A STUDY OF SOME FACTORS ASSOCIATED WITH THE OCCURRENCE OF CRACKS IN THE TOMATO FRUIT.

by

William A. Frazier.

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Statement of the Problem

The appearance of "growth" cracks in tomato fruits is very common, and constitutes an important economic loss in the grading of such fruits for the market, as well as in their preparation for the table or for manufacture. Although the need for detailed studies on the problem has long been recognized, practically no data are available which might indicate the factor or factors associated with the phenomenon. This is partly due to the general opinion that rupturing of the fruit is mainly the result of weather conditions which cannot be controlled. For example, it is often stated that the severe cracking during or following rainy periods may be explained by water increase in the fruit, causing an expansion which is too sudden for the skin to bear. Can it be shown that by applying water to the soil, the water content of the fruit can be increased? Is it possible that the fruit itself may absorb rainwater through its skin or through the corky layer of the stem end? Are there varietal differences in susceptibility to cracking? On what part of the fruit are cracks most likely to occur? Will fruits on vines given a plentiful water supply throughout the season crack as badly as those on vines kept dry, then heavily watered? At what stage of maturity is the fruit most susceptible to cracking? Does position of the fruit on the vine affect cracking? It has been the purpose of this investigation to seek an answer to these practical questions. Further, a study of the causes of noted differences in cracking between varieties and of experimental treatments has been attempted. This part of the work, necessary in the ultimate solution of the problem, has included studies of: (1) chemical composition as influenced by variety and treatment, (2) freezing point depressions, (3) H-ion concentration, (4) pressure tests, (5) rehydration rates, (6) absorption of water by immersed fruits, (7) intake of dye solutions, (8) temperature affects, (9) possible effect of sunshine.

A complete solution of the problem was not expected here because of its many complications, and the lack of helpful literature. Yet certain definite factors have been found to be closely connected with the rupture of the fruit and other supposed factors have been eliminated. By considering only the most potent of the causal factors, it should be possible to render more helpful suggestions for control, and to describe definite characteristics to be developed in breeding crack resistant varieties.

Review of Literature

Statements in the literature concerning the occurrence of cracks in the tomato fruit are confined almost entirely to a mere recognition of the problem. No less surprising is the fact that data on cracking of apples, cherries, prunes, oranges and other fruits are almost as scarce. On account of this dearth of knowledge on the subject it is felt that as complete a review of existing literature as possible should be made here. It must not be assumed that the conditions promoting cracking in a certain kind of fruit would cause cracking in another. This has yet to be conclusively shown; still the literature cited below will show some apparent agreement among existing ideas of the cause of rupturing of various fruits.

Barre (1910) noted that tomato fruits approaching maturity were especially susceptible to cracking. He thought that a period of rain following a period of hot, dry weather promoted cracking by a filling of the cells of the fruit with water, with a subsequent expansion more rapid than that of the epidermis. A uniform rate of growth throughout the season would, he thought, decrease the amount of cracking.

Poole (1923) stated that it is common to find both green and ripe fruits of Earliana, Bonny Best, and Greater Baltimore varieties cracking under New Jersey conditions. He suggests a sudden change of moisture conditions during July and August as a possible cause of the trouble. He advised the maintenance of a more nearly constant moisture supply in the soil.

Kraus (1929) grew nine tomato plants in boxes under greenhouse conditions. Five plants were fertilized with phosphoric acid, and the remaining four left as checks. None of the plants treated with phosphoric acid bore fruits that cracked, while the check fruits cracked appreciably.

Gardner, Bradford, and Hooker (1922) stated that suddenly renewed growth following a check is the cause of cracking in most orchard fruits. They suggested that the slow growth rate may be accompanied by some change in the fruit skin, which renders it more easily split when rapid swelling is resumed. They recommended cultural practices that maintain a sufficient water supply to keep the fruit growing.

Chandler (1925) believed that heavy irrigation in the late stages of development of the fruit, providing a check in growth had occurred earlier, was the principle cause of cracking.

