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Effects of High Temperature on Fruit Set in Tomatoes Lycopersicon Esculentum

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EFFECTS OF HIGH TEMPERATURE ON FRUIT SET IN TOMATOES

LYCOPERSICON ESCULENTUM

by

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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I

INTRODUCTION

Flower and fruit drop is a great problem to growers in many tomato producing areas. Workers have observed this phenomenon of the loss of flowers or undeveloped fruit and have associated it with heat, moisture and physiological condition of the plant.

In view of the association of carbohydrate level with yield, one phase of this experiment was designed to determine the separate and combined effects of temperature and light on fruit setting. Both normal and abnormal (high) temperatures were used following a dark treatment. This phase of the work was planned for two main purposes. One was the effect of holding transplants in the dark before planting in the field. This might be of significance in areas where abnormally high temperatures follow transplanting. Another reason for this phase of the work was to obtain an indication of the role of light intensity in fruit setting. The feasibility of future work along this line might be indicated by the results.

Seventeen varieties of tomatoes in phase 3 were used in part of the experiment in order to detect varietal differences in regard to ability to set fruit under adverse conditions.

Another phase of the work concerned stages of flower development at which abscission is most likely to occur. The author felt that there was a need for further work in determining at which of various stages, before or after fertilization, abscission is most likely to occur.

Applications for commercial growing, for the production of commercial hybrids, and for making crosses in the course of tomato breeding could conceivably be made from these findings. That time of pollination in relation to high temperature might have some bearing on fruit set is to be considered.

II

REVIEW OF LITERATURE

1. Morphology of the Tomato Plant.

Bouquet (2) made a study of the inflorescences of several varieties in order to determine their differences in fruiting habit. He described three types of inflorescence which sometimes occur on the same plant:

Simple raceme

Dichotomous or two forked flower cluster

Polychotomous inflorescence, having more than two forks or branches.

Loomis (8) divided development in plants into two separate phases: growth and differentiation. He defined growth as increase in size due to cell division and cell enlargement, and differentiation as the sum of the chemical and morphological changes which start during cell enlargement and end with the death of the cell. Variation in the form, chemical composition and growth behavior of genotype are explained on the basis of variation in the growth - differentiation balance within the plant.

Boswell (1) and his co-workers found that the more important commercial varieties bear an average of four to five flowers per cluster and usually from two to four flowers set fruit. Ordinarily, it is unusual for more than two flowers of an inflorescence to open at one time.

Tiedjens and Schermerhorn (16) classified varieties into five classes according to their capacity for fruitfulness and growth.

Hayward (5) mentioned that Kendal in his work has described the histology of the pedicel of the flower and fruit with reference to the development of the separation zone, the process of abscission, the time involved and the experimental methods of inducing abscission. The zone of separation in Lycopersicon is located at a mid-point in the pedicel in contrast to Nicotiana where it occurs at the base. It is possible for abscission to cause the fall of the fruit at any stage in its development, but this rarely occurs except at about two or three days after anthesis.

Dehiscence of the stamens begins 24-48 hours after the opening of the corolla. Each locule contains several hundreds of pollen grains, and the anther splits longitudinally in an introrse manner so that the pollen may fall directly on the stigmatic surface of the pistil.

The type of dehiscence, the pendant position of the flower, and the fact that the stigmas are receptive to pollen one or two days before the anthers split, usually result in self-pollination. Some crossing does occur, however, and as much as 5 percent cross pollination has been recorded in certain long-styled varieties in which the style and the stigma project beyond the staminal cone.

The growth of the pollen tube is relatively slow even at optimum temperature. According to Smith and Cochran (14) no case was found where fertilization could be observed in less than 50 hours after pollination. Germination and growth were very poor below 50°F. and above 100°F.

Boswell (1) found that under greenhouse conditions, some unproductive flowers occur. These may be classified into three categories:

1. Those producing small fruits that ripen prematurely before attaining a marketable size.
2. Those having a persistent calyx, but in which the fruit does not develop.
3. Flowers that absciss.

2. <u>Flowers and Fruit Development</u>.

Learner (7) studied the effect of temperature and moisture levels on seedlings of tomatoes prior to transplanting. Subjecting the plants to 40-60°F. significantly reduced both early and total yields. Decreasing the water supply was significantly more effective in increasing the sugar content of both tops and roots than ten days treatment of temperature exposure to 40°F.

Mayberry (10) evaluated the response of the tomato plant to foliar applied sucrose, its absorption, translocation and utilization, and a suggestion as to why plants become hardy. In Michigan he found that intensity and duration of light are two important limiting factors in the growth of the greenhouse crops, during the fall, the winter and spring months. If foliar sprays of sucrose were added to compensate for the carbohydrates which are normally synthesized by its leaves, it was assumed that the effect of light deficiency might be partially overcome, as has already been suggested by Went et al. (20).

It was found that sucrose sprays caused an increase in vegetative growth only when high temperatures (70-80°F) were combined with short photoperiods (7 hours or less). It was found that weekly foliar applications of 10 percent sucrose solutions had no effect on the yield of ten varieties of greenhouse tomatoes grown in the winter at 60°F. night temperature and 9-10 hours photoperiod.

Watts (17) indicates that an increase in either intensity of light or duration of the photoperiod was followed by increase in dry weight, and in carbohydrate content, and decrease in percentage of nitrogen with special reference to the amino fraction. High nitrogen is associated with increased growth and unfruitfulness.

However, Watts (18) observed that under summer conditions in Arkansas it is difficult to produce an over vegetative growth condition.

As a result of many experiments (17) it was indicated that when conditions were favorable to the production of carbohydrates, a limitation of nitrogen supply may increase fruitfulness, especially with respect to the percentage of the buds produced which set fruits; associated with this condition is a decrease in the size of the plant. There is also evidence to the effect that when the nitrogen supply is limited a reduction in the supply of carbohydrates may increase fruitfulness, especially with respect to the percentage of buds produced which set fruits; associated with this condition is an increase in plant size. A condition of moderate succulence and moderate vegetativeness was more closely associated with fruitfulness than either extreme succulence and vegetativeness or extreme woodiness and a weak vegetative condition, regardless of the size of the plants or of the environmental factors which caused the condition.

