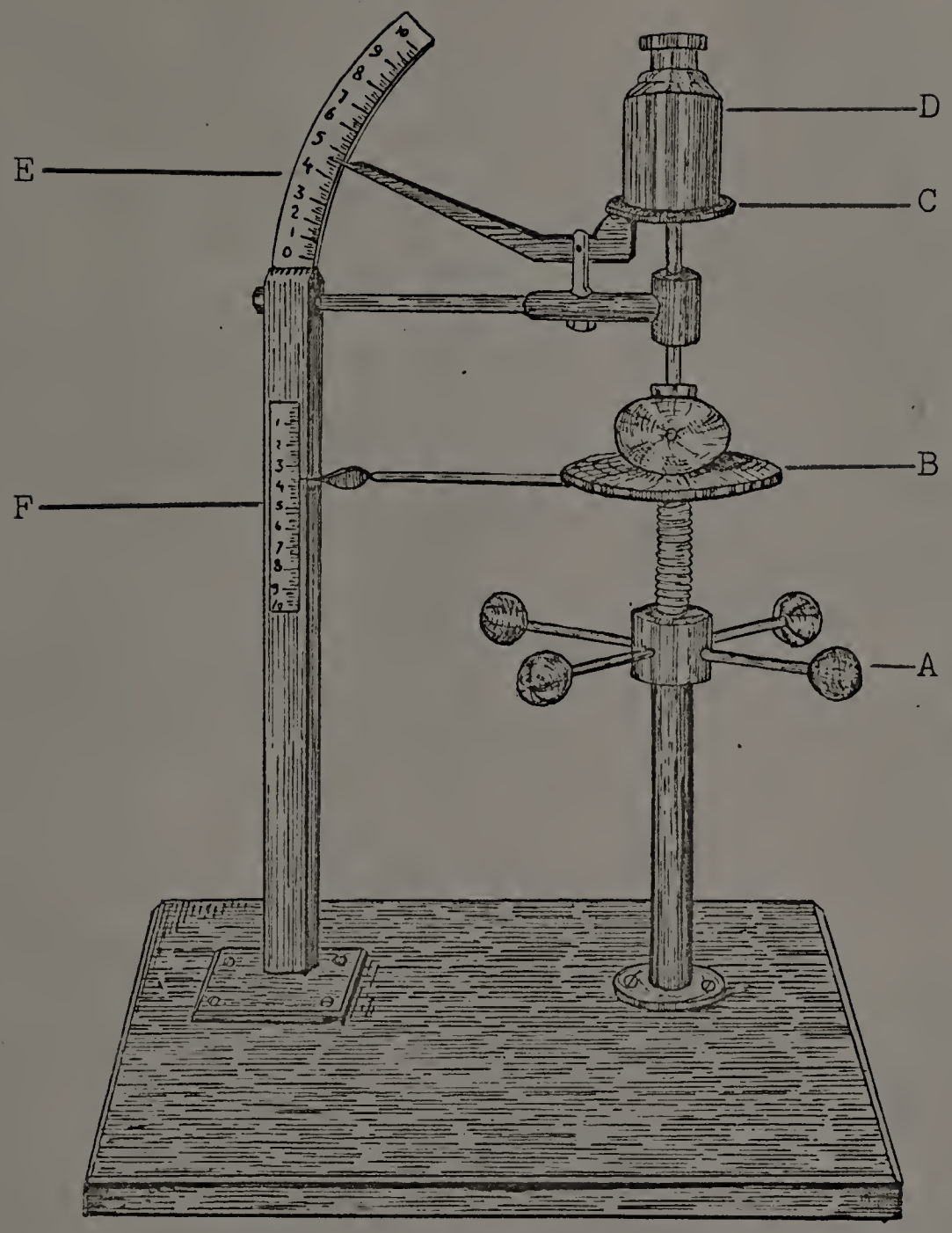

Fig. 7. Cornell Pressure Tester.

A. Hand nut
B. Specimen platform
C. Indicating platform
D. Weight
E. Calibrated scale for indicating degree of firmness
F. Calibrated scale for indicating diameter of fruit.

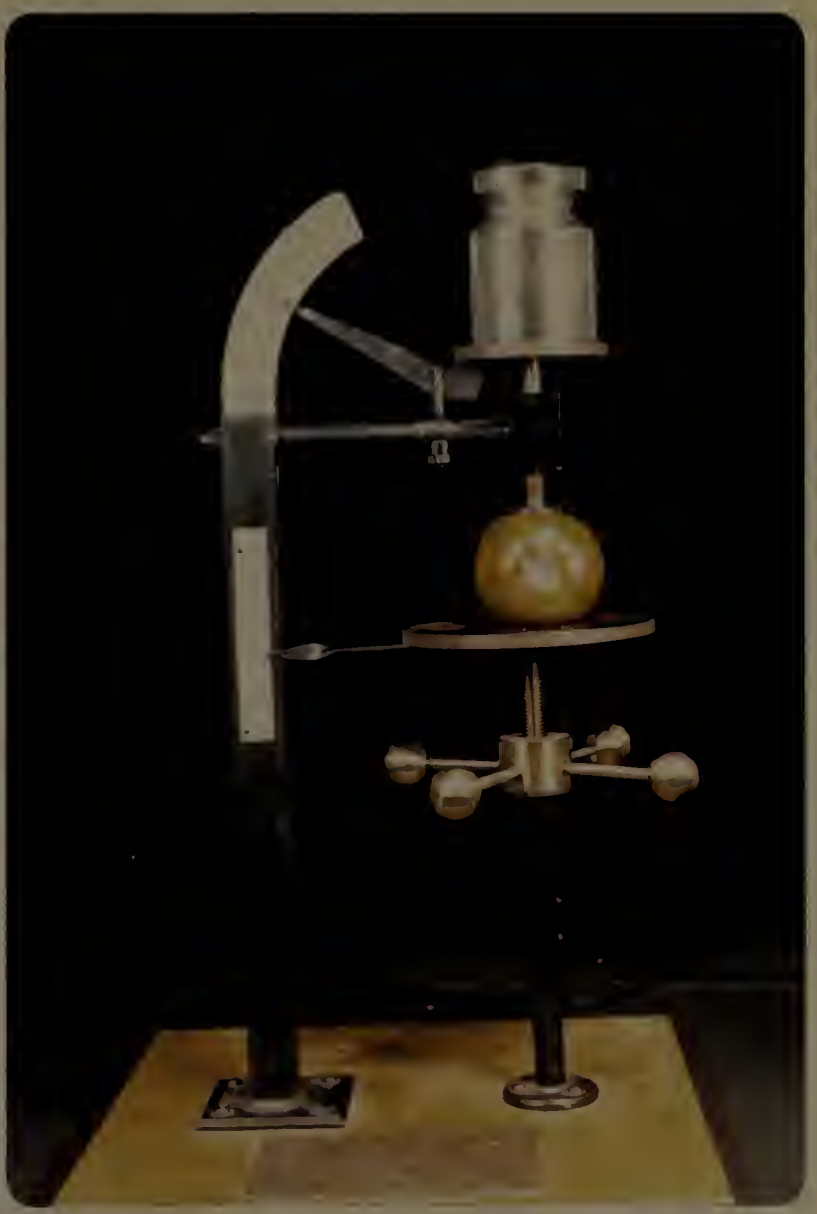

Fig. 7. Cornell Pressure Tester.

RESULTS AND DISCUSSION

Section I

In the summer of 1963, the tomato cultivars Valiant and Trellis #22 were grown in the field and during the months of August, September and October various lots of fruit in the mature green stage were selected for use in the following experiments.

Experiment 1

Duplicate samples of preclimacteric Valiant tomatoes were treated with solutions containing 10, 50 and 100 ppm of N6-B at the rate of 0.5 ml. per 100 grams of fresh fruit weight. Comparable lots treated with an equivalent amount of distilled water served as controls in all of the experiments. Each lot contained 14 fruits.

The data in Figure 8 show that preclimacteric Valiant tomatoes treated with 10 ppm N6-B tended to have a slightly lower respiratory rate than fruits treated with distilled water. Moreover, fruits treated with 10 ppm N6-B respired less than fruits receiving treatments of 50 and 100 ppm N6-B. Fruits treated with 50 ppm N6-B respired at a rate not consistently different from that of the controls. When N6-B was used at 100 ppm it appeared to stimulate the rate of respiration.

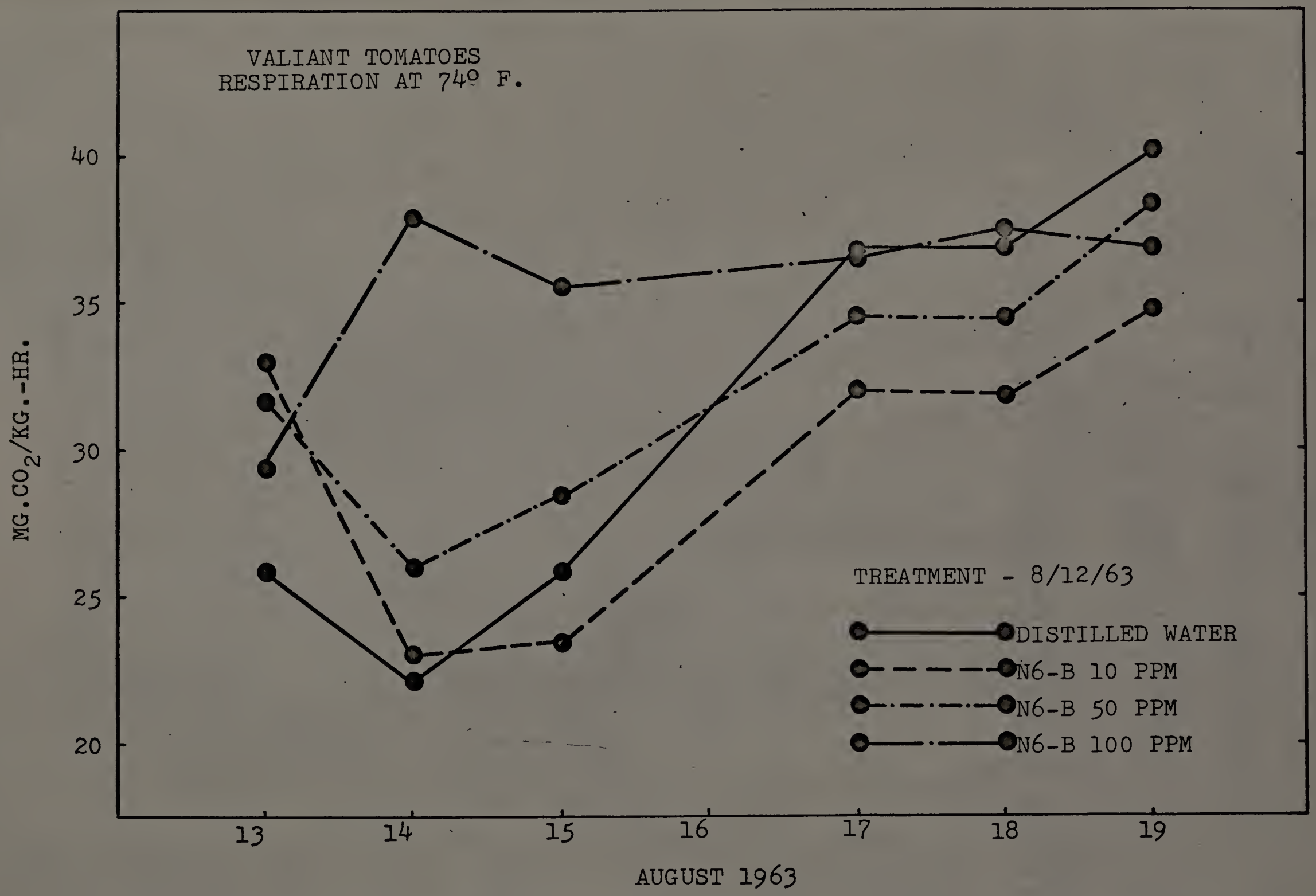

Fig. 8. The influence of N6-B on the rate of respiration of detached tomato fruits.