The sweet cherry appears to be one of the most susceptible of all fruits to cracking. Hartman and Bullis (1929) noted that as sweet cherries approach maturity, they are more susceptible to cracking. They believed that "the trouble may occur as a result of excessive water absorption <u>either through the root system or through the epidermis of the fruit itself</u>." Immature or thoroughly ripe fruits were less susceptible to cracking. The Bing variety was found more likely to crack than Lambert or Napoleon.

Gardner (1930) stated that cracking of cherries may occur simply as a result of high humidity, especially following a dry period.

Verner and Blodgett (1931), working with sweet cherries, concluded that, under Idaho conditions, cracking is mainly due to absorption of rain water through the skin of the fruit. They were unable to demonstrate that cracking is caused by application of water to the soil, possibly because the trees with which they were working had, in some portion of their root area, sufficient moisture to keep the fruits growing. By using the specific gravity of the juice, obtained by a Balling scale hydrometer as a rough measure of osmotic pressure and sugar content, they showed an increased cracking index as osmotic concentration increased. The susceptibility to cracking was measured by placing the fruits in water at various temperatures. The higher the temperature, the higher was the rate of cracking, other factors being the same.

According to Carne (1924-1925) cracking of apples in certain seasons is common in western Australia, especially in the variety known as Dunns. Carne noted the most severe cracking on trees which were low in vigor and which bore light crops. He believed the trouble to be "essentially one of sap movement."

Campbell (1928) states that in New Zealand cracking of Dunn's and Cox's Orange apples is sometimes serious. The preventive practices in that region are good cultivation, fertilizing, spraying, and pruning.

McAlpine (1911) stated that Dunn's apple cracks, in wet seasons in Victoria only at the stem end. At other times the skin is "smooth like wax." One of the causes of russetness in apples he attributes to the rapid swelling of the surface of the apple, with the inability of the epidermis to keep up with it. He explained further that following a dry period "there comes a rush of sap, so that the growth of the flesh is so rapid that the skin cannot keep up with it, then something must give way, and small rents are produced, as well as disruption of the stomata, to be replaced by minute openings, which, in their function and mode of origin, correspond to the lenticels."

Splitting of citrus fruits is brought about, according to Reed (1930), by a distentive force in the pulp vesicles sufficient to break open the pericarp layers. The high turgor in the pulp vesicles results from their content of a high solute concentration. He says that "the water which distends the fruit comes from the tree on which it is borne."

Carne (1928) states that cracking of oranges may occur if the trees are irrigated following a rather long dry period. He believed, agreeing with Reed, that this was due to such a rapid swelling of the juice cells in the quarters of the fruit that the rind and rag cannot expand fast enough." In some cases only the rag is split. The rind tends to collapse into this fissure, and produces rough, sunken areas over the surface of the fruit, termed "crinkles." As high as seventy-five percent of the crop is affected in this way in some seasons, adversely affecting the shipping quality and appearance of the fruit.

Rixford (1918) found that figs may crack as the result of high humidity following a dry period, especially the fruits which are near maturity. He observed that figs borne on trees standing near irrigating ditches, thus receiving more uniform supplies of water, were less likely to crack.

It is apparent that with the exception of Verner and Blodgett's work, the knowledge concerning cracking of fruits is primarily observational in nature. The general agreement that water intake, either through the conducting system of the plant, or absorption through the fruit surface, is a primary cause of cracking, would lead one to at first study this factor in experimental treatments designed to produce cracking. For this reason the effects of soil moisture and of moisture applied to the surface of the fruit have been given particular attention throughout the present investigation of the occurrence of cracks in the tomato fruit.

Experimental Material

Summer of 1931: One-hundred plants of the Bonny Best variety, growing on a sandy loam soil in the student gardens at College Park were used for preliminary studies.

Summer of 1931: The author was given access to several varieties growing on the Arlington Experimental Farm of the United States Department of Agriculture. The varieties studied were: Gulf State Market, Globe, Early Detroit, Santa Clara Canner, Stone, Greater Baltimore, Marglobe, and Bonny Best. Though the plants had been injured early in their development by hail this injury had been largely outgrown at the time of beginning this study on August 14th. Each variety was represented by twenty-four uniform plants. The soil was a silt loam, producing large plants with a heavy set of fruit. The plants were neither staked nor pruned.