Associated with the moderately vegetative but very fruitful condition just described is a balance, within the plant, of carbohydrates and amino-nitrogen content. Extreme vegetativeness and nonfruitfulness are associated with relatively low carbohydrate content and high amino-nitrogen content. Woody and weakly vegetative growth and nonfruitfulness is accompanied by high carbohydrate content and low amino-nitrogen content. High carbohydrate content, especially starch, is in general accompanied by low amino-nitrogen content, while low carbohydrate content, especially starch, is accompanied by moderate to high amino-nitrogen.

Cooper and Wigans (3) reported data concerning fruit drop and style elongation as a result of high temperature. It was reported in this paper that fruits drop from two principal causes:

1. Lack of fertilization of the ovule because of failure of the pollen tube to reach the ovule, or of defective conditions of either pollen-tube nuclei or the egg-sack mechanism of the ovule.
2. From competition.

The first heavy drop which occurs immediately after the petals fall is due to the first cause, and all subsequent dropping is due to the second.

Loomis (9) reported that the ability of different organs to compete for nutrients varies with the species and with the conditions, but for many plants, the order seems to be: rapidly growing young fruit---vegetative buds---flowers---freshly pollinated fruit, in decreasing order of competitive ability.

Experimental results by Watts (17) have pointed to the importance of the role played by temperature in influencing plant performance. Temperatures as low as 50-60°F. or other factors serving to check growth caused excessive wrinkling of the fruits resulting from the buds produced under such conditions. Temperatures of 95°F. or over caused excessive lengthening of styles, poor pollination, and hence poor setting of fruits.

Optimum temperatures for setting of fruits lie between the two extremes mentioned above. When the plants are grown under long day conditions and high temperatures, such as prevail during the summer months in Arkansas, an abundance of nitrogen is needed, and on soil deficient in this element its application should prove profitable.

3. Flower and Fruit Drop.

Watts (18) said that in the tomato, the length of the style in comparison with the length of the anther cone influences ease of pollination by determining the location of the stigma; the short style facilitating self-pollination. In 1931 it was observed that under field conditions all styles found in almost all field treatments were longer than the anther cone during periods of extreme hot weather, but that only a very small percentage of such long styles appeared in relatively cool weather.

Since the behavior of style elongation seemed to be correlated with vegetative growth, an experiment (18) was run in the greenhouse in the winter, in which the vigor of the plants was varied by nutrient treatment. No blossoms had styles which protruded beyond the anther cone, but the distance of the stigma below the tip of the cone seems to have been influenced by vegetative conditions. The most weakly vegetative plants were found to have their stigmas an average of slightly over one-half millimeter below the tip of the cones, the medium vigorous plants about 0.8 mm., and the most vigorous plants 1.2 mm.

Schneck (11) and some other workers, on the other hand, designated the length of the style to be a varietal factor. He also noticed that the morphology of the tomato flower differs with varieties and has an important bearing on the method of pollination.

Smith and Cochran (14) made an extensive study on pollen germination and pollen-tube growth in the tomato style at various temperatures. It was found that temperature has a marked effect on the germination percentage of pollen as well as on the rate of pollen-tube growth. They found that the best germination of pollen was obtained at 85°F. Germination was almost as high at 70°F. but much lower at 50°F. and was exceedingly poor at 100°F. Germination percentage has a tendency to increase on styles which have a smaller number of pollen grains.

The maximum rate of pollen-tube growth occurred at 70°F. with 85, 50 and 100°F. resulting in lower rates in decreasing order. Pollen-tube growth in the tomato is relatively slow even at the optimum temperature of 70-85°F. Fertilization before disintegration of the embryo-sac contents is very unlikely when the plants are grown at a temperature of approximately 100°F.

In a study of pollination and life history of the tomato, Smith (13) has observed that the tomato flower remains open for several days, the length of time depending largely on the temperature. The tomato plant has no one definite flowering peak; anthesis appears to be correlated with temperature. The tomato flower is usually self-pollinated. Extremely high temperature causes the style to elongate abnormally, and exceptionally early. This condition results in the destruction of the stigmatic surface before pollination can be effected. These flowers fail to become fertilized and soon abscise. The optimum pollen germination was obtained at 85°F. although at70°F the germination was only a trifle less, whereas at 50°F. it was somewhat better than 100°F. Pollen-tube growth was relatively slow at all temperatures; pollen remains apparently inactive for several hours, after pollination, before it starts germination. Fertilization was first observed 50 hours after pollination. The embryo does not begin division until 36-48 hours after fertilization.

In a separate study Smith (13) also examined the relation of temperature to anthesis and blossom drop of the tomato, together with a histological study of the pistil. He considered flowering to be largely dependent upon soil moisture and temperature. Blossom drop is greatly increased by hot, dry winds and low humidity as well as by low soil moisture.

On ten plants under observation 47.4 percent of the flowers aborted. There is a lag of approximately three days between the time that temperature exerts an effect on blossoms drop and the time that the effect becomes visible. During the period of hot dry wind and low soil moisture, the styles elongate abnormally, even before anthesis. Few flowers that have elongated styles in hot dry weather develop normally and set fruit.

Cordner (4) working with a similar problem also said that the principal cause of blossom drop in tomatoes is high atmospheric temperature. As temperature approaches 90-92°F. and higher, the floral parts fail to function in a normal manner, and as a result pollination and fertilization of the ovule are prevented and blossom or small fruit drop results. A dry atmospheric condition, high wind and deficiency of moisture in the soil are factors of secondary importance, which in association with high temperatures may intensify the blossom drop. When temperatures are near the critical point these factors may become of practical importance, in relation to fruit set.

Kraus and Kraybill (6), however, stated that the lack of fruit development is not alone due to the lack of pollination or fertilization. The flower may fall soon after pollination (markedly vegetative plants) or remain attached for many days without development of the fruit (markedly nonvegetative plants). When the opportunity for carbohydrate manufacture within the plant itself is greatly reduced or eliminated, even though there is relative abundance of moisture and available nitrogen, vegetation is decreased. But when there is a carbohydrate reserve within the tissue under the same conditions of nitrogen and moisture supply, growth is active. Very large reserves of carbohydrates in proportion to moisture and nitrate supply, also accompany decreased vegetation.