It was found that preclimacteric Valiant tomato fruits treated with N6-B at concentrations of 50 and 100 ppm caused internal injury and breakdown in many of the treated fruits. This effect was localized principally around the stem-end scar as a brownish discoloration in the flesh which was soft and watery in texture. Approximately 60 per cent of the fruits treated with 100 ppm of N6-B showed these symptoms, whereas only about 35 per cent of fruits treated with 50 ppm N6-B were affected similarly. Fruits treated with 10 ppm of N6-B showed no apparent injury. The acceleration of the respiratory rate in fruits treated with 100 ppm N6-B may be related to the injurious influence of the chemical.

The inhibition of the respiratory rate of fruits treated with 10 ppm N6-B and its acceleration following treatment of 100 ppm N6-B was reflected in the red color development as shown in Table 2. The least red color development was found in lots treated with 10 ppm of N6-B and the controls. Twelve days after treatment 64 per cent of the control fruits and those treated with 10 ppm N6-B were in the red class in comparison to 71 per cent of the fruits treated with 50 and 100 ppm of N6-B. Fruits treated with all concentrations of N6-B were slightly softer than the controls.

The findings in Experiment #1 suggest that N6-B at 10 ppm may have a slight inhibiting influence on the rate of respiration of immature tomatoes. Obviously, 50 and 100

Table 2. The influence of N6-B on the red color development and firmness of detached Valiant tomato fruits treated in the mature green stage and held for 12 days at 74°F.

Treatment[a]	Per cent of fruit			Surface color[b]	Firmness (C.p.u.)[c]
	green	pink	red		
Distilled water	28	8	64	86.3	2.9
10 ppm N6-B	25	11	64	85.4	3.2
50 ppm N6-B	21	8	71	89.7	3.3
100 ppm N6-B	7	22	71	93.2	3.4

[a]Fruits were treated on 8/12/63; 28 fruits per lot.

[b]Values are reported in arbitrary units; see text.

[c]Cornell pressure units.

ppm were unsuitable because of their injurious effect.

Experiment 2

Twin samples (20 fruits per lot) of preclimacteric Valiant tomato fruits were treated with 5, 10 and 25 ppm of N6-B and placed in the respirator at 74° F. The respiratory rate was measured for 8 days after treatment. Fruits were then removed from the respiration apparatus and allowed to ripen for another 6 days at room temperature (65-75° F.). During this latter period the surface color was determined at various intervals.

Figure 9 suggests that treatments of 5, 10 and 25 ppm of N6-B inhibited the amount of carbon dioxide output of these tomatoes during the preclimacteric phase. The lower concentrations of N6-B (5 and 10 ppm) had a greater inhibitory effect than 25 ppm. However, this inhibitory effect did not continue during the postclimacteric period. The data in Table 3 show that 9 days after treatment 5 ppm of N6-B had an inhibiting effect on chlorophyll breakdown and lycopene development. Only 5 per cent of the fruits treated with 5 ppm of N6-B were in the red class (and had the lowest surface color readings) in comparison to 15 per cent for the controls and 17.5 per cent for fruits treated with 10 and 25 ppm of N6-B. Fourteen days after treatment, the influence of 5 ppm of N6-B on lycopene development was no longer evident to the unaided eye. No significant differences in fruit firmness among treatments existed at this time.

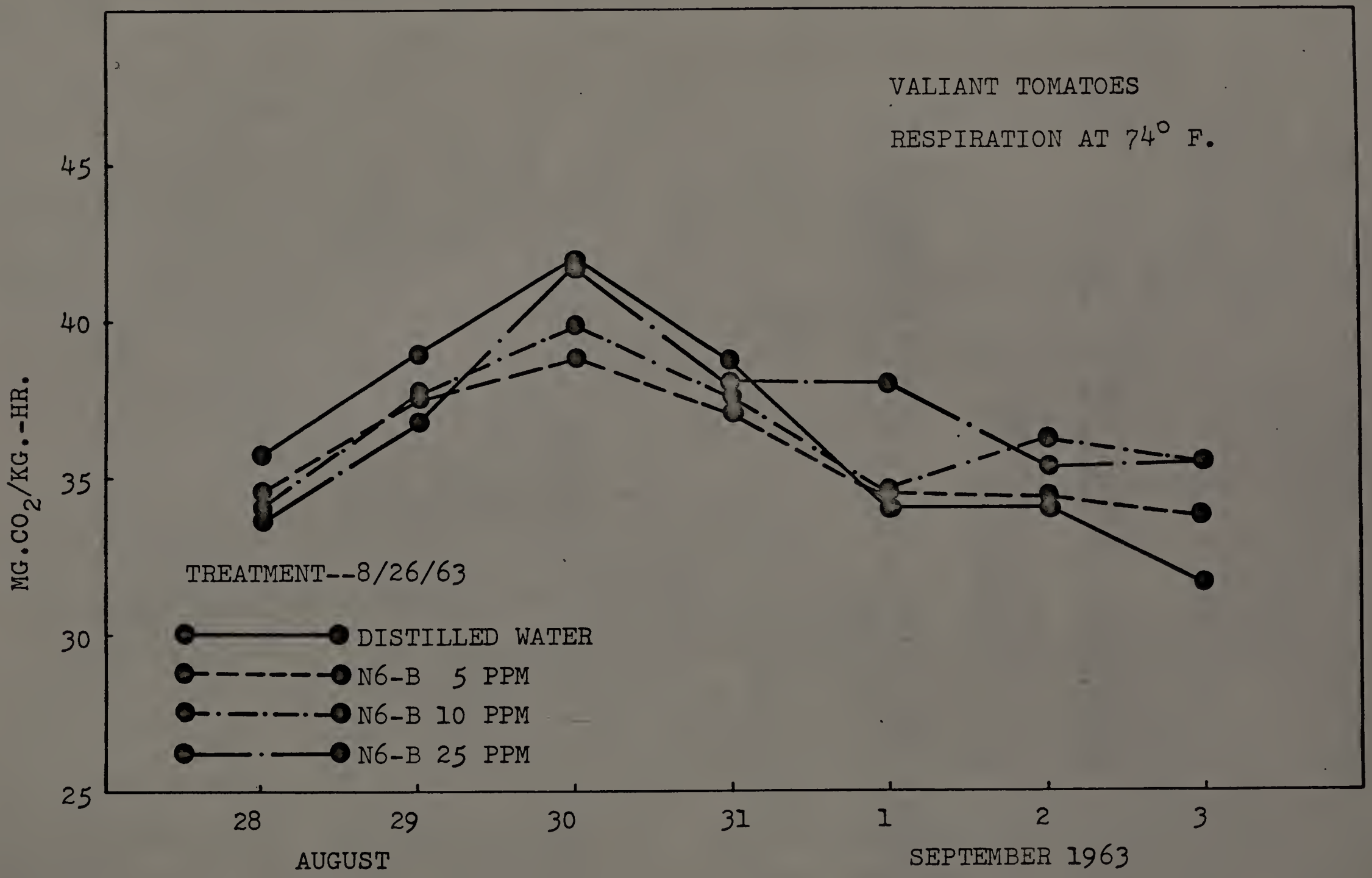

Fig. 9. The influence of N6-B on the rate of respiration of detached tomato fruits.

Table 3. The influence of N6-B on the red color development and firmness of detached Valiant tomato fruits, held for the first 8 days at 74° F. and at room temperature (65-75° F.) thereafter.

Treatment[a]	Per cent of fruit			Surface color[b]	Firmness (C.p.u.)[c]
	green	pink	red		
9 days after treatment					
Distilled water	62.5	22.5	15.0	60.0	--
5 ppm N6-B	62.5	32.5	5.0	58.2	--
10 ppm N6-B	60.0	22.5	17.5	61.6	--
25 ppm N6-B	60.0	22.5	17.5	60.0	--
11 days after treatment					
Distilled water	32.5	30.0	37.5	71.7	--
5 ppm N6-B	32.5	30.0	37.5	71.4	--
10 ppm N6-B	35.0	27.5	37.5	74.1	--
25 ppm N6-B	27.5	40.0	32.5	72.8	--
14 days after treatment					
Distilled water	15.0	10.0	75.0	87.4	2.9
5 ppm N6-B	20.0	10.0	70.0	86.6	3.1
10 ppm N6-B	17.5	7.5	75.0	86.6	3.1
25 ppm N6-B	10.0	15.0	75.0	90.7	3.1

[a]Fruits were treated on 8/26/63; 40 fruits per lot.

[b]Values are reported in arbitrary units; see text.

[c]Cornell pressure units.

Experiment 3

In an attempt to confirm whether low concentrations of N6-B have an inhibiting influence on the respiratory rate of preclimacteric Valiant tomato fruits, as suggested by the data of Experiment 2, an additional experiment was conducted. Duplicate samples (20 fruits per lot of preclimacteric Valiant tomato fruits were again treated with solutions of 5, 10 and 25 ppm of N6-B.

The data in Figure 10 suggest once again that treatment of 5 ppm of N6-B has an inhibiting influence on the respiratory rate of detached Valiant tomato fruits. However, fruits treated with 10 and 25 ppm N6-B did not respire at a rate significantly different from the controls. Red color development, after 13 days of treatment, appears to be in harmony with the respiration data. At this time Table 4 shows that 70 per cent of fruits treated with 5 ppm of N6-B were in the red class in comparison to 72.5 and 77.5 per cent for the controls and other treatments with N6-B.

Even at 5 ppm, it is apparent that N6-B has no marked ability to delay lycopene development and this compound has no appreciable influence on fruit firmness. It is possible that concentrations of N6-B below 5 ppm might have been more influential in delaying ripening.

Experiment 4

Samples consisting of 20 preclimacteric Trellis #22 tomato fruits received treatments of 5, 10 and 25 ppm of

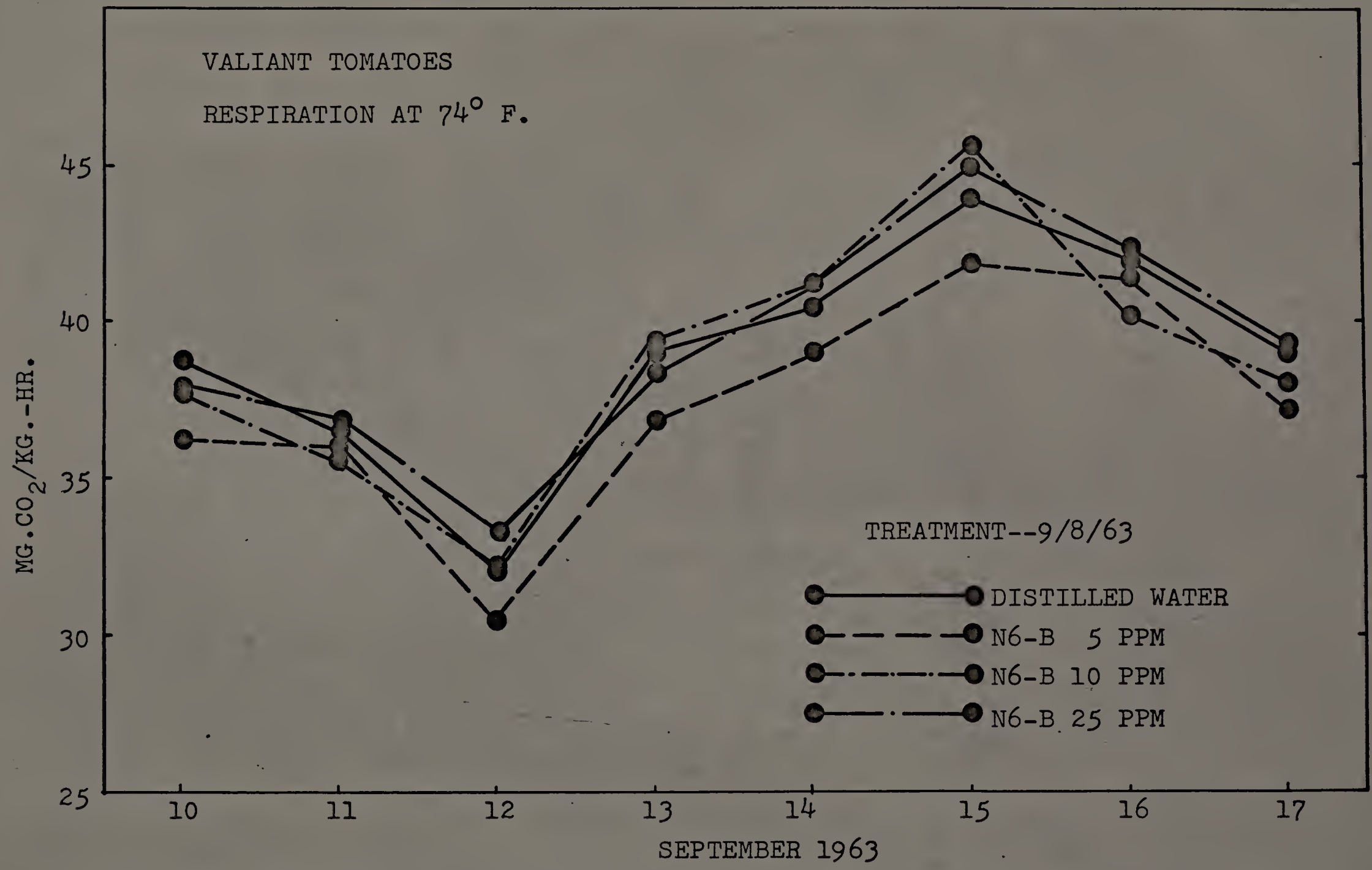

Fig. 10. The influence of N6-B on the rate of respiration of detached tomato fruits.