Greenhouse crop Fall of 1931: Two varieties, Gulf State Market, and Globe were chosen for subsequent studies following the data recorded at Arlington. For the greenhouse crop in the winter of 1931-1932, seeds were planted August 18th, the plants transplanted to flats August 25th, and to greenhouse benches September 26th. The benches were filled with six inches of a somewhat infertile clay loam soil, and a 7-6-5 fertilizer applied at the rate of one thousand pounds per acre. The plants were kept growing at a medium rate until December 8, 1931. At that time water treatments were begun, and were designated as high, low, and medium water. Each treatment of each variety consisted of duplicate plots of twelve plants. Spacing in the row and between rows was 24 x 18 inches, respectively. At the time of starting the water treatments, the fruits on the first cluster were nearing the mature green stage. The leaves of plants in the low water series were often somewhat wilted at mid-day. Variations in the water treatment were secured through applying uniformly different (weighed) amounts of water. Plants were pruned to a single stem and topped past the third cluster.

Greenhouse crop Fall of 1932: Seeds were planted August 5th, 1932, and transplanted to flats August 12th. The plants were set in the same raised benches that were used in 1931, and which had been refilled with an infertile clay loam soil and given an application of one thousand pounds of 7-6-5 per acre. Four plots of each treatment were planted -- six Globe plants in each plot alternating with six Gulf State plants. The two varieties were inter-planted in this way to escape variations in soil moisture between plots, since it had been found difficult in 1931 to keep the soil in the raised benches at a uniform moisture content. The plants were pruned to a single stem and topped past the third cluster. The plants were placed in the benches September 3rd, 1932, and kept growing uniformly until October 19th, when one-third of the plots were given high water, the remainder left dry. At this time the fruits on the first cluster were about half grown.

In view of the fact that the plants grown in these benches in 1931 had showed signs of a scarcity of nutrient materials, toward their later stages of development, it was thought advisable to thoroughly fertilize the plants of the

1932 crop, as they seemed to require it. The high amount of nutrients required was probably due to the rather poor soil and the necessity of heavy applications of water to offset the rapid loss by evaporation from the shallow benches. On October 12th an application of 7-6-5 at a rate of 750 pounds per acre was thoroughly worked in around the plants; November 24th $NaNO_3$ at a rate of two-hundred pounds was applied, to be followed November 29th by an application at the rate of one-hundred and fifty pounds per acre. The application of the nitrogenous fertilizer was necessitated by a slight yellowing of the leaves, noticeable by November 20th. On December 5th one-half of the dry plots were changed to high water treatment. At this date the last fruits on the first cluster were turning ripe. Few fruits, however, had been harvested.

Field: Summer of 1932: Seeds were planted March 31st, 1932. Plants were transplanted to flats April 25th, 1932, and to the field May 28th. A 7-6-5 fertilizer at the rate of seven hundred pounds per acre, and superphosphate at the rate of three hundred pounds per acre were applied in the furrows a week previous to planting. Three treatments were run under field conditions: (1) wet, (2) dry (normal rainfall), and (3) dry-wet. The wet series was kept thoroughly watered throughout the experiment, beginning early in July, when the first fruits had set. The dry series was never irrigated. Fortunately for this study the rainfall of the summer of 1932 was abnormally low. The dry-wet series was left dry until

Figure 1(A) — Field plots. College Park, 1932.

Figure 1-B -- Field Plots. College Park, 1932.

Rows	Series 5.	Series 4.	Series 3.	Series 2.	Series 1.
Border					
Globe Gulf State Market	Wet	Dry	Dry-Wet	Dry-Wet	Dry
Buffer					
Gulf State Market Globe	Dry	Dry-Wet	Wet	Dry	Dry-Wet
Buffer					
Globe Gulf State Market	Dry-Wet	Wet	Dry	Wet	Wet
Buffer					
Gulf State Market Globe	Wet	Dry	Dry-Wet		
Buffer					
Globe Gulf State Market	Dry	Dry-Wet	Wet		
Border					

October 11th, when heavy irrigation was applied until the end of the experiment. By October 11th about one-fifth of the tagged fruits had reached the pink stage. Seven replications of each variety and treatment were uniformly scattered over the area. Each of the seven plots consisted of eleven plants of Gulf State and eleven of Globe, each variety planted in a single row. Buffer rows on either side of the plots, and buffer plants at each end of the plot were provided for. Rows were five feet apart, and plants three feet apart in the row. In the irrigated plots water was run down furrows on both sides of the row. The plants were neither staked nor pruned.