The conditions for the initiation of floral primordia and even blooming are probably different from those accompanying fruit setting. The greatest number of flowers are produced neither by conditions favoring highest vegetation nor by conditions markedly suppressing vegetatioh, but in a condition when carbohydrate/nitrogen balance is maintained. This propostion is similar to what Loomis (8), Watts (18) and Mayberry (10) have found in their work. Irrigation or moisture supply is effective in increasing growth or fruitfulness only when accompanied by an available nitrogen supply.

To compromise between the different theories, and to shorten the argument, Loomis (8) suggested the growth-differentiation balance. He said that at moderately high temperatures growth in plants is dependent upon moisture supply at the growing point and upon the supply of synthesizable protoplasm building materials. Differentiation under the same conditions is assumed to be dependent upon the concentration of the sugar in the cell sap of the differentiating cells or upon substances closely correlated with the concentration. Growth-differentiation balance differs from the carbohydrate/nitrogen balance in the following ways:

1. In assuming an independent and major role to moisture.
2. Including with nitrogen the equally essential if not so commonly limiting factors concerned in the synthesis of protoplasm.
3. Recognizing the effect of temperature, and
4. Emphasizing the importance of active carbohydrates as opposed to storage forms.

The concept of growth-differentiation balance is not offered as a complete and final statement of the development process in the plant but as a convenient and simplified scheme for predicting or explaining plant behavior.

Watts (17) in reply to what Kraus and Kraybill (6) and Cooper and Wigans (3) have found about how important lack of fertilization, competition and unfavorable carbohydrate/nitrogen balance are in fruit drop, said that the answer is still connected with another and most important factor which is temperature. He found that when tomato plants were grown in the greenhouse during the cloudy short day season of the year, there is a negative correlation between succulent growth and temperature; that is, succulence of the plants decreased as temperature increased. In the meantime it was clear that vigorous but moderately succulent plants were most fruitful. On the other hand, very vigorous and very succulent plants were unfruitful due to the production of abortive blossoms and nubbins when produced during a period of limited light. These same plants produced seedless fruits or puffs after the weather became less cloudy and the days longer. Very woody, weak vegetative plants were unfruitful due to a small number of buds produced and the characteristic of blossom and fruit dropping although these were pollinated. The same fact was stated by Kraus and Kraybill in relation to carbohydrate/nitrogen balance. Low temperature, on the other hand, caused limited pollination of fertile flowers due to failure of the pollen sacs to open, and induced the production of "cripples" or irregularly shaped fruit due to poor growth.

In support of the previous idea presented by Watts, Strong (15) made a four-year study on spring crops of greenhouse tomatoes. He indicated that neither humidity nor treatment with fruit setting hormones at time of pollination, had any effect on fruit production. On the other hand, temperature did affect the number and size of fruits. He indicated that solar radiation and optimum temperature of 80°F. were directly correlated with the seasonal yield per plant.

To answer the question of temperature Went (21) has emphasized the point quite clearly. In his study concerning the thermoperiodicity in growth and fruiting of the tomato he stated that temperature was not only of paramount importance for vegetative growth but also for fruiting. When all plants were continuously subjected to temperature of 80°F., (different humidities) very few fruits developed. But plants kept warm during the day (80°F.) and cool during the night (63-68°F.) grew more rapidly than any of the other groups (27 mm. per day). The lower temperatures are only effective when maintained during the dark period.

Approximately the same temperature relation held for fruit development. Fruit set was abundant only when the night temperatures are between 59-68°F. With lower and higher temperature during the night, fruiting was reduced in amount or even absent. Artificial light when applied during the cool night period completely inhibits fruit formation.

Went and Hull (20) applied an indirect procedure to examine the effect of temperature on the tomato plant, by simply measuring the rate of bleeding. Tomato plants, he said, with healthy root system will bleed for a considerable length of time after decapitation. The rate of bleeding depends upon the activity of the root system, and this in turn is affected by its sugar content. By recording the rate of bleeding, it was found that in the tomato plant both the rate and intensity of sugar transport have a Q_{10} well below 1.

Returning to the work carried on by Tiedjens and Schermerhorn (16) in relation to the balance between the state of fruitfulness and the state of vegetativeness, it was stated that these genetic differences are reflected in their metabolic or respirational rate which increases with temperature. This approach is different from that of the other workers discussed here. The highly vegetative types have a high metabolic rate while the highly fruitful type has a relatively lower rate. Considering all varieties, the best growth and fruitfulness obtained were when the root temperature ranged at or between 65-80°F. There were, however, marked differences in response shown by the different varieties. The varieties that possessed the highest rate of metabolism made growth at the low temperature and were least affected by the high temperature.

As mentioned earlier in this discussion, Mayberry (10) tackled the problem of sugar absorption through the foliage only. Went and Carter (19) on the other hand, studied the effect of sugar application to different parts of the tomato plants and followed that line under various external conditions. The response has been recorded as changes in growth rate and flowering, when compared with untreated controls. Roots take up very little sugar, stems take it up mainly through wounds, but intact leaves absorb it readily, apparently through the whole surface and especially through the stomata, the lower surface being more permeable for sugars. The sugar uptake through the leaves is independent of the humidity of the air, but when applied through cuts in the stem much more sugar is absorbed at lower than at higher humidity and for this stem uptake the presence of leaves is essential. The spray application was simple and could be used to treat large numbers of plants without any apparent injury. Whereas in each experiment carried out in a dark room the applied sugar greatly increased the growth rate and life span of the tomato plants, the experiments in daylight in the greenhouse were much more variable. It was conclud-ed that applied sugar increased growth and flower production only when the plants were growing at fairly high temperatures and low light intensity, corresponding to winter greenhouse conditions in northern latitudes.

Furthermore, a single sugar application in light improv-ed the condition of the plants when later transplated after a bare-root storage period in a dark room. As a conclusion, Went and Carter suggested that many applications of the use of sugars should be used to improve plant growth.