Table 4. The influence of N6-B on the red color development and firmness of detached, preclimacteric Valiant tomato fruits, held for 9 days at 74° F., followed by 4 days at 65-75° F.

Treatment[a]	Per cent of fruit			Surface color[b]	Firmness (C.p.u.)[c]
	green	pink	red		
Distilled water	7.5	20.0	72.5	88.4	3.0
5 ppm N6-B	5.0	25.0	70.0	89.1	3.1
10 ppm N6-B	7.5	15.0	77.5	91.5	3.1
25 ppm N6-B	5.0	17.5	77.5	93.1	3.2

[a]Fruits were treated on 9/8/63; 40 fruits per lot.

[b]Values are reported in arbitrary units; see text.

[c]Cornell pressure units.

N6-B; 25, 50 and 100 ppm of kinetin; 50, 100,250 and 500 ppm of B-995 and 10, 25 and 50 ppm of IAA. Fruits were then allowed to ripen on a table at room temperature (65-75° F.). The influence of these treatments on surface red color development was evaluated 5, 9 and 15 days after treatment. After 19 days the experiment was terminated and the firmness of all fruits in each lot was determined.

The data in Figure 11 indicate that treatments of 5 and 10 ppm N6-B inhibited chlorophyll degradation and delayed the lycopene development in preclimacteric Trellis #22 tomato fruits during the first 5 days following treatments. Table 5 shows that after 5 days of treatment none of the fruits treated with 5 and 10 ppm N6-B were red, while 10 per cent of the controls and those treated with 25 ppm were in this class. After 9 days, 15 per cent of the lots treated with 5 and 10 ppm of N6-B were red compared to 25 per cent of the controls and those treated with 25 ppm N6-B. However, the aforementioned inhibiting influence of N6-B at all concentrations was not evident 15 days after treatment. Nineteen days after treatment there were no appreciable differences in fruit firmness among the N6-B treated or control fruits.

The data in Figure 12 and Table 5 indicate that treatment of 25 ppm kinetin slightly accelerated the rate of chlorophyll degradation and lycopene development of detached Trellis #22 tomato fruits as indicated by surface red color determinations. The rate of lycopene development

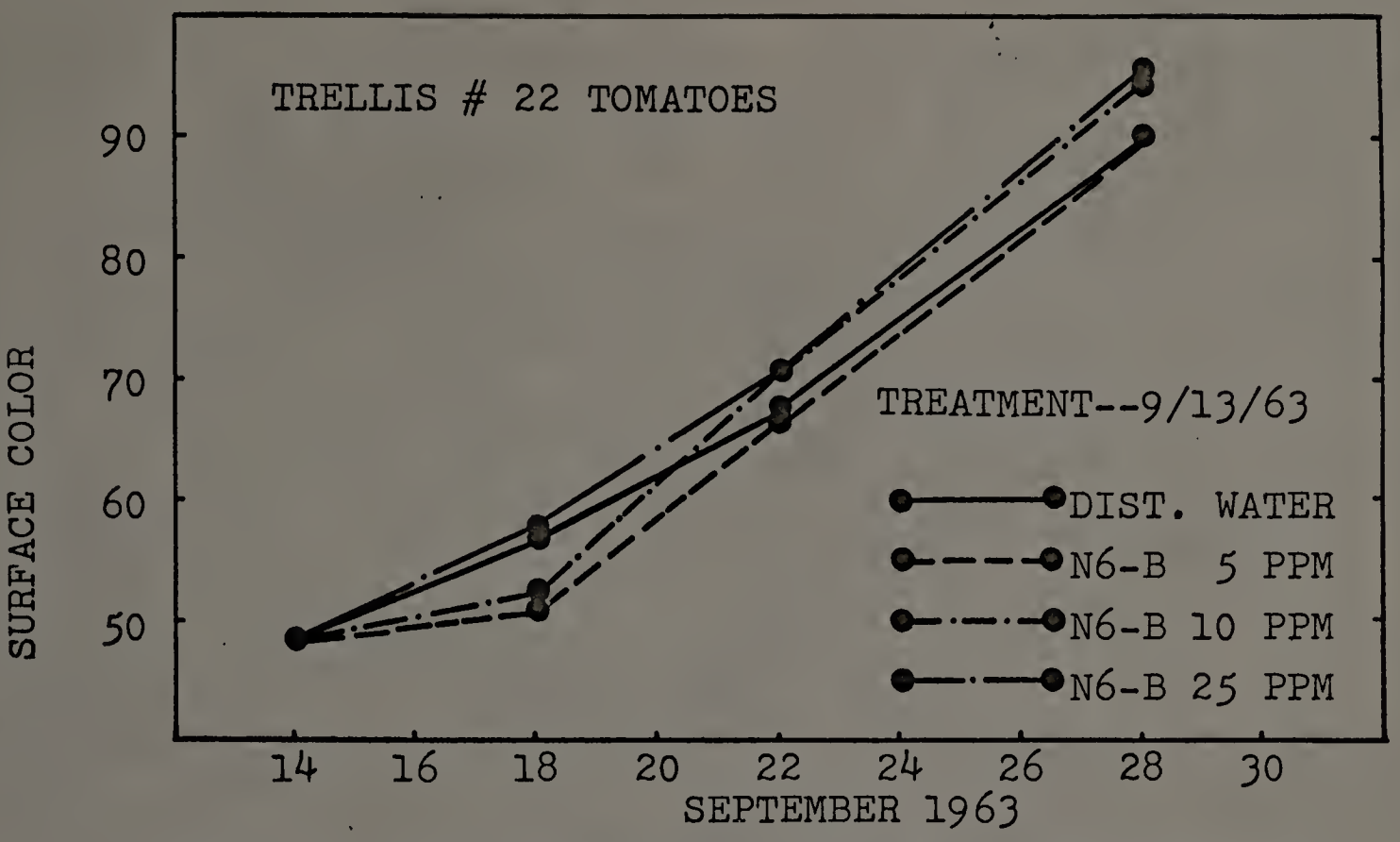

Fig. 11. The influence of N6-B on the red color development of detached tomato fruits held at room temperature (65-75° F.)

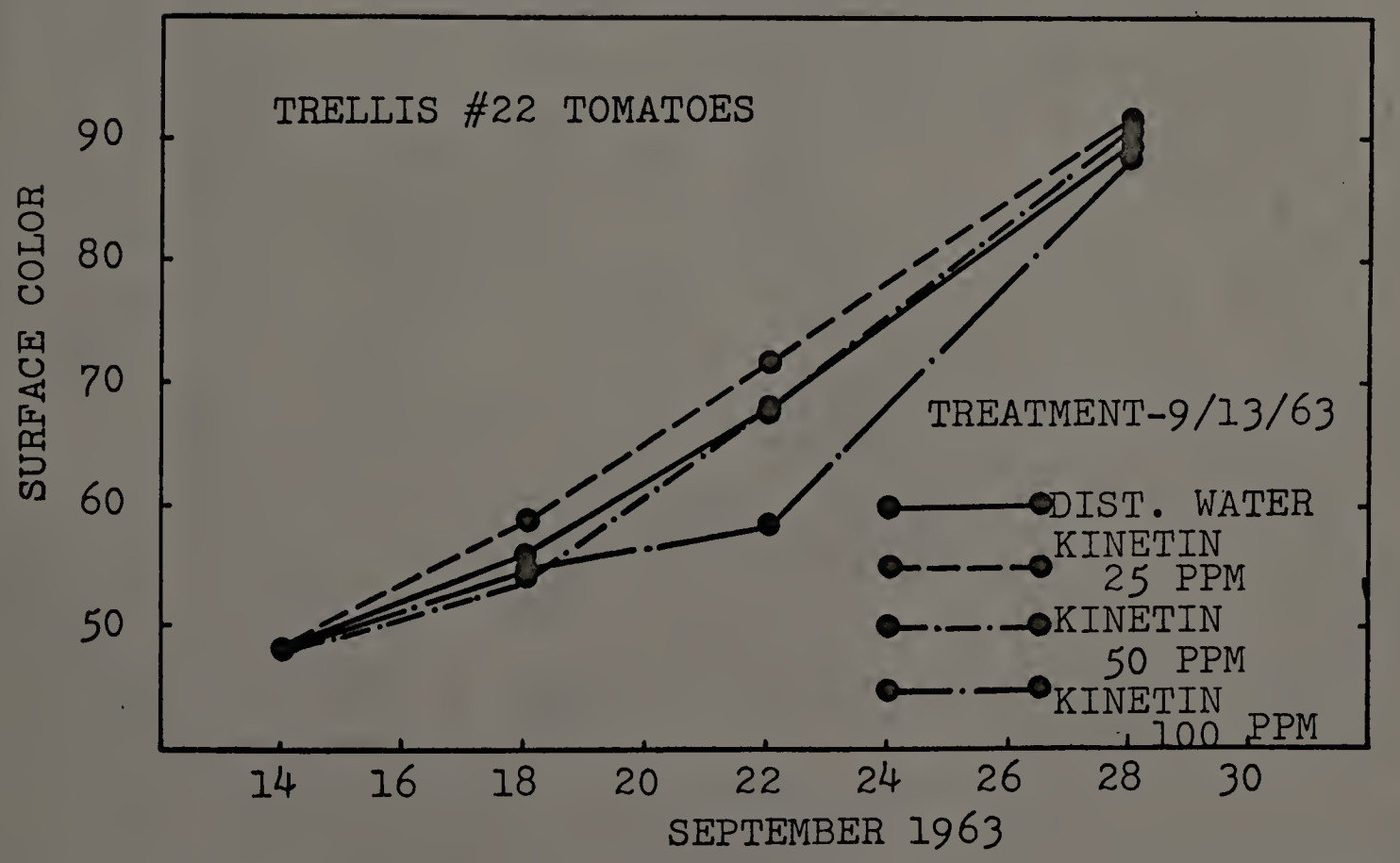

Fig. 12. The influence of kinetin on the red color development of detached tomato fruits held at room temperature (65-75° F.).

Table 5. The influence of N6-B, kinetin, B-995 and IAA on the red color development and firmness of detached, preclimacteric Trellis #22 tomato fruits held at room temperature (65-75°F.).