Recording Data: In the greenhouse each flower was tagged the day it opened. All flowers were hand pollinated in the greenhouse. More than 20,000 blossoms were tagged in the field over a seven weeks period. Tags were put on every other day. A heavy set of fruit, together with a poor soil, combined to cut the season short, however, and only the flowers tagged over the first four or five weeks produced fruits that were included in this study. The following data were recorded on all tagged fruits that attained the pink or later stages of ripeness. (1) the position of the cluster on the plant (with the exception of field-grown plants), (2) the position of the fruit on the cluster, (3) time of tagging, (4) the day the fruit turned pink, (5) the day the fruit was red-ripe (except field-grown plants), (6) the day that cracking occurred, (7) degree of cracking (number and size, as well as position of cracks) when cracking first occurred, and (8) degree of cracking (number, size, and position of cracks) at the time of harvest, was kept on all tagged fruits, which reached a pink stage of maturity.

Varietal Susceptibility to Cracking

The eight varieties growing at Arlington Experiment Farm afforded an opportunity to study their susceptibility to cracking. Accordingly, on August 14th, August 31st, September 9th, and September 14th, counts were made of the number of cracked and non-cracked fruits of mature green, pink, and red ripe stages of maturity borne on the eight varieties. On October 2nd similar counts were again made for Globe, Gulf State, and Marglobe varieties. Any fruit showing a rupture of the skin - either concentrically or radially from the stem end, was considered as a cracked fruit.

Table I presents data showing the percentage of total fruits of a given stage of maturity which were cracked for each of the eight varieties, and on the five dates. Let us compare, first, the first three varieties listed in the table -- Gulf State, Globe, and Marglobe, at the mature-green stage of maturity. In every instance it is noted that Gulf State cracks least, followed by Globe and then Marglobe. If we use the pink fruits as a basis for comparison, we again note that in every case a smaller percentage of Gulf State fruits was

TABLE I -- PERCENTAGE OF CRACKED FRUITS OF EIGHT VARIETIES OF TOMATO, SHOWING RELATION OF CRACKING TO STAGE OF MATURITY UPON DIFFERENT DATES. ARLINGTON FARM, VA. 1931.

Variety	Aug. 14			Aug. 31			Sept. 9			Sept. 14			Oct. 2		
	Mature Green	Pink	Red	Mature Green	Pink	Red	Mature Green	Pink	Red	Mature Green	Pink	Red	Mature Green	Pink	Red
Gulf State Market	23.91	27.27	67.73	80.88	84.93	100.00	8.00	82.60	90.24	2.85	8.00	82.14	13.15	18.00	52.22
Globe	32.61	67.86	95.52	95.38	96.36	100.00	25.00	93.33	100.00	13.33	43.48	88.23	15.78	65.63	95.34
Marglobe	69.57	47.90	84.20	100.00	95.45	100.00	36.84	88.88	100.00	17.39	54.54	100.00	46.03	50.00	89.47
Bonny Best	50.00	60.62	84.50	100.00	94.45	100.00	33.33	100.00	100.00	20.00	32.43	100.00	--	--	--
Santa Clara Canner	50.00	93.33	100.00	100.00	100.00	100.00	--	--	100.00	--	100.00	100.00	--	--	--
Stone	27.77	35.00	70.60	44.44	70.58	75.00	72.72	83.33	94.11	--	80.00	100.00	--	--	--
Greater Baltimore	18.20	29.20	70.83	90.62	91.89	100.00	72.50	83.33	100.00	8.33	50.00	100.00	--	--	--
Early Detroit	16.42	58.69	100.00	87.50	91.37	100.00	33.33	100.00	86.66	11.11	80.00	75.00	--	--	--

cracked. In four cases out of five more pink fruits of Globe were cracked than Marglobe. For red ripe fruits, Gulf State again was low in the percentage of cracked fruits, with Globe and Marglobe showing no consistent differences. The remaining varieties, with the exception of the large-fruited Santa Clara Canner, which cracks badly, show a percentage of cracking ranging near that of Globe. The following table (Table II) gives percentages of the fruits of all stages of maturity showing cracks averaged from data taken August 14th, August 31st, September 9th, and September 14th. The percentages are based on total numbers of fruits for the several dates.