III

MATERIALS AND METHODS

The tomato plans used in the various phases of the experiment were grown in the greenhouse during the period from autumn of 1954 until spring of 1955. The seeds were planted in seedling flats and transplanted to five inch clay pots. All the treatments were conducted with the plants growing in the pots. The greenhouse temperature throughout the experiment was thermostatically controlled at a constant 75°F. This temperature was held in order to insure viability of the pollen.

The soil used in all treatments was a mixture of 1/5 peat, 4/5 loam soil and a small amount of sand. The mixture was steam sterilized.

The seedlings were watered once a day until they were about 8-10 inches high. After that stage the demand for larger quantities of water was quite obvious. They were given water twice a day; 9 A. M. and 4 P. M., and on bright sunny days they were also watered at noon. Precautions were taken to avoid watering at night in order to reduce the danger of disease spread.

Ra-Pid-Gro solution was used as a fertilizer at the concentration recommended by the manufacturer. It was applied three times during the life of the plant. The three stages

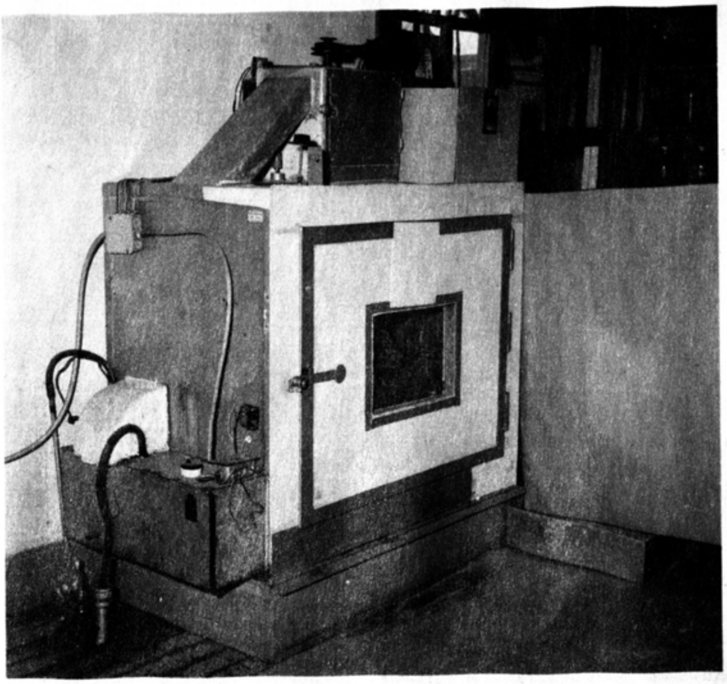

Fig. 1. Heating Chamber: is a steel box with outside dimensions of 4 x 3 x 2½ feet covered with asbestos paper for insulation. The heating unit can be seen on top and the dehumidifier on the side. Hot air from the heating unit is blown downward along the sides by a fan and comes up from the bottom to heat the plants.

Fig. 2. The chamber (Fig. 1) is equiped with three daylight bulbs of about 200-225 foot candles

during which the plants were given nutrients were when the plants were about six inches tall, at the time of flowering, and one week later. Care was taken to give equal amounts of fertilizer to all plants in each phase of the experiment.

No obvious symptoms of disease or insect damage were noticed. Smoking in the greenhouse was prohibited to discourage tobacco mosaic and precautions were taken to prevent foliage diseases from developing. The foliage was kept dry as much as possible and plants were sprayed with Malathion and Parzate.

Pots ready to be treated in the heating chamber were covered with pieces of aluminum foil large enough to cover and seal the soil from around the stem to the edges of the pot. This device was used to avoid moisture evaporation from the soil and somewhat reflect heat. By the same device, too, we decrease accumulation of water vapor in the heating chamber. (Fig. 1).

From one to three pots were placed in long metal containers, prepared especially for this occasion, to hold the insulating material, vermiculite, around the pots. In thus insulating the individual pots, the soil temperature is held lower (Fig. 2).

After the four-hour period in the chamber, all individual plants were removed from the metal containers, uncovered and watered with sufficient quantities of water to cool off the soil. Later, the pots were returned to the greenhouse and spaced one foot apart on the benches as they were before.

Light and Temperature Treatments

In order to determine the effect of photosynthetic activity on ability to set fruit under high temperatures, a study was conducted involving pre-darkening plants before subjecting them to high temperatures. The variety Sioux was used in this study.

The pre-darkening treatment consisted of holding the plants under a frame covered by a double layer of black cloth. Some light was allowed to enter at the bottom but light intensity was approximately 18-20 foot candles.

The four treatments involved in this study were the following:

1. Pre-darkening for 42 hours; then placed in heating chamber for four hours at 105-110°F.
2. Pre-darkening for 42 hours; then placed in heating chamber for four hours at 80-85°F.
3. Taken directly from greenhouse and placed in heating chamber for four hours at 105-110°F.
4. Taken directly from greenhouse and placed in heating chamber for four hours at 80-85°F.

Plants for treatment 1 were placed in the dark at 8 P.M. and removed 42 hours later, at noon on the third day. Two plants thus treated were then placed immediately in the heat-

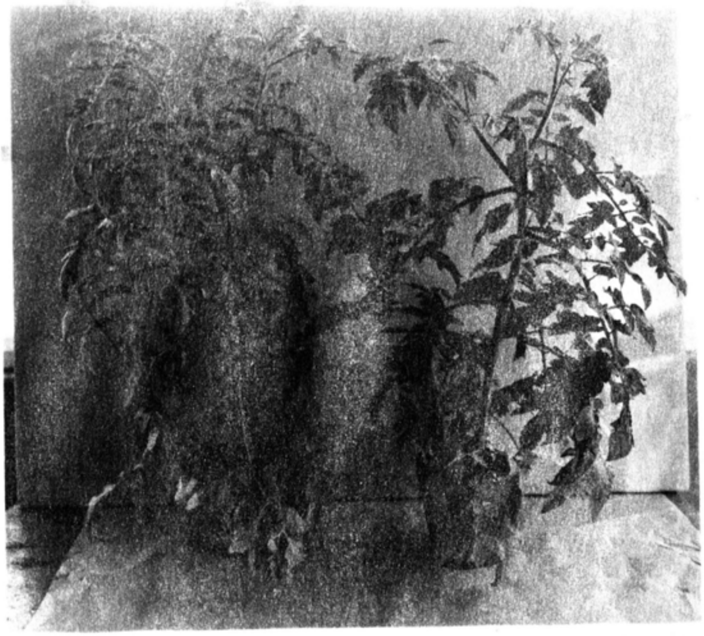

Fig. 3. Flowers in the first two phases are tagged according to their stage of development.

ing chamber along with two other plants from treatment 3 at the same stage of flower development, chosen from several on the greenhouse bench.