Treatment[a]	Per cent of fruit			Surface color[b]	Per cent of fruit			Surface color[b]	Per cent of fruit			Surface color[b]	Firmness (C.p.u.)[c]
	green	pink	red		green	pink	red		green	pink	red		
	Sept. 18 5 days after treatment				Sept. 22 9 days after treatment				Sept. 28 15 days after treatment				Oct. 2 19 days after treatment
Distilled water	80	10	10	56.7	40	35	25	67.8	10	5	85	89.7	4.1
5 ppm N6-B	95	5	0	51.6	40	45	15	66.4	15	0	85	89.5	3.9
10 ppm N6-B	80	20	0	52.8	25	60	15	70.1	5	5	90	93.6	3.9
25 ppm N6-B	70	20	10	57.6	20	55	25	70.0	0	0	100	95.1	4.1
25 ppm kinetin	60	30	10	58.8	20	50	30	63.4	5	0	95	92.0	4.1
50 ppm kinetin	85	10	5	54.4	30	50	20	67.7	5	10	85	90.0	3.8
100 ppm kinetin	85	5	10	55.0	35	50	15	59.2	5	20	75	89.1	4.1
50 ppm B-995	85	15	0	57.6	35	60	5	64.9	0	5	95	93.2	3.9
100 ppm B-995	95	5	0	50.7	40	55	5	65.3	0	20	80	90.7	4.2
250 ppm B-995	85	10	5	52.1	30	55	15	66.1	0	0	100	92.3	4.0
500 ppm B-995	70	25	5	55.2	20	50	30	72.3	5	0	95	92.8	4.3
10 ppm IAA	90	10	0	51.1	55	40	5	60.4	15	15	70	85.7	3.8
25 ppm IAA	80	10	10	54.7	30	50	20	65.4	10	10	80	87.1	3.9
50 ppm IAA	95	0	5	51.9	40	55	5	62.2	10	10	80	86.5	4.2

[a]Fruits were treated on 9/13/63; 20 fruits per lot.

[b]Values are reported in arbitrary units; see text.

[c]Cornell pressure units.

in fruits treated with 50 ppm of kinetin did not differ appreciably from the control fruits. Tomatoes treated with 100 ppm of kinetin retained their chlorophyll and developed less lycopene 9 days after treatment than the control fruit. However, this inhibiting effect was not apparent 15 days after treatment. No significance is attached to the slight differences in firmness of fruits (Table 5) treated with kinetin in comparison to the controls after 19 days at room temperature.

Figure 13 and Table 5 show that, after 9 days, treatments of 50 and 100 ppm B-995 slightly inhibited the lycopene development of detached preclimacteric Trellis #22 tomato fruits. However, after 17 days of treatment, fruits developed more lycopene, as indicated by the surface color determinations, than the controls. The rate of red color development of fruits treated with 250 and 500 ppm of B-995 did not differ appreciably from the control fruits. The data in Table 5 indicate that fruit firmness was not influenced appreciably by B-995.

As shown in Figure 14 and Table 5, treatments of 10, 25 and 50 ppm of IAA appears to inhibit the degradation of chlorophyll and development of lycopene of detached Trellis #22 tomato fruits throughout the holding period. Table 5 shows that after 17 days of treatment, 70 per cent of fruits receiving a treatment of 10 ppm of IAA were in the red class in comparison to 80 per cent of the fruits treated with 25 and 50 ppm of IAA and 85 per cent of the

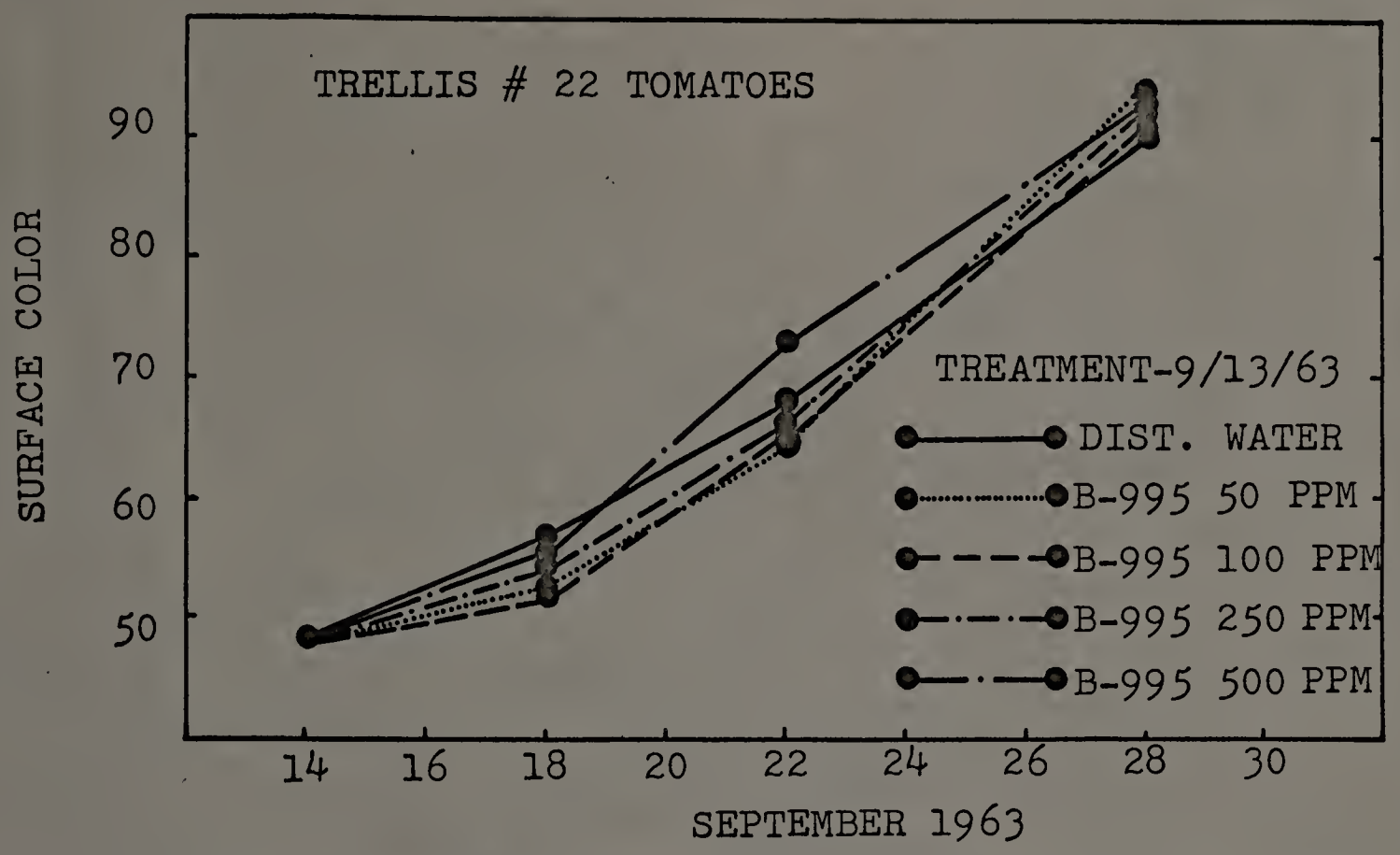

Fig. 13. The influence of B-995 on the red color development of detached tomato fruits held at room temperature (65-75° F.).

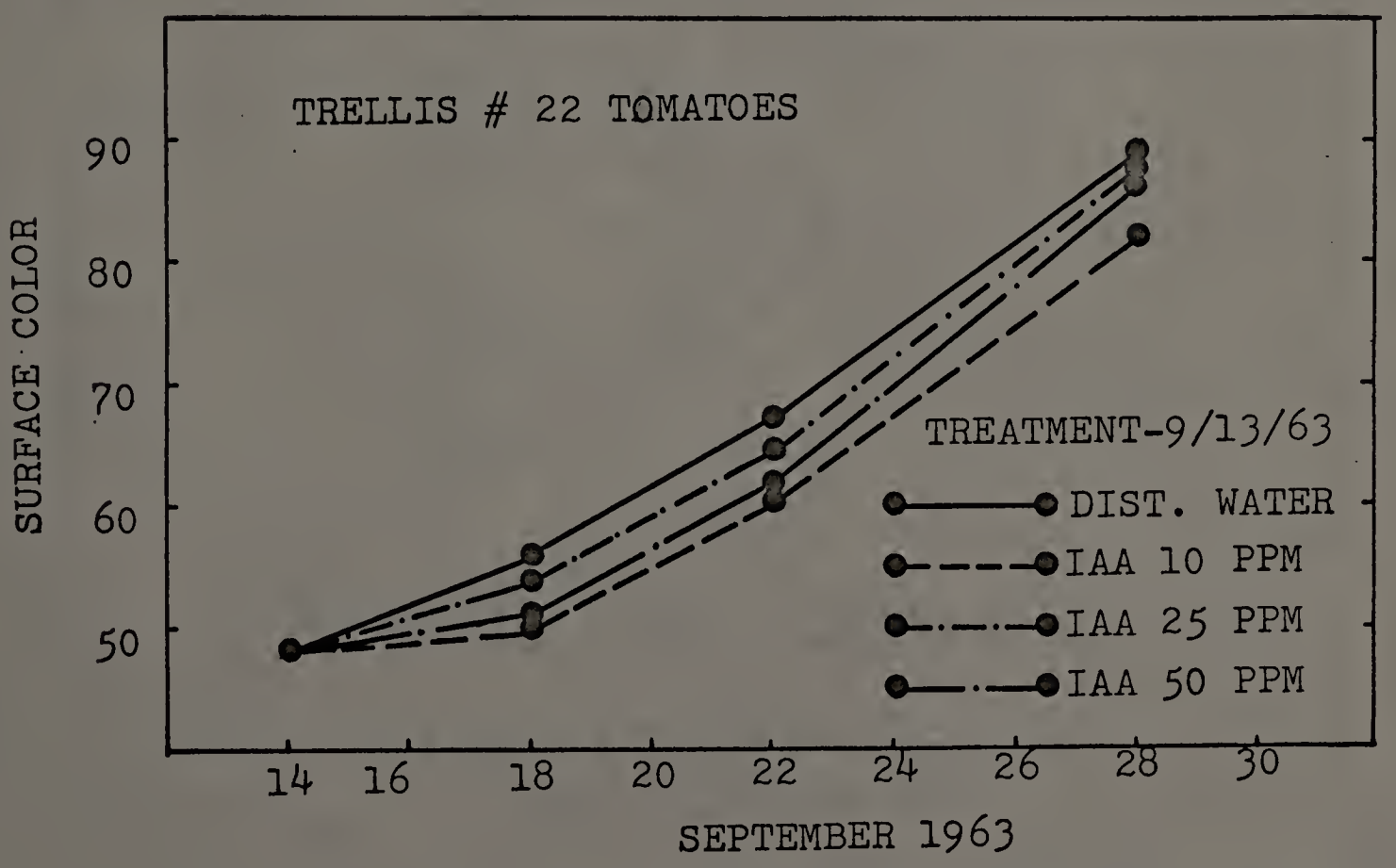

Fig. 14. The influence of IAA on the red color development of detached tomato fruits held at room temperature (65-75° F.).

control fruits. It also shows that fruits treated with 10 and 25 ppm of IAA were slightly, but probably not significantly, firmer.

Treatments of distilled water

In the previous experiments, samples of untreated fruit were used to evaluate the influence of distilled water on the respiratory rate and red color development of detached Valiant and Trellis #22 tomato fruits (untreated fruits were subjected to the same vacuum conditions as treated fruits). The data in Figure 15 indicate that treatment with distilled water generally tends to increase the amount of carbon dioxide output of detached preclimacteric Valiant tomato fruits. Table 6 suggests that detached Valiant and Trellis #22 tomato fruits developed more red color than similar untreated lots. Fruit firmness was not influenced appreciably by treatment with distilled water.