TABLE II -- Percentage of Cracked Fruits of Eight Varieties of Tomato. A Summary of Table I.

Variety.	Cracked Fruits	Number of Fruits.
Gulf State Market,	55.30	528
Stone,	66.81	140
Greater Baltimore,	67.07	261
Early Detroit,	69.96	273
Globe,	70.92	500
Bonny Best,	72.93	144
Marglobe,	74.56	293
Santa Clara Canner,	90.92	71

The figures show, as would be expected by glancing at Table I that relatively few Gulf State fruits were cracked; that Santa Clara Canner cracked badly, and that the remaining varieties ranged between these two, showing no marked differences.

It is thus shown that differences in susceptibility to cracking occur among tomato varieties. Obviously it was impossible to use all of the above varieties in a further detailed study of the problem. The question arose as to which should be selected for further work. Gulf State Market and Globe are almost identical in vine and fruit appearance, yet they have shown decided differences in the occurrence of cracked fruits. It was because of their apparent similarity that they were chosen, since obvious differences in varietal characteristics, with their possible relation to cracking, were thereby eliminated.

Cracking of Globe and Gulf State Market in Field, 1932 at College Park: In table III are presented data showing the percentage of red ripe fruits which were cracked, at the time of harvest, throughout the season. It is noted that in every one of the twenty plots, consisting of eleven plants of each variety, there were more Globe fruits cracked than Gulf State Market fruits, corroborating the indications noted at Arlington.

In these varietal studies, we have not yet considered the degree of cracking of individual fruits. May

TABLE III — PERCENT OF TOTAL RED RIPE FRUITS WHICH WERE CRACKED AT TIME OF HARVEST.

FIELD, 1932. COLLEGE PARK.

Series	Dry Treatment		Wet Treatment		Dry - Wet Treatment	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
1	65.00	76.08	76.00	84.78	98.18	100.00
2	50.60	86.00	80.85	86.58	86.25	98.14
3	52.50	88.88	57.14	73.21	77.02	92.45
3	—	—	68.00	80.64	63.00	94.20
4	43.18	48.48	—	—	68.83	89.65
4	39.78	52.63	75.94	84.52	75.51	98.24
5	46.01	50.79	72.15	75.00	72.11	95.34
5	48.14	69.56	—	—	—	—

it not be possible that though more Globe fruits crack, they do not crack as severely as Gulf State? This factor of the size of crack is of obvious practical importance, in the waste occuring when the fruits are prepared for culinary purposes. For the evaluation of this factor, cracking indices were arbitrarily fixed, in which each small crack (less than one-fourth inch long) was given a value of 1 -- medium size cracks (approximately one-half inch) a value of 2 -- and large cracks (over one-half inch long) a value of 3. Concentric cracking was given a value of 3, or 2, depending upon severity. Data on the number and relative size of cracks were obtained at the time cracking occurred, as well as at the time the fruit was harvested (at the red-ripe stage). Since there were some fruits that did not crack, two means were calculated for each plot, one including the non-cracked fruits, and the other excluding them. In the latter case the values so obtained are of interest only in so far as they indicate the degree of cracking when rupture does occur. In a comparison of varieties, or of experimental treatments, however, there is no reason why non-cracked fruits should not be given a value of zero. Accordingly, the means of cracking indices of individual fruits from each of the twenty plots, are presented in Table IV. Probable errors were obtained by Bessel's formula. In nineteen of the twenty plots, cracking indices of Globe are larger than those of Gulf State. Odds (Table V) calculated from these figures, prove conclusively that under the conditions of

TABLE IV — CRACKING INDICES OF SIZE AND NUMBER OF CRACKS AT TIME OF HARVEST AT RED RIPE STAGE.* FIELD, 1932. COLLEGE PARK.