The stage of development when the plants were placed in the chamber was such that as many stages of flower development as possible were present on the first flower cluster. Stages of flower development as used in the experiment are:

1. The sepals are not open.
2. The sepals only are open.
3. The sepals and petals are open.
4. The sepals and petals are straight and perpendicular to the pedicel and the stamens. The petals in this case are golden yellow in color. This stage is considered the best for pollination.
5. The sepals and petals start to shrink and wither. The petals turn light yellow in color. It is considered good for pollination.
6. Sepals and petals are about to close around the stamens and the pistil.
7. Sepals and petals are completely closed, fertilization has occurred and the fruit starts to develop.

Each flower and flower bud of the first flower cluster of all plants used in the study was tagged (Fig. 3) as to its stage of development at the time it was put in the heating chamber. In this way information could be obtained concerning the result of the treatments on the various stages.

After the heat treatment the plants were returned to the greenhouse and all four pots from each chamber treatment were kept together in random order.

Plants for treatment 2 were placed in the dark at 4 P.M. and removed at 8 A.M. on the third day, also giving 42 hours pre-darkening treatment. Heating chamber temperatures were kept at 80-85°F. as a temperature check.

The chamber was used for check treatments because it was thought that pollination could be affected by the constant vibration caused by the motor and the fan.

Treatments 3 and 4 consisted of the same two heating chamber temperatures as treatments 1 and 2 but different in that the plants were taken directly from the greenhouse to the heating chamber. There was no pre-darkening treatment.

Three weeks after the heat treatment date of each plant, the data were collected. These data consisted of noting lack of fruit set and the weight of each fruit developed.

Varietal Response to Temperature Treatments

A total of 204 plants of seventeen varieties, as listed on the next page, were divided into three replications on the central bench of the greenhouse, completely randomized.

Four pots of each variety were used to make up the full replication. This brings the total number of pots in each replication to 68. To lessen the effects of the greenhouse environment, each replication was arranged in four blocks and each two blocks represent one treatment. Each block consists of one pot of each variety and the entire block is designated for either the high or low temperature treatment. As a further precaution, each replication was surrounded by one extra row of plants to serve as a buffer against heat and air currents and hence decrease the amount of water loss.

<u>Variety List</u>

1. Firesteel
2. Chatham
3. Earliana
4. Valnorth
5. Sioux
6. Victor
7. Ponderosa
8. Cavalier
9. German Dwarf
10. Red Jacket
11. Queens
12. Rutgers
13. Bounty
14. Gem
15. Ill-T-19
16. Valiant
17. Bison

It should be noted that not all replications were planted at the same time. There is an interval of 15-20 days between each replication.

In this study there were also two ranges of temperature; 80-85°F. and 105-110°F. Plants to be subjected to low temperature, 80-85°F., were watered, covered with aluminum foil, each flower in the first cluster was tagged as described earlier and the pots were placed in the metal containers and immediately put into the heating chamber for four hours. Plants subjected to high temperature, 105-110°F., were treated the same as those in the low temperature treatment, with the exception of the chamber temperature. The plants in both treatments were put into the heating chamber when there was a maximum number of flower stages in the first cluster.

The plants for the lower temperature treatment were placed in the heating chamber at 8 A.M., while those treated at high temperature were placed in the chamber at 12 noon. Afternoons were used for the high temperature treatment in order to most closely approach natural conditions.

The heating chamber was also used for the check treatment because of possible effects of vibration of the motor on pollination.

Time of Pollination and Temperature Treatments

As a corollary to the study of the relationship between high temperature and stage of the flower development in fruit set, a study involving artificial pollination was conducted. The following treatments were given:

1. Pollinated 48 hours before heating.
2. Pollinated 24 hours before heating.
3. Pollinated immediately before heating.
4. Pollinated immediately after heating.

The high temperature period used was the same as that used in other phases of the experiment; i.e., four hours at 105-110°F.

Four plants, one of each treatment, were placed in the heating chamber together for the four-hour high temperature treatment. Only one flower, the first to develop on the first cluster, was used from each plant. All other buds were removed at time of emasculation.

Since treatment number 4 required a four-hour period between emasculation and pollination, it was necessary to leave a similar period between emasculation and pollination for the other three treatments. Treatment number 4 was emasculated at noon and pollinated within a few minutes after removing from the heating chamber at 4 P.M.

The flower buds used for pollination were at the stage of development wherein the stigmatic surface was receptive and before self-pollination occurs naturally. At this stage the sepals had opened and the petals were expected to open shortly after.

For the sake of uniformity of pollen growth for all treatments and to make this study more comparable to natural conditions, all pollen used was from the same variety, Sioux, used for the female parents. Although it is hoped that some of this data can be applied to the making of artificial crosses, pollen from the same variety was used, in view of insufficient information concerning the differential growth rates of pollen from various varieties and various crosses.

Three weeks after the pollination date of each plant, the data were collected. These data consisted of noting lack of fruit set and a measurement of fruit diameter.

IV

RESULTS AND DISCUSSION

Light and Temperature Treatments

Tables I and II show the effect of high temperature and greatly reduced light intensity on fruit weight. The average weights for treatments in table I show that high temperature (treatments 1 and 3) exerted a great effect on reducing the average weight of fruit, regardless of pre-darkening treatment of 42 hours. Similarly, the results of low temperature (treatments 2 and 4) were larger fruits, regardless of the pre-darkening treatment.