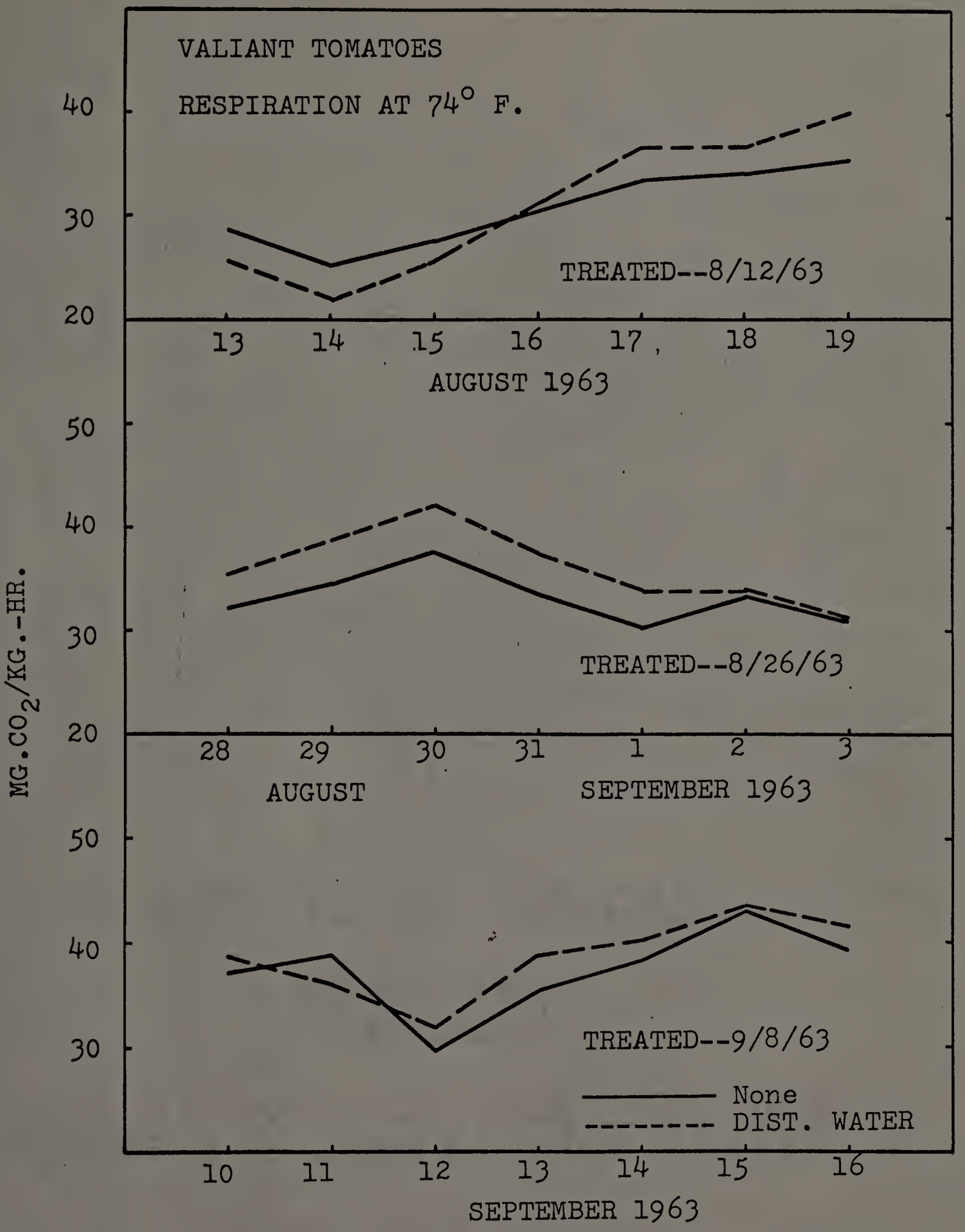

Fig. 15. The influence of distilled water on the rate of respiration of detached tomato fruits.

Table 6. The influence of distilled water on the red color development and firmness of detached tomato fruits.

Treatment	Variety	Days after treatment	No. of fruits	Per cent of fruit			Surface color[a]	Firmness (C.p.u.)[b]
				green	pink	red		
None	Valiant	12	28	25.0	14.0	61.0	83.0	3.1
Dist. water	Valiant	12	28	28.0	8.0	64.0	86.3	2.9
None	Valiant	14	40	22.5	10.0	67.5	84.6	2.8
Dist. water	Valiant	14	40	15.0	10.0	75.0	87.4	2.9
None	Valiant	13	40	7.5	20.0	72.5	88.0	3.3
Dist. water	Valiant	13	40	7.5	20.0	72.5	88.4	3.0
None	Trellis #22	19	20	10.0	10.0	80.0	82.8	4.2
Dist. water	Trellis #22	19	20	10	5.0	85.0	89.7	4.1

[a]Values are reported in arbitrary units; see text.

[b]Cornell pressure units.

Section II

In the fall of 1964, Trellis #22 tomato plants were grown in the greenhouse. Samples were selected during February and March for the following experiments.

Experiment A

The findings of Experiments 1, 2 and 3 in Section I suggested that treatments of 25, 50 and 100 ppm N6-B accelerated the respiratory rate of detached mature green tomato fruits, while treatments of 5 and 10 ppm N6-B may have an inhibiting effect. These findings suggested the testing of lower concentrations of N6-B on detached tomato fruits. Duplicate samples (12 fruits per lot) of detached, preclimacteric Trellis #22 tomato fruits were treated, 56 days after pollination, with aqueous solutions of 0.5, 2 and 5 ppm N6-B. The data in Figure 16 show that treatment with 2 ppm of N6-B accelerated the rate of carbon dioxide output of maturing detached Trellis #22 tomato fruits. Treatment with 0.5 ppm of N6-B had a slight accelerating effect, while treatment with 5 ppm of N6-B had a slight inhibiting action on the respiratory rate of these preclimacteric fruits. After 9 days at 74° F., subjective evaluation of the red color development showed that fruits treated with 5 ppm N6-B developed the least red color, followed by the controls, fruits treated with 0.5 ppm and 2 ppm N6-B, respectively.

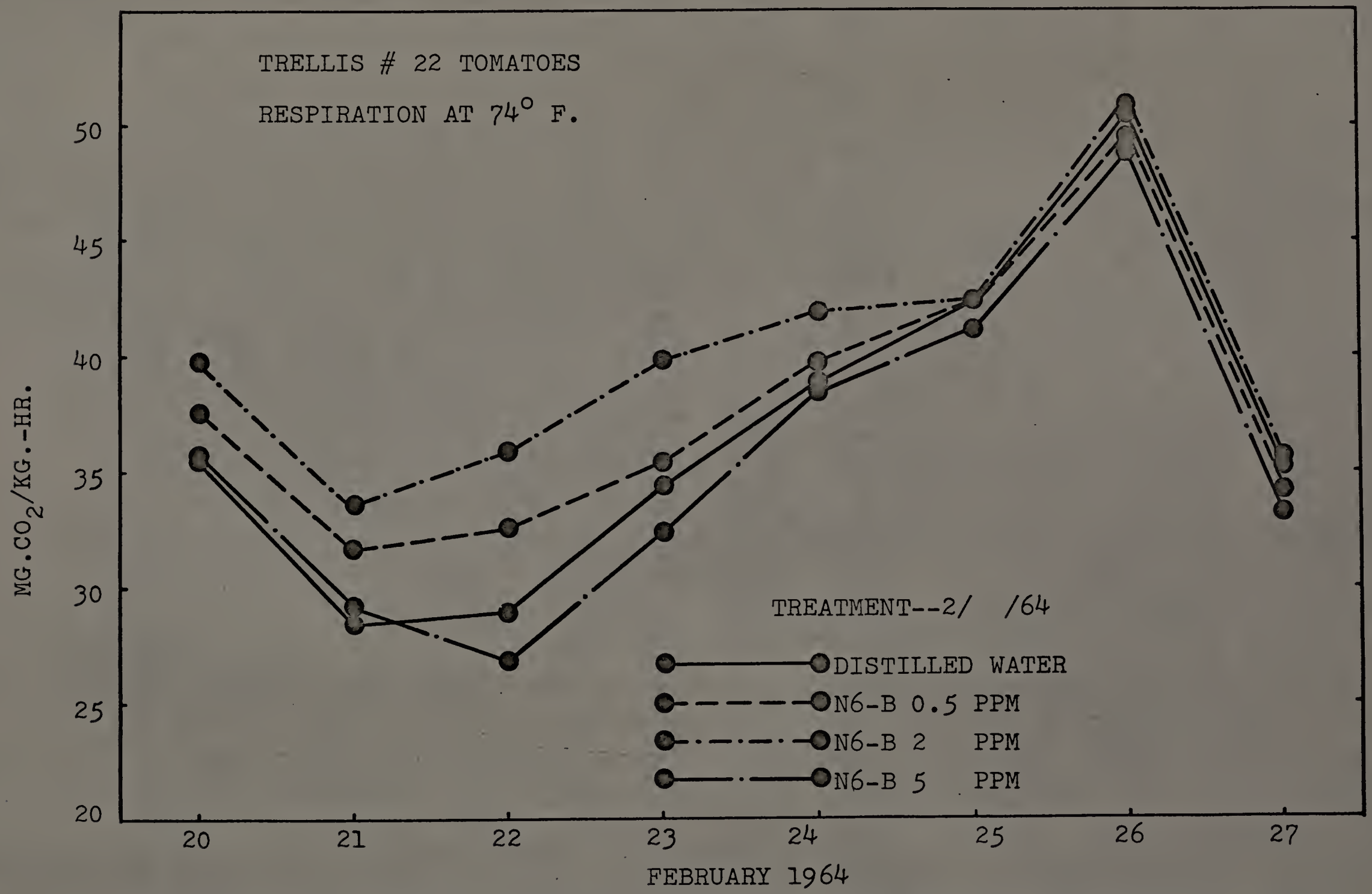

Fig. 16. The influence of N6-B on the rate of respiration of detached tomato fruits.

Experiment B

Similar lots (10 fruits per lot) of preclimacteric Trellis #22 tomato fruits were treated with 0.5, 2, 5 and 10 ppm of N6-B and 50, 100 and 200 ppm of B-995. Fruits were then allowed to ripen on a table at room temperature (65-75° F.). The influence of these treatments on red color development was evaluated 5, 8 and 11 days after treatment.

The surface and interior color data in Figures 17 and 18 show that treatments with 5 and 10 ppm of N6-B inhibited the rate of chlorophyll degradation and lycopene development in preclimacteric Trellis #22 tomato fruits. The inhibiting effect of 10 ppm of N6-B was most pronounced. Table 10 shows that after 5 days of treatment, 75 per cent of fruits treated with 10 ppm of N6-B were in the green class in comparison to 41.7 per cent for the control fruits. After 8 days of treatment, 41.7 per cent of the fruits treated with 10 ppm of N6-B were in the red class while 83.4 per cent of the control fruits were in this category. Treatment with 2 ppm of N6-B accelerated the rate of chlorophyll breakdown and lycopene development, while fruits treated with 0.5 ppm N6-B were similar to the control fruits.

The data in Table 10 and Figures 19 and 20 suggest that treatment with 50 and 100 ppm of B-995 inhibited the chlorophyll breakdown and lycopene development of detached Trellis #22 tomato fruits as indicated by surface color