Series	Dry		Wet		Dry → Wet	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
1	3.21 ± .307	3.45 ± .355	2.88 ± .274	5.69 ± .473	6.65 ± .418	9.69 ± .426
2	2.02 ± .206	4.40 ± .391	4.27 ± .416	6.33 ± .361	5.22 ± .270	7.35 ± .422
3	2.60 ± .250	5.17 ± .378	2.48 ± .219	3.85 ± .344	3.53 ± .286	6.79 ± .373
3	—	—	3.17 ± .288	5.25 ± .557	4.36 ± .277	7.33 ± .440
4	1.24 ± .139	2.35 ± .248	—	—	3.67 ± .263	6.01 ± .416
4	1.37 ± .154	1.06 ± .146	4.58 ± .344	6.05 ± .426	4.35 ± .237	7.08 ± .400
5	1.60 ± .167	2.86 ± .382	2.91 ± .239	5.18 ± .415	3.91 ± .245	7.66 ± .336
5	1.40 ± .141	2.57 ± .358	—	—	—	—
Total	1.83 ± .074	3.01 ± .128	3.30 ± .127	5.51 ± .171	4.38 ± .109	7.41 ± .154

* Non-cracked fruits were included in the calculations.

TABLE V -- ODDS THAT GLOBE CRACKS MORE BADLY THAN GULF STATE MARKET. FIELD, 1932. COLLEGE PARK. (See Table IV. for means and probable errors).

Series.	Dry Plots.	Wet Plots.	Dry-Wet Plots
1	1:1	Infinite	4,800:1
2	6,000:1	78:1	267:1
3	13,500:1	44:1	Infinite
3	---	37:1	13,500:1
4	174:1	---	825:1
4	1:1	14:1	15,500:1
5	26.4:1	142:1	Infinite
5	26.4:1	---	---
TOTAL	Infinite	Infinite	Infinite

this experiment, Globe fruits crack more severely than Gulf State Market. Not only, therefore, do more fruits of this variety crack, but the cracking is more severe.

As an absolute measure of degree of cracking of each individual fruit it is better, as has been stated, to disregard those fruits which show no cracks at all. Table VI. gives indices in which non-cracked fruits are disregarded. By the omission of the zero values and the consequent decrease in the

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* Non-cracked fruits were included in the calculations.

TABLE VI -- CRACKING INDICES.* FIELD, 1932. COLLEGE PARK. FIGURES REPRESENT DEGREE OF CRACKING AT TIME OF HARVEST (RED RIPE STAGE.)

Series	Dry		Wet		Dry - Wet	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
1	4.94 ± .352	4.54 ± .392	3.00 ± .337	6.71 ± .509	6.77 ± .418	9.69 ±.426
2	4.00 ± .287	5.11 ± .406	5.28 ± .449	7.30 ± .358	6.05 ± .256	7.49 ±.418
3	4.95 ± .351	5.82 ± .397	4.35 ± .248	5.26 ± .373	5.60 ± .351	7.21 ± .368
3	--	--	4.66 ± .344	6.52 ± .570	5.66 ± .363	7.93 ± .428
4	3.13 ± .223	4.48 ± .369	--	--	5.33 ± .265	6.71 ± .416
4	3.18 ± .241	2.18 ± .238	6.03 ± .374	7.16 ± .394	5.64 ± .225	7.21 ± .401
5	3.33 ± .232	4.00 ± .484	4.03 ± .275	6.89 ± .442	5.42 ± .269	8.03 ± .329
5	3.05 ± .224	5.07 ± .562	--	--	--	--
Total	3.78 ± .109	4.61 ± .162	4.74 ± .148	6.77 ± .177	5.77 ± .110	7.77 ± .151

* Non-cracked fruits were not included in the calculation.

value of N, the indices are larger. Further, since more fruits of Gulf State Market were non-cracked than Globe, we would expect the differences in Table VI. to be smaller, as is the case. However, the odds in Table VII. show severe cracking in Globe at the time the fruits are harvested - even though non-cracked fruits have been discarded.