The analysis of variance for the data mentioned in table I shows that the effects of temperature on fruit weight per plant three weeks after the heat treatment were highly significant. The analysis in table II also shows that the pre-darkening treatment did not significantly affect fruit weight.

Table I. Effect of temperature and pre-darkening treatments on fruit weight. Weights (in grams) were taken three weeks after treatment. Individual entries in the table are based on total fruit weight for two plants.

Replication	1. Dark 105-110°F.	2. Dark 80-85°F.	3. Light 105-110°F.	4. Light 80-85°F.
1.	17.07	17.55	33.85	33.44
2.	18.27	40.93	20.34	36.49
3.	0.01	4.50	33.92	53.90
4.	0.01	23.61	0.01	62.75
5.	0.01	65.87	44.26	138.86
6.	57.70	128.05	6.51	52.15
7.	0.01	97.61	99.12	80.91
8.	98.18	84.97	5.77	13.64
9.	18.47	106.67	60.59	70.99
10.	0.01	100.25	71.14	69.47
11.	0.01	70.54	29.50	72.46
12.	51.37	81.85	10.04	117.49
13.	0.01	119.55	36.51	200.54
14.	0.01	52.13	32.65	57.16
15.	7.63	191.59	57.55	159.76
16.	73.75	116.79	0.01	183.44
17.	-	155.14	-	85.88
Total	342.52	1457.60	541.77	1489.33
Ave. Wt. Per Fruit	11.05	20.53	9.34	19.34

Table II. Analysis of variance for data in table I, based on total fruit weight per plant.

	S.S.	D.F.	M.S.	F.
Temperature	57462.27	1	57462.27	31.67 **
Pre-darkening	1270.26	2	635.13	0.35
Error	112476.52	62	1814.14	

** Highly significant at 0.01 level.

In addition to the effect of temperature and light on fruit weight, the effect of the same treatments on percent fruit set was also recorded and analysed in tables III and IV. The effects on percent fruit set are shown in table III to be different from the effects on fruit weight.

Table III. Effect of temperature and pre-darkening treatment on percent fruit set.

Replication	1. Dark 105-110°F.	2. Dark 80-85°F.	3. Light 105-110°F.	4. Light 80-85°F.
1.	75.00	80.00	85.70	100.00
2.	40.00	100.00	100.00	100.00
3.	50.00	100.00	100.00	100.00
4.	42.90	100.00	66.70	100.00
5.				
5.	25.00	100.00	100.00	100.00
6.	100.00	87.50	50.00	81.80
7.	0.00	87.50	100.00	100.00
8.	44.40	100.00	16.70	90.00
9.	22.20	90.00	100.00	100.00
10.	0.00	88.90	100.00	90.90
11.	0.00	88.90	77.80	85.70
12.	66.70	100.00	25.00	83.30
13.	0.00	72.70	88.90	70.00
14.	0.00	100.00	45.50	38.50
15.	81.80	66.70	78.60	83.30
16.	66.70	44.40	0.00	90.90
17.	-	75.00	-	100.00
Total	614.70	1481.60	1134.90	1514.40
Average	38.42	87.15	70.93	89.08

The greatest reduction in fruit set was found in treatment 1, in which high temperature was combined with the pre-darkening treatment. Comparing treatment 1 with treatment 3, both high temperature treatments, it can be seen that when high temperature was combined with pre-darkening, the percent fruit set was nearly half of that in the treatment in which pre-darkening did not precede high temperature. Considering the low temperature treatments (2 and 4) the difference in percent fruit set as a result of pre-darkening was negligible.

The results can be further clarified by comparing the two light treatments (3 and 4) with the dark treatments (1 and 2). Considering them as two groups, it will be seen that percent fruit set with light is higher than the group subjected to pre-darkening. It should be noted, however, that treatments 1 and 2 are lower because of the reduction in fruit set resulting from the combination of high temperature and pre-darkening. Thus high temperature appears to affect fruit set but the effect is far more pronounced in combination with pre-darkening.

The analysis of variance for the data in the preceding discussion is given in table IV.

Table V consists of data concerning flower drop and fruit weight resulting from flowers at various stages of development at the time of treatment. A discussion of the data occurs under the third phase of the experiment dealing with pollination time and high temperature.

Table IV. Analysis of variance for data in table III. (Percentages were transformed to arc sines for analysis)

	S.S.	D.F.	M.S.	F.
Temperature	11795.97	1	11795.97	23.44**
Pre-darkening	6348.58	2	3174.29	6.31**
Error	31197.00	62	503.18	

** Highly significant at 0.01 level.

Varietal Response to Temperature Treatments

The data in table VI and the analysis of variance in table VII indicate that, while the general effect of temperature on fruit weight was greatly significant, the differential response by the different varieties tested was not. It should be noted, however, that this analysis is on the basis of fruit weight rather than percent fruit set. In the case of the temperature and light study, described earlier, the fruit weight was not affected in the same manner as percent fruit set. This also appears to be the case in the varietal response phase of the experiment.

Table V. Effects of temperature and pre-darkening treatment on flowers at different stages of development. Weights (in grams) were taken three weeks after treatment.

Stages	Total Weight	No. Fruit Treated	No. Fruit Attached	Percent Attached	Ave. Fruit Weight
1. Dark 105-110°F.					
1.	0.03	16	2	12.5	0.02
2.	0.04	14	3	21.4	0.01
3.	9.45	13	6	46.2	1.58
4.	100.72	20	8	40.0	12.59
5.	157.48	15	7	46.7	22.50
6.	17.60	6	3	50.0	5.87
7.	57.39	5	2	40.0	28.70
2. Dark 80-85°F.					
1.	0.14	29	12	41.4	0.01
2.	4.56	18	10	55.6	0.46
3.	102.63	20	12	60.0	8.55
4.	636.95	28	16	57.1	39.81
5.	489.01	23	13	56.5	37.72
6.	181.17	12	7	58.3	25.78
7.	23.57	1	1	100.0	23.57
3. Light 105-110°F.					
1.	7.40	22	9	41.3	0.82
2.	5.06	27	10	37.4	0.51
3.	0.15	16	8	50.0	0.02
4.	306.60	23	12	52.2	25.55
5.	179.58	18	13	72.2	13.81
6.	33.59	10	4	40.2	8.40
7.	0.02	2	2	100.0	0.01
4. Light 80-85°F.					
1.	19.07	19	8	42.1	2.38
2.	12.68	24	14	58.3	0.91
3.	70.80	27	15	55.6	4.72
4.	524.87	26	16	61.5	32.80
5.	457.92	19	12	63.2	38.16
6.	176.01	21	8	38.1	22.00
7.	260.67	5	4	80.0	65.17

Fruit attached referred to in table V indicates that fruit remained attached to the plant three weeks after treatment. The term attached as used here means that the abscission layer formation was not complete. Fruit set as used in other parts of this paper indicates a visible development of the fruit.