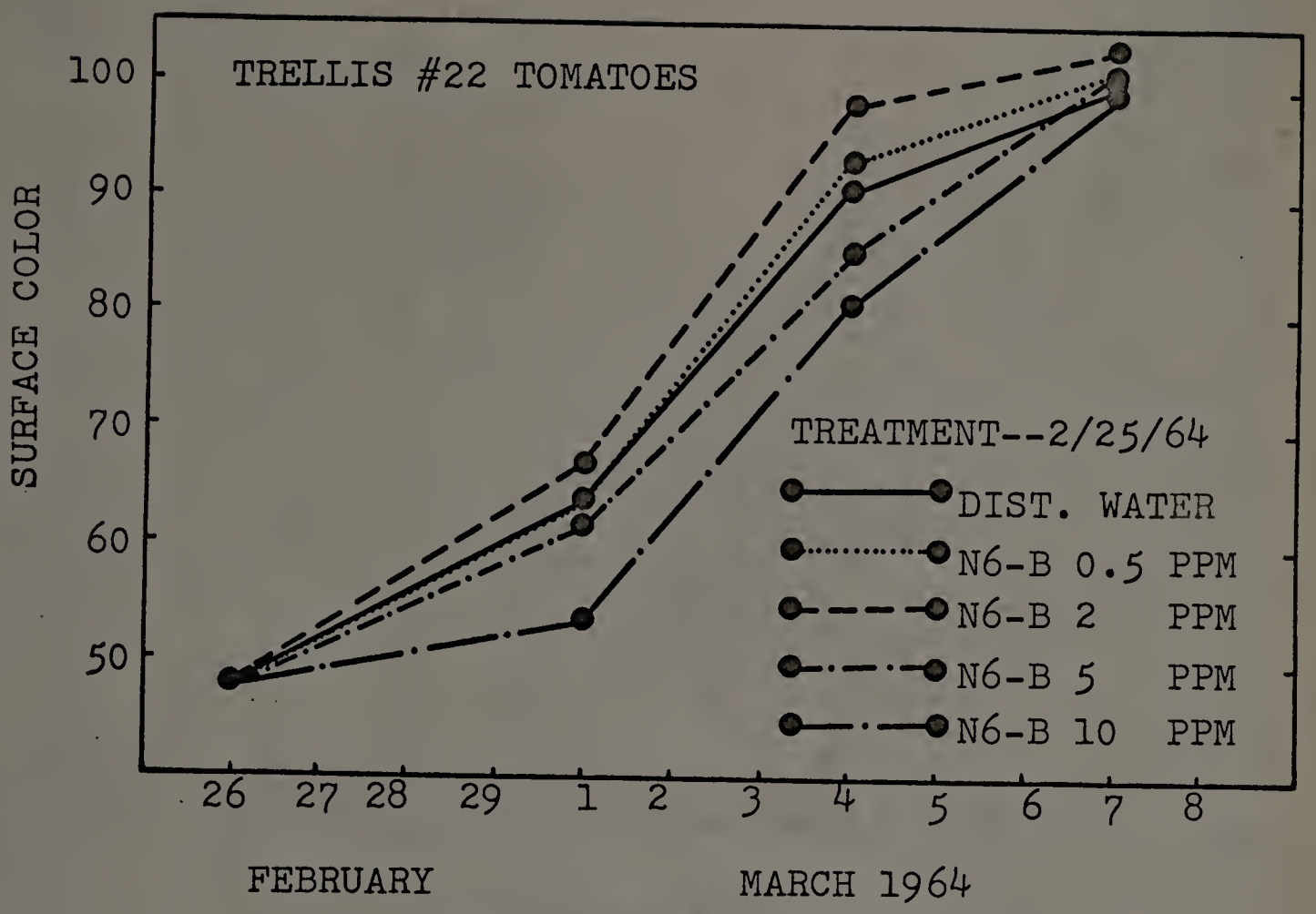

Fig. 17. The influence of N6-B on the red color development of detached tomato fruits held at room temperature (65-75° F.).

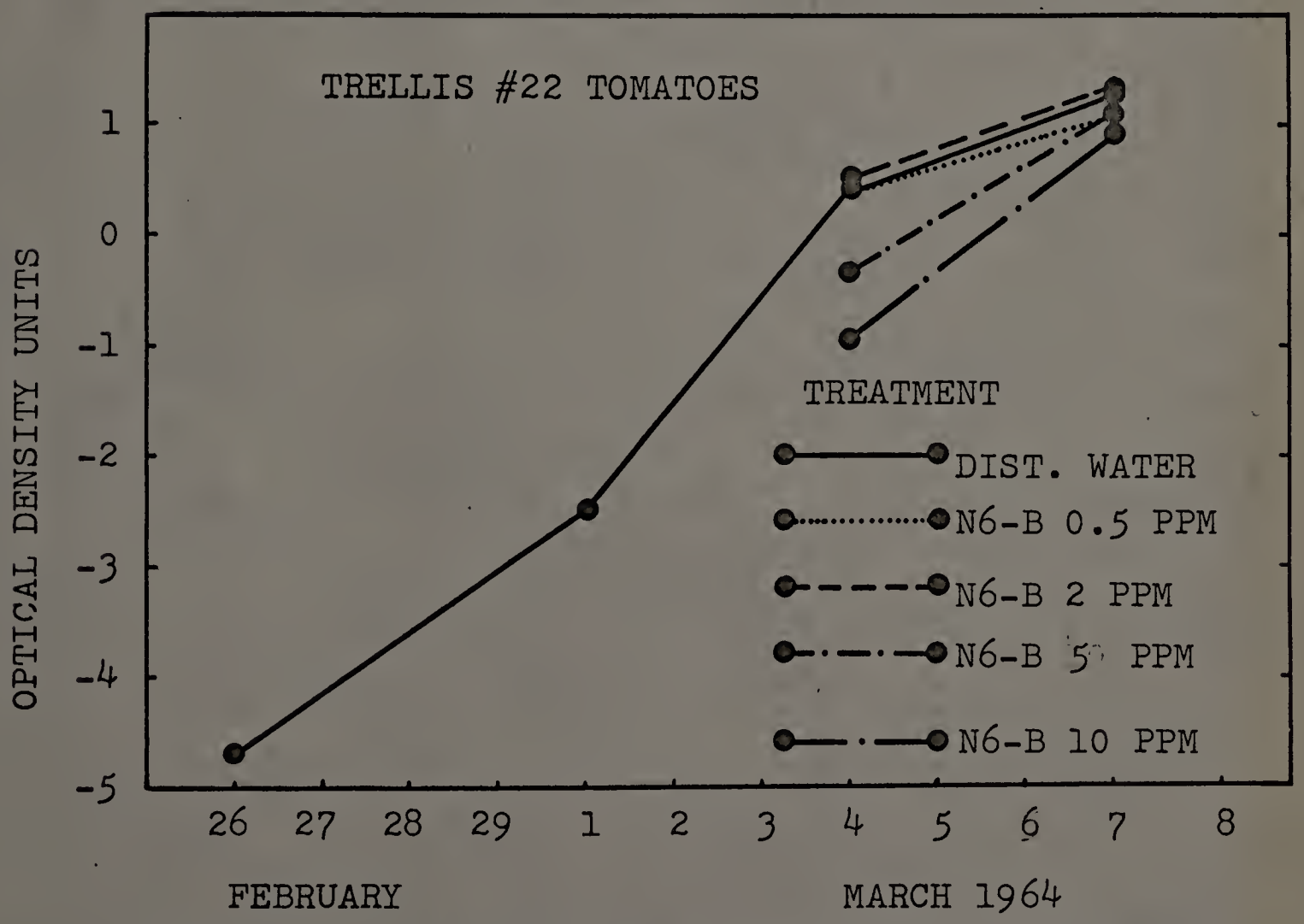

Fig. 18. The influence of N6-B on the red color development of detached tomato fruits held at room temperature (65-75° F.).

Table 10. The influence of N6-B and B-995 on the surface and interior color of detached Trellis #22 tomato fruits held at room temperature (65-75° F.).

Treatment[a]	Per cent of fruit			Surface	Interior	Per cent of fruit			Surface	Interior
	green	pink	red	color[b]	color[c]	green	pink	red	color[b]	color[c]
	March 1[d] 5 days after treatment					March 4 8 days after treatment				
Dist. water	41.7	41.7	16.7	63.7	-2.5	8.3	8.3	83.4	91.4	0.32
0.5 ppm N6-B	50.0	41.6	8.4	63.6	---	0.0	16.6	83.4	93.8	0.33
2 ppm N6-B	25.0	58.3	16.7	67.6	---	0.0	8.3	98.0	98.0	-0.35
5 ppm N6-B	41.7	58.3	0.0	61.8	---	8.3	0.0	91.7	85.5	0.54
10 ppm N6-B	75.0	25.0	0.0	53.7	---	8.3	50.0	41.7	81.2	-0.96
50 ppm B-995	75.0	25.0	0.0	54.0	-3.84	8.3	33.3	58.4	84.5	-0.85
100 ppm B-995	58.3	33.3	8.4	58.4	-3.09	0.0	41.6	58.4	85.8	-0.38
200 ppm B-995	58.3	25.0	16.7	61.8	-2.90	0.0	33.4	66.6	91.7	0.41
						March 7 11 days after treatment				
Dist. water						0.0	0.0	100	99.8	1.25
0.5 ppm N6-B						0.0	0.0	100	101.0	1.17
2 ppm N6-B						0.0	0.0	100	103.0	1.33
5 ppm N6-B						0.0	0.0	100	101.1	1.00
10 ppm N6-B						0.0	0.0	100	99.4	0.96
50 ppm B-995						0.0	0.0	100	100.0	0.83
100 ppm B-995						0.0	0.0	100	99.4	0.66
200 ppm B-995						0.0	0.0	100	100.7	1.25

[a]Applied on 2/25/64, 56 days after pollination; 10 fruits per lot.

[b]Values are reported in arbitrary units; see text.

[c]Optical density units.

[d]Interior color data for fruits treated with N6-B are not available.

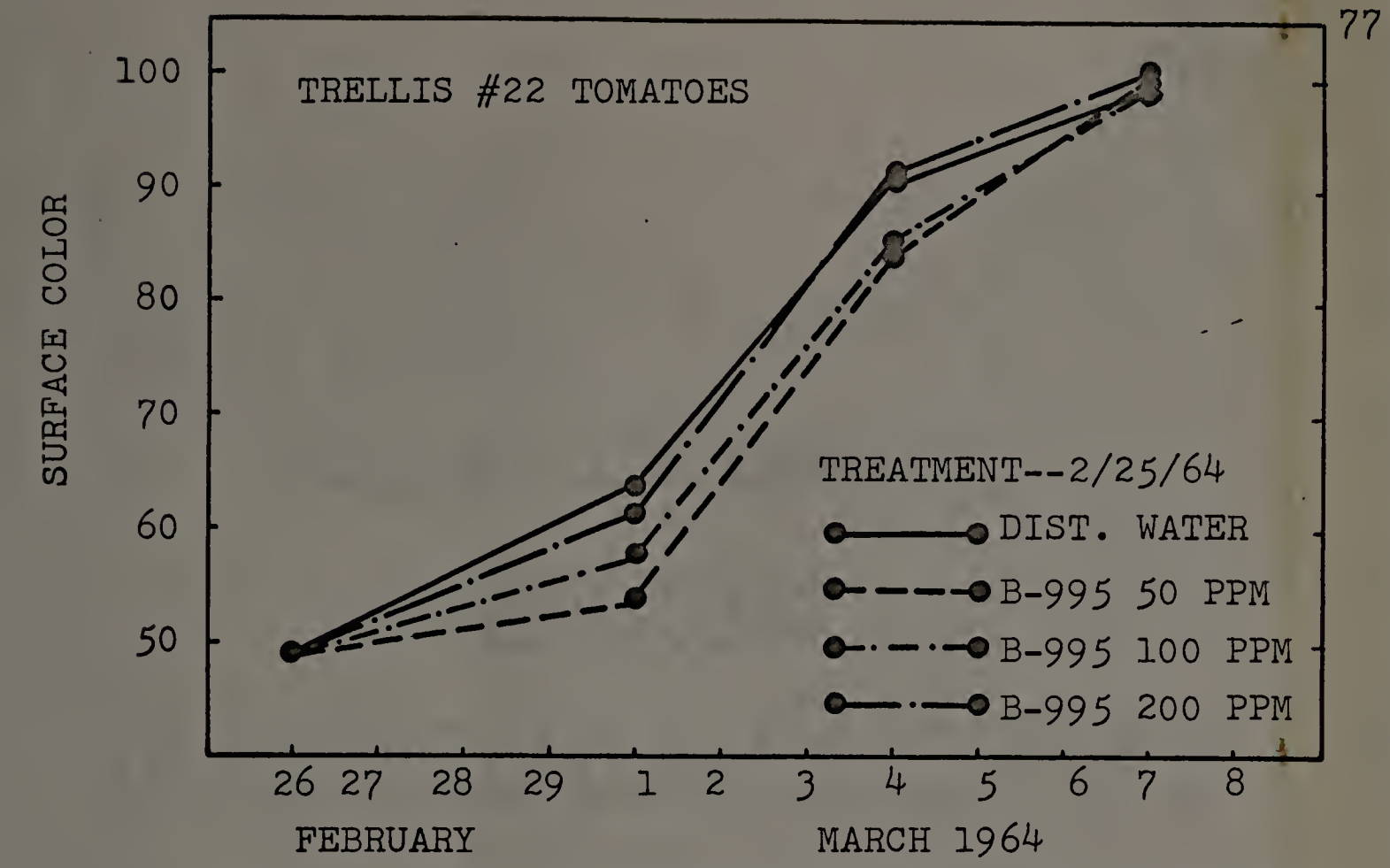

Fig. 19. The influence of B-995 on the red color development of detached tomato fruits held at room temperature (65-75° F.).