Table VI. Effect of temperature on average fruit weight in seventeen tomato varieties. Weights (grams) were taken three weeks after treatment.

Variety	80-85°F. Total Wt. 3 Repl.	80-85°F. No. Fruits	80-85°F. Ave. Wt.	105-110°F. Total Wt. 3 Repl.	105-110°F. No. Fruits	105-110°F. Ave. Wt.
1.*	357.68	19	18.83	378.50	11	34.41
2.	446.17	17	26.25	259.12	13	19.93
3.	748.93	28	26.75	472.19	17	27.78
4.	452.98	13	34.84	320.96	9	35.66
5.	641.01	19	33.74	496.11	18	45.10
6.	497.99	16	31.12	278.66	8	34.83
7.	210.35	8	26.29	43.31	4	10.83
8.	710.08	16	44.38	331.06	9	36.78
9.	488.91	29	16.86	400.49	23	17.41
10.	534.86	16	33.99	524.99	13	40.38
11.	647.96	19	34.10	352.79	9	39.20
12.	422.01	14	30.14	222.91	9	24.77
13.	461.44	21	21.97	349.59	16	21.85
14.	798.08	23	34.70	431.89	10	43.19
15.	513.14	12	42.76	606.61	14	43.33
16.	807.30	26	31.05	361.37	13	27.80
17.	678.59	22	30.85	496.48	13	38.19
Average	554.50	18	30.50	372.18	12	31.85

* Variety names will be found in the Materials and Methods section.

Table VII. Analysis of variance for data in table VI.

	S.S.	D.F.	M.S.	F.
Temperature	96096.90	1	96096.90	23.49 **
Temp. x Var.	19641.54	16	1227.60	0.30
Error	130907.86	32	4090.87	

** Highly significant at 0.01 level.

Table X, dealing with flower drop (a response similar in effect to percent fruit set) rather than fruit weight shows that the interaction, Stages x Temperature x Variety, is highly significant. This indicates that there is a differential response to the difference in temperature in percent flower drop by stages of flower development, and the variety undergoing the high temperature treatment.

The information contained in tables VI and VIII indicate the reason for varietal response to temperature being greater from the standpoint of percent fruit set than from the standpoint of fruit weight. A comparison of the average number of fruits set from each temperature treatment shows a great difference due to a difference in temperature. On the other hand, average weight of fruits from each temperature treatment appears to be similar. In fact, there is a slight increase with high temperature. Apparently the effect of high temperature on tomato fruit weight is not as pronounced as on number fruit set because, with few fruits on a plant, those that develop do not have as much competition for growth as where there are large numbers of fruits set in a cluster. Although this modifying influence of fruit weight appears to overcome the disadvantages.

Table VIII. Effect of temperature on percent fruit set.

Variety	Treatments				
	80-85°F.		105-110°F.		
	Number Treated	Percent Fruit set	Number Treated	Percent Fruit Set	Diff.
1.	67	28.36	67	16.42	11.94
2.	36	47.22	35	37.14	10.08
3.	66	42.42	81	20.99	21.43
4.	23	56.52	25	36.00	20.52
5.	38	50.00	34	52.94	- 2.94
6.	35	45.71	32	25.00	20.71
7.	35	22.85	32	12.50	10.35
8.	29	55.17	38	23.68	31.49
9.	38	76.32	41	56.10	20.22
10.	37	43.24	39	33.33	9.91
11.	38	50.00	26	34.62	15.38
12.	31	45.16	31	29.03	16.13
13.	41	51.22	40	40.00	11.22
14.	35	65.71	36	27.78	37.93
15.	30	40.00	41	34.15	5.85
16.	34	76.47	35	37.14	39.33
17	61	36.07	66	19.70	16.37

of a poor fruit set, the commercial disadvantages may still be present if the difference in size, at the end of the three weeks of development, is still present at harvest time. Consumers, especially when tomato prices are high, often prefer a larger number of fruits per pound for table use. Also, total pounds per plant would usually be lower with a lighter fruit set.

Table IX. Effect of temperature on flowers at different stages of development in seventeen tomato varieties.

Stages	(80-85°F.)	Treatments		(105-110°F.)		
	No. Fruit set	No. Flower Treated	Percent Fruit set	No. Fruit set	No. Flower Treated	Percent Frt. set
1.	10	95	10.52	6	95	6.32
2.	12	106	11.32	4	109	3.67
3.	26	123	21.14	3	110	2.73
4.	113	133	84.96	75	130	57.62
5.	95	113	84.07	80	132	60.61
6.	53	94	56.38	38	107	35.51
7.	2	2	100.00	2	2	100.00

Table X. Analysis of variance for data in table VIII and IX.

	S.S.	D.F.	M.S.	F.
Stages	9919.87	6	1653.31	5.47 **
Stag. x Temp.	10166.70	7	1452.39	4.80 **
Stag. x Temp. x Var.	147396.68	96	1535.38	5.08 **
Stag. x Var.	150061.99	96	1563.15	5.17 **
Error	123365.14	408	302.37	

The analysis in table X is on the basis of fruits attached at the end of three weeks rather than percent fruit set. Tables VIII and IX are based on percent fruit set.

The number of plants used in the phase of the experiment dealing with varieties was perhaps too small to draw a conclusion concerning a given variety's ability to set fruit under adverse conditions. There is, however, a good indication that this method can be used to determine a variety's adaptability. Furthermore, it should be avaluable tool in selecting lines for a tomato breeding program.

Time of Pollination and Temperature Treatments

In the preceding phase of this experiment, high temperature was shown to have an influence on fruit set. This phase of the experiment was designed to determine the importance of pollination time on fruit development under high temperature conditions.

Tables XI and XIII show that the smallest average size fruit occurred when the stigmatic surface was pollinated 48 hours before being subjected to four hours of high temperature. It might appear more likely that when pollination was accomplished just prior to the high temperature treatment there would be less chance of fertilization and slower fruit development. This might be expected to be especially true when the female parent has been emasculated, as in this case, because of the exposure of the ungerminated pollen grains.

Table XI. Effects of high temperature on fruit size of the variety Sioux at four different times of hand pollination. (Diameter is measured in centimeters three weeks after pollination.)

Replication	Diameters in Centimeters			
	Time of Pollination in relation to beginning of heat treatment. (105-110°F.)			
	48 hours before	24 hours before	0.0 hours before	4 hours after
1.	0.1	4.0	4.4	3.8
2.	2.6	3.8	4.5	3.2
3.	4.5	5.0	4.7	4.9
4.	4.1	0.1	4.3	5.0
5.	0.4	4.0	6.1	4.6
6.	5.5	4.4	6.1	4.8
7.	5.5	5.2	4.5	5.6
8.	5.8	4.9	5.2	5.1
9.	3.6	3.8	4.3	4.5
10.	3.5	4.3	5.0	4.9
11.	3.0	5.3	4.3	4.9
12.	0.1	5.5	5.4	0.1
13.	5.4	5.1	5.2	5.6
14.	4.2	5.2	2.9	4.7
15.	4.6	4.8	5.6	5.4
16.	4.8	5.3	4.6	4.7
Total	57.7	70.7	77.1	71.8
Average	3.6	4.4	4.8	4.5

The fact that the earliest pollinated plants produced the smallest fruit is, however, in accord with the views of Loomis (9) who considers freshly pollinated fruit to be generally lower in competitive ability than other parts of a plant. According to Smith and Cochran (14) the zygote is not formed before 50 hours after fertilization; hence, the flowers pollinated 48 hours before the beginning of the heat treatment were the only ones that could be fertilized during the period of high temperature.

Table XII. Effect of temperature in flowers at different stages of development in the variety Sioux. Weights (grams) were taken three weeks after treatment. (Data taken from table V).

Stages	Total Weight	No. Flowers Treated	No. Fruit Attached	Percent Attached	Weight Ave. Fruit
Light 105-110°F.					
1.	7.40	22	9	41.3	0.82
2.	5.06	27	10	37.4	0.51
3.	0.15	16	8	50.0	0.02
4.	306.60	23	12	52.2	25.55
5.	179.58	18	13	72.2	13.81
6.	33.59	10	4	40.2	8.40
7.	0.02	2	2	100.0	0.01
Light 80-85°F.					
1.	19.07	19	8	42.1	2.38
2.	12.68	24	14	58.3	0.91
3.	70.80	27	15	55.6	4.72
4.	524.87	26	16	61.5	32.80
5.	457.92	19	12	63.2	38.16
6.	167.01	21	8	38.1	22.00
7.	260.67	5	4	80.0	65.17

As mentioned in the Materials and Methods section, all flowers and flower buds on the female parent were removed with the exception of the one pollinated for the experiment. As a result of this procedure, fruit weights are more accurately a measure of temperature effects than they could be if all flowers were allowed to develop. Competitive effects of other developing fruits are thus eliminated.

Table XIII. Analysis of variance for data in table XI.

	S.S.	D.F.	M.S.	F.
Pollination Time	12.72	3	4.24	2.57*
Replications	41.72	15	2.78	1.68
Error	74.44	45	1.65	

* Significant at the 0.05 level.

Data concerning fruit set and flower drop from flowers at various stages of development at the time of the high temperature treatments during this phase of the experiment, were also collected and tabulated. Table X shows that the stage of flower development at the time the plant is exposed to high temperatures has a highly significant role in its setting fruit.

The number of flowers observed at each stage, particularly the earliest stage, and interactions from other flowers in the cluster makes an analysis of the results difficult. Certain findings, however, are worth considering. Table XII, for instance, shows that there is a sharp difference in average weight of fruits developed from stages 6 and 7, depending on temperature treatment. While the numbers are small, stage 6 had enough flowers treated to seriously consider the results.

Stages 6 and 7, being past the stage in which dehiscence usually occurs, may be considered similar to the first treatment listed in table XI. The poor development of these fruits indicates that possibly the recently fertilized fruit is damaged more by high temperatures than are flower parts before fertilization.

Percent fruit set and flower drop do not appear to follow the same trend as that noted in connection with fruit weight. Further work along this line would benefit in interpreting the results.

The fact that table IX is composed of a composite of several varieties may give somewhat different results than would be obtained from a single variety.

CONCLUSION AND SUMMARY

High temperature treatments consisted of four hours at 105-110°F., with checks at 80-85°F. Plants were grown in pots and subjected to temperature treatments when the first cluster was in blossom. Except where noted, conclusions were based on the variety Sioux.

1. High temperature at time of flowering was found to lower total fruit weight per plant three weeks after treatment, but pre-darkening the plants for 42 hours before treatment had no effect.
2. Both high temperature treatment and pre-darkening of plants lowered percent fruit set when the two treatments were combined.
3. High temperature lowered average fruit weight of seventeen varieties three weeks after treatment, considering the average of the seventeen varieties. There was no significant variety by temperature interaction.
4. High temperature was found to highly significantly affect percent flower drop in seventeen varieties. The following factors also highly significantly affected percent flower drop: stage of flower development at the time of treatment, stage by temperature interaction, stage by temperature by variety interaction, and stage by variety interaction.

5. Pollination 48 hours before subjecting the plant to heat treatment resulted in smaller fruits at the end of three weeks than pollination 24 hours before, immediately before, or immediately after the heat treatment.

6. Recently pollinated fruits appeared to develop less rapidly after having been subjected to high temperature than did the fruit from flowers at a slightly earlier stage at the time of heat treatment.

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