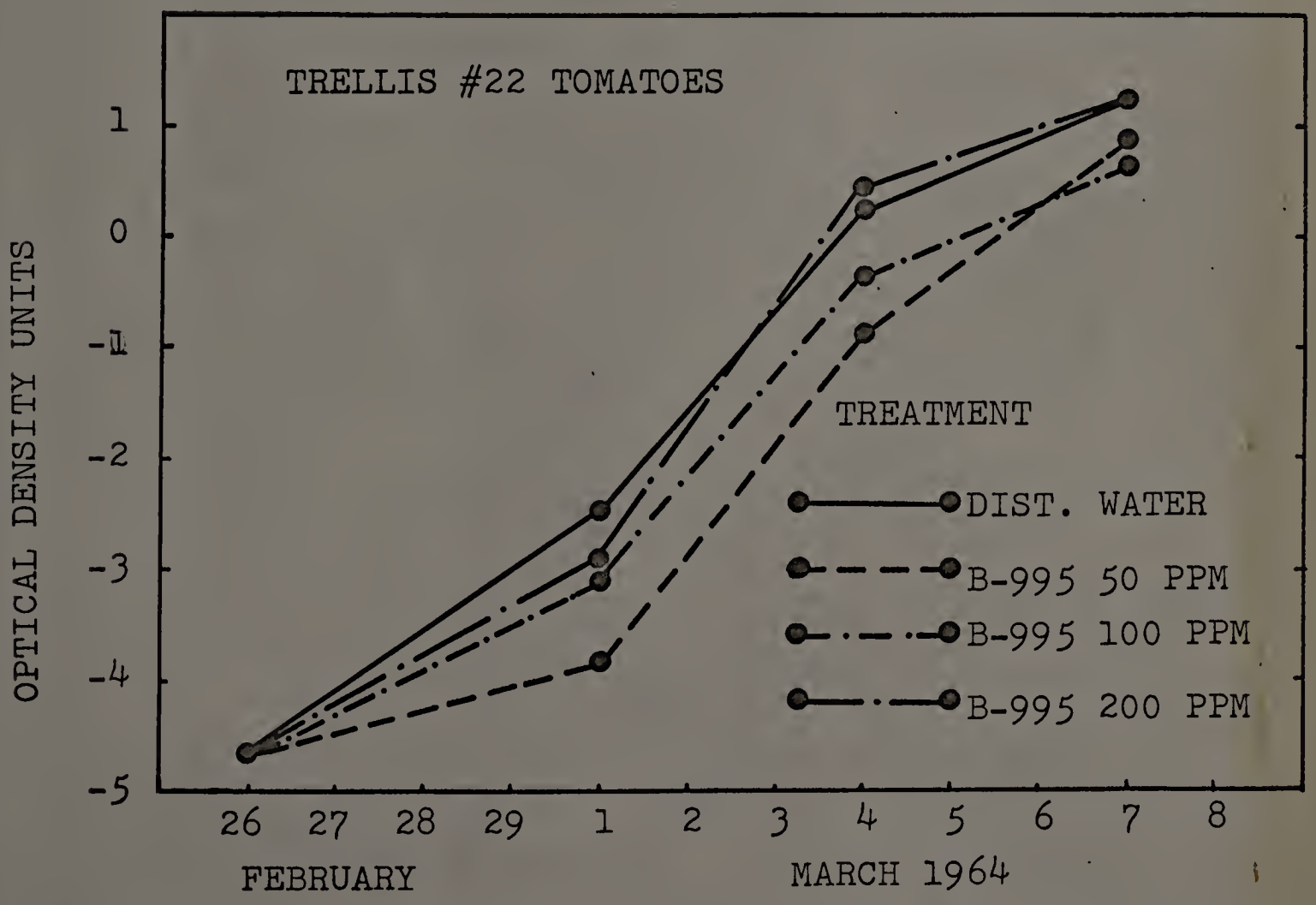

Fig. 20. The influence of B-995 on the red color development of detached tomato fruits held at room temperature (65-75° F.).

measurements. However, after 11 days, fruits treated with 50 and 100 ppm of B-995 developed an amount of red color similar to the controls. The rate of red color development in fruits treated with 200 ppm of B-995 did not differ appreciably from the control fruits.

Experiment C

This experiment was a repetition of Experiment A to test the influence of 0.5, 2 and 5 ppm of N6-B on detached preclimacteric tomato fruits. Duplicate samples (10 fruits per lot) of detached preclimacteric Trellis #22 tomato fruits were treated, 58 days after pollination, with 0.5, 2 and 5 ppm of N6-B. Their respiratory rates were determined for 9 days at 74° F.; then fruits were removed from the respiration apparatus and allowed to ripen for another 4 days at room temperature (65-75° F.). Thirteen days after treatment, the surface, interior color and firmness of the fruits were determined.

Figure 21 suggests that fruits treated with 0.5 and 2 ppm of N6-B respired at a rate not consistently different from the controls. N6-B at 5 ppm seemed to inhibit the amount of carbon dioxide output of detached Trellis #22 tomato fruits. The data in Table 11 indicate that 13 days after treatment, all fruits were in the red class. However, surface color data suggest that fruits treated with 2 ppm of N6-B developed more red color than the fruits in any other treatment. The data show no appreciable difference in the interior color of the test fruits. Also, there were

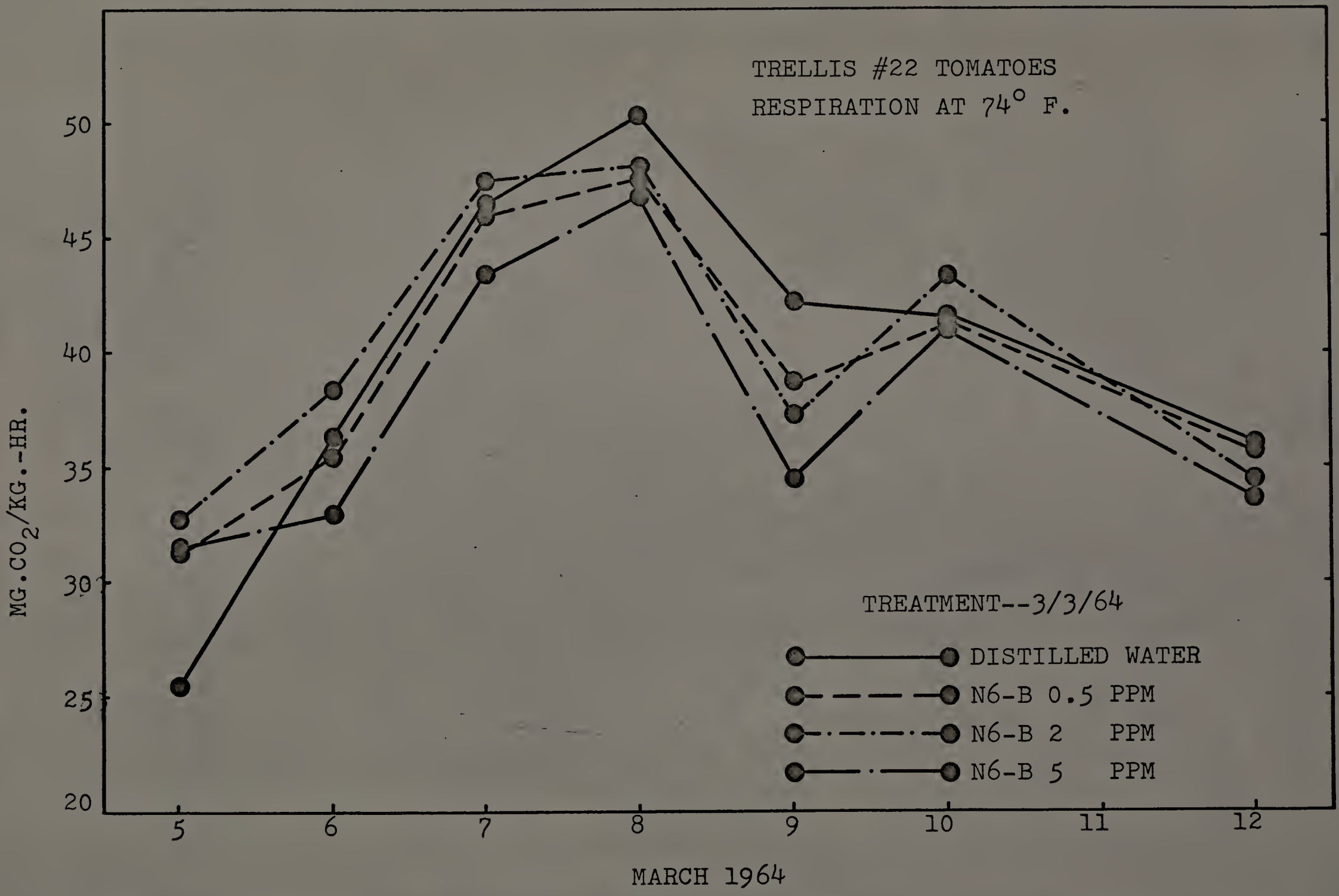

Fig. 21. The influence of N6-B on the rate of respiration of detached tomato fruits.

Table 11. The influence of N6-B on red color development of detached Trellis #22 tomato fruits held for 9 days at 74° F., and 4 days at room temperature (65-75° F.).

Treatment[a]	Per cent of fruit			Surface color[b]	Interior color[c]	Firmness (C.p.u.)[d]
	green	pink	red			
Distilled water	00	00	100	100.9	1.48	3.6
0.5 ppm N6-B	00	00	100	101.7	1.50	3.8
2 ppm N6-B	00	00	100	103.3	1.50	3.8
5 ppm N6-B	00	00	100	100.4	1.52	3.8

[a]Applied on 3/3/64, 58 days after pollination; 20 fruits per lot.

[b]Values are recorded in arbitrary units; see text.

[c]Optical density units.

[d]Cornell pressure units.

no significant differences in fruit firmness between the N6-B treated or control fruits.

Experiment D

Similar lots, each consisting of 10 preclimacteric Trellis #22 tomato fruits were treated 55 days after pollination with 0.5, 2, 5 and 10 ppm of N6-B. Fruits were then allowed to ripen on a table at room temperature (65-75° F.). The influence of these treatments on surface and interior color changes were evaluated every three days. Nine days after treatment all the fruits were red; therefore, the experiment was terminated and the firmness of all fruits in each lot was determined.

The data in Table 12 and Figures 22 and 23 indicate that treatments with 5 and 10 ppm of N6-B inhibited the chlorophyll degradation and lycopene development in detached preclimacteric Trellis #22 tomato fruits. After 6 days of treatment only 20 per cent and 30 per cent of the fruits treated with 10 and 5 ppm N6-B, respectively were in the red class in comparison to 50 per cent for the control fruits. However, the aforementioned inhibiting influence of 5 and 10 ppm of N6-B was not evident 9 days after treatment. Treatment with 2 ppm of N6-B accelerated the rate of lycopene development as indicated by surface and interior color measurements, while fruits treated with 0.5 ppm of N6-B behaved similarly to the controls in regard to red color development.

Table 12. The Influence of N6-B on the red color development and firmness of detached Trellis #22 tomato fruits held at room temperature (65-75° F.).

Treatment[a]	Per cent of fruit green	pink	red	Surface color[b]	Interior color[c]	Firmness (C.p.u.)[d]
				3 days after treatment		
Distilled water	80	20	00	51.1	-4.35	---
0.5 ppm N6-B	80	20	00	50.8	-4.30	---
2 ppm N6-B	60	40	00	53.4	-3.95	---
5 ppm N6-B	70	30	00	52.4	-3.60	---
10 ppm N6-B	90	10	00	50.1	-4.20	---
				6 days after treatment		
Distilled water	00	50	50	82.2	-0.45	---
0.5 ppm N6-B	00	40	60	83.3	-0.30	---
2 ppm N6-B	00	10	90	95.2	0.15	---
5 ppm N6-B	00	70	30	75.2	-2.20	---
10 ppm N6-B	00	80	20	70.1	-2.55	---
				9 days after treatment		
Distilled water	00	00	100	99.0	0.5	3.6
0.5 ppm N6-B	00	00	100	102.0	1.0	3.9
2 ppm N6-B	00	00	100	103.0	1.25	3.7
5 ppm N6-B	00	00	100	101.3	1.20	3.4
10 ppm N6-B	00	00	100	100.6	0.55	3.5

[a]Applied on 3/7/64, after 55 days from pollination; 10 fruits per lot.

[b]Values are recorded in arbitrary units; see text.

[c]Optical density units.

[d]Cornell pressure units.

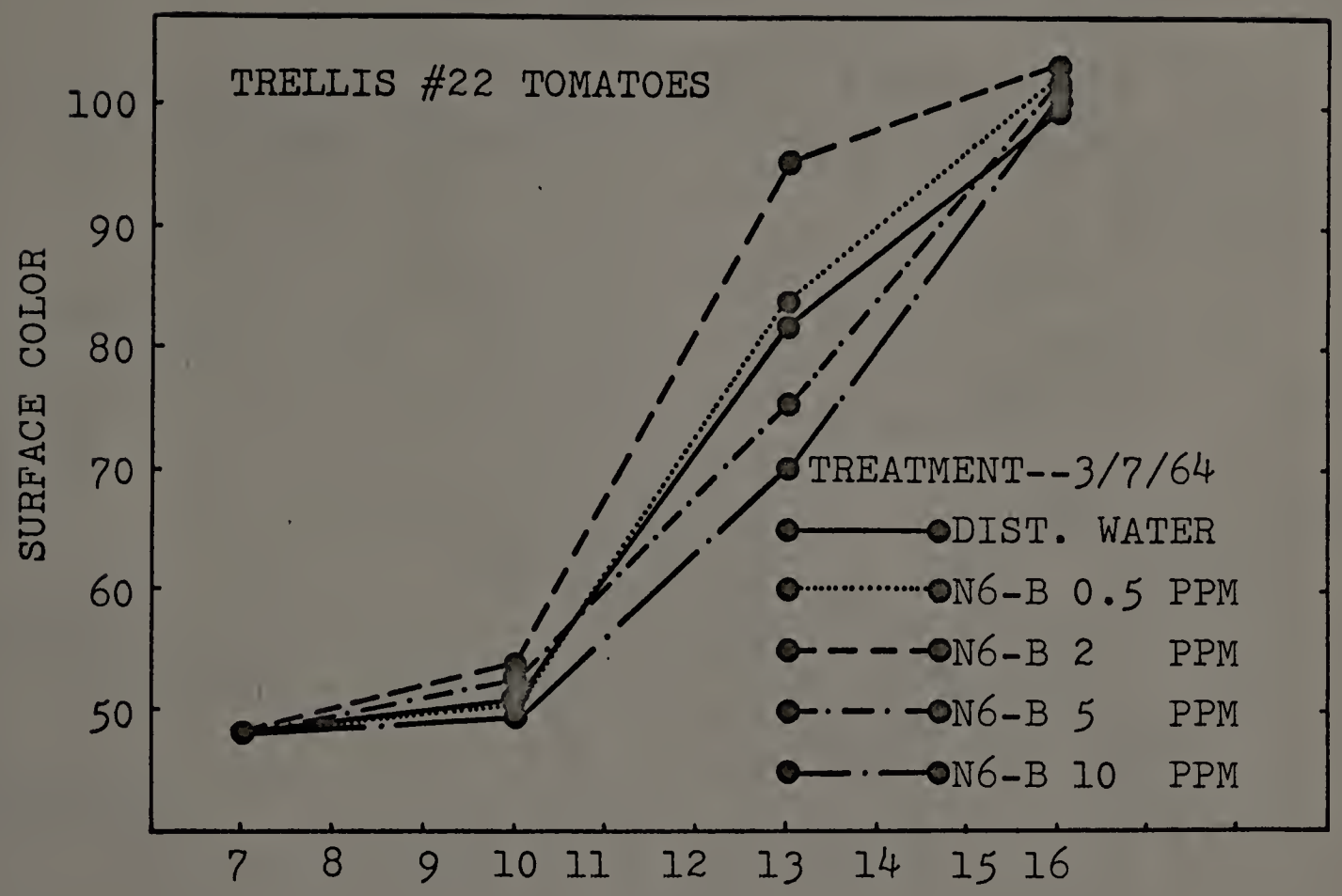

Fig. 22. The influence of N6-B on the red color development of detached tomato fruits held at room temperature (65-75° F.).

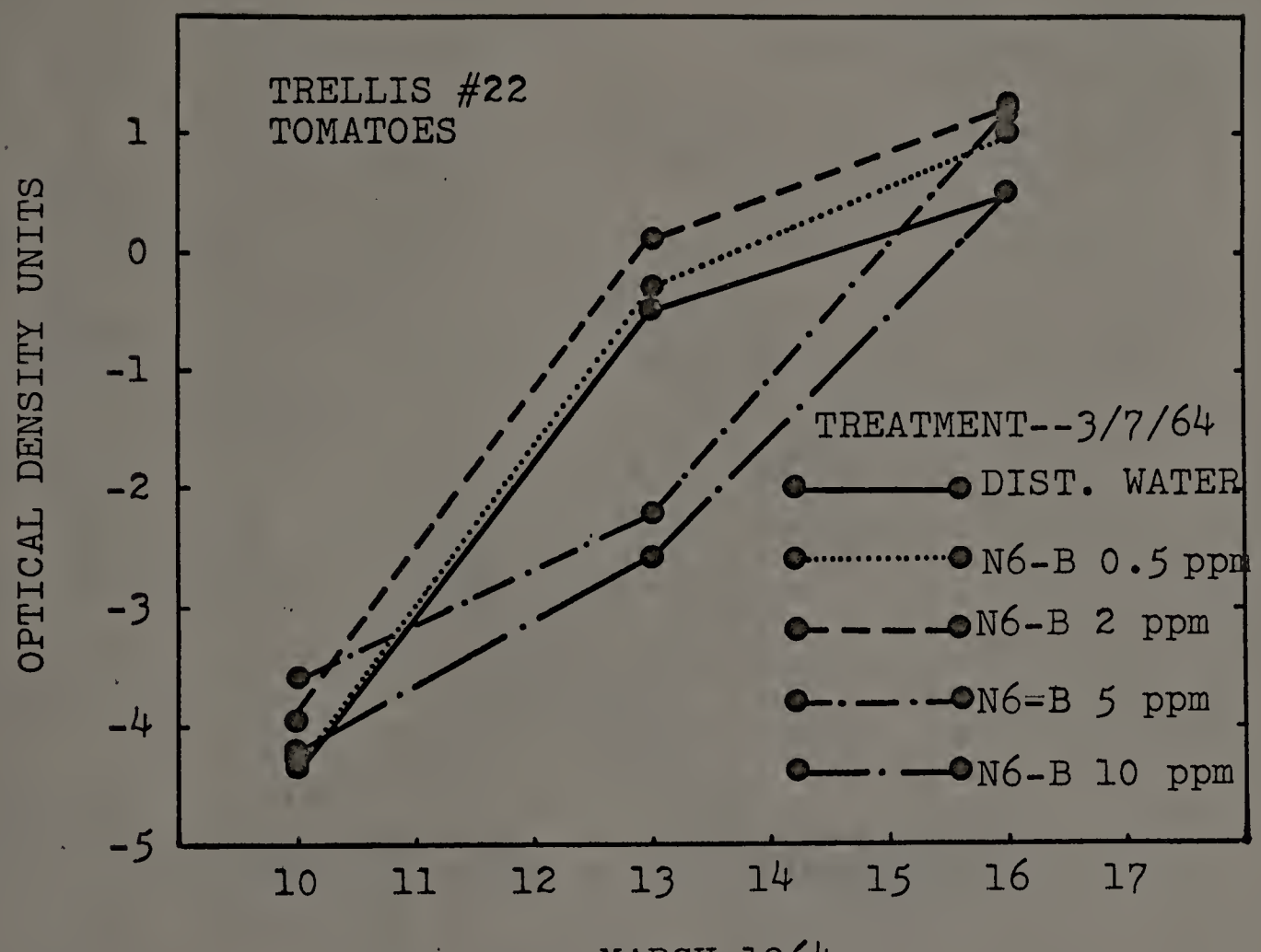

Fig. 23. Influence of N6-B on the interior color changes of detached Trellis #22 tomato fruits held at room temperature (65-75° F.).

Nine days after treatment, there were no significant differences in fruit firmness between the M6-B treated or the control fruits.

SUMMARY

In these experiments, size, color, and other apparent external characteristics of fruit were not reliable indicators for selecting green tomato fruits of similar maturity. This is in agreement with many other workers.

However, Lyon's (48) method of selection of tomato fruits of the same physiological age was found to be reliable. Fruits of uniform maturity were obtained by tagging and pollinating a single flower on a cluster, eliminating the rest of the flowers of the cluster and finally limiting the number of developing fruits per plant.

The "vacuum" method, developed in this experiment, whereby a known amount of chemical solution may be introduced into a detached tomato fruit through the stem-end scar, appears to be a suitable procedure for treating intact tomato fruit with chemical compounds in solution. This procedure results in complete intake of chemical solutions into test fruits.

In these experiments, treatment with distilled water hastened the ripening of detached preclimacteric tomato fruits as indicated by their rate of respiration (CO_2 evolution) and color development. These findings support the earlier findings of Southwick and Lachman (78), and indicate

the importance of using fruits treated with equivalent volumes of distilled water as a control whenever the effect of chemical compounds in solution are being determined.

Although most workers who have investigated the influence of treatments with N6-B on the shelf life and quality of several vegetables, fruits, and cut flowers agree that treatment with N6-B has extended the marketability and retained the freshness and green color of several horticultural products, there is some disagreement concerning its effect on the rate of respiration of some of these products. In these experiments, treatments with 50 and 100 ppm of N6-B appeared to increase the respiratory rate of detached maturing tomato fruits as indicated by the amount of carbon dioxide evolution and had an injurious effect on detached tomato fruits. Presumably the observed acceleration in the respiratory rate of fruits treated at these concentrations is related to their injurious effect on the fruits.

On the other hand, treatments with lower concentrations (0.5, 5, 10, and 25 ppm) of N6-B often had a slight inhibiting action on the rate of respiration and chlorophyll degradation in preclimacteric tomato fruits. Eventually, the treated fruits respired at a similar rate and developed red color in a manner similar to the control fruits. This suggests a relationship between the rate of respiration and visible signs of tomato fruit maturity such as red color (lycopene) development.

Treatments with concentrations ranging from 0.5 and 100

ppm of N6-B had no significant effect on the firmness of detached mature green tomato fruits when ripened to full red color.

Treatment with 25 ppm of kinetin appeared to accelerate the rate of chlorophyll degradation and lycopene development of detached Trellis #22 tomato fruits. However, those fruits treated with 100 ppm of kinetin retained their chlorophyll longer and developed less lycopene than the controls. The inhibiting effect observed on fruits treated with 100 ppm of kinetin was more pronounced than any inhibiting effect obtained with treatments of N6-B.

There was no appreciable difference in firmness between fruits treated with kinetin in comparison to the controls. This experiment indicates that the influence of treatments with kinetin on the rate of respiration and color development of detached preclimacteric tomato fruit is worthy of further investigation.

Indoleacetic acid, when applied at concentrations ranging from 10 and 50 ppm, inhibited the degradation of chlorophyll and development of lycopene of detached mature green Trellis #22 tomato fruits. However, no significance is attached to the minor differences in the firmness between fruits treated with IAA and the control fruits. IAA may be a promising substance for inhibiting the processes of ripening of detached tomato fruits and needs further investigation for determining its effect on the respiratory rate and quality of tomato fruits.

Treatment with 50 and 100 ppm of B-995 inhibited the chlorophyll breakdown and lycopene development of detached Trellis #22 tomato fruits. The rate of red color development in fruits treated with 200 and 500 ppm of B-995 did not differ appreciably from the control fruits. No appreciable differences were detected between the firmness of fruits treated with B-995 and the control fruits.

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