TABLE VII — ODDS - THAT CRACKING INDICES OF GLOBE ARE LARGER THAN THOSE OF GULF STATE MARKET. FIELD, 1932 COLLEGE PARK.*

(See Table VI. for means and probable errors)

Series.	Dry Plots.	Wet Plots.	Dry-Wet Plots.
1	1:1	20,000:1	1000:1
2	7:1	50:1	21:1
3	3:1	5:1	25:1
3	---	16:1	420:1
4	24:1	---	18:1
4	** 21:1	6:1	43:1
5	2:1	1,000:1	10,000:1
5	32:1	---	---
TOTAL	267:1	Infinite	Infinite

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* Non-cracked fruits were <u>not</u> included in the calaulations.

** Odds that Gulf State indices are larger than those of the Globe.

TABLE VIII -- CRACKING INDICES OF SIZE AND NUMBER OF CRACKS AT TIME OF FIRST OCCURRENCE OF CRACKS. FIELD FRUITS, 1932. COLLEGE PARK.

Series	Dry		Wet		Dry - Wet	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
1	2.64	3.88	2.21	2.02	2.75	2.46
2	2.78	2.41	1.92	2.15	2.65	2.54
3	2.64	1.89	2.21	1.87	3.11	2.46
3	-	-	2.09	2.12	3.94	3.08
4	2.18	2.04	-	-	3.45	2.65
4	2.44	1.81	2.05	2.76	3.40	3.10
5	2.13	2.12	1.77	1.85	2.89	2.52
5	1.96	1.71	-	-	-	-

Effect of Water on the Occurrence of Cracking

If we turn to Table I. and note the percentage cracking of Gulf State Market fruits at the mature green stage for the various dates, we see at once extreme fluctuations. On August 14th, 23.9 percent of the mature green fruits were cracked. The percentage on August 31st had increased to 80.8, yet nine days later had dropped to only 8.0. The other varieties show similar variations, for these same dates, and for the mature green fruits. It is apparent that some factor is in operation which has an extremely important effect on the occurrence of cracks. A study of the rainfall data (Table IX) for Washington, D. C., during this period shows that rain is without doubt an important factor. Rain, or a trace of rain, fell on fourteen consecutive days between August 18th and August 31st. On August 31st an average of 85.5 percent of the mature green fruits of all varieties showed cracks. Between September 1st and September 9th when the next data were taken, four days had occurred without rain, and the percentage of cracking had dropped to 38.8. The counts made on September 14th were preceded by a week of dry weather, and cracking of mature green fruits had dropped to 12.1 percent. Only mature green fruits have been mentioned because of the fact that the fruits were allowed to remain on the vines until red ripe, in which case counts of cracked fruit of pink or red ripe maturity on a given date without doubt included fruits which had cracked several days earlier, possibly

TABLE IX — DAILY RAINFALL, IN INCHES, FOR
WASHINGTON, D. C. FALL OF 1931

Date.	Rainfall.	Date.	Rainfall.	Date.	Rainfall
Aug. 1	—	Aug. 26	.30	20	.05
2	T.	27	.11	21	—
3	.02	28	T.	22	—
4	.09	29	.15	23	1.68
5	.03	30	T.	24	T.
6	—	31	T.	25	—
7	—	Sept. 1	—	26	.64
8	—	2	.12	27	—
9	.03	3	.02	28	—
10	.03	4	—	29	—
11	.50	5	.03	30	—
12	.45	6	.09	Oct. 1	—
13	—	7	—	2	—
14	T.	8	—		
15	.49	9	—		
16	—	10	—		
17	—	11	—		
18	.58	12	—		
19	T.	13	—		
20	.02	14	—		
21	1.08	15	T.		
22	.60	16	.15		
23	.29	17	.01		
24	.01	18	—		
25	.14	19	—		

during a wet period. It will be shown later that green fruits (a few days preceding the pink stage) are not as susceptible to cracking as older fruits.

The effect of rainfall in increasing the number of cracked fruits, is enormous. This was evident in the daily counts of cracked fruits under field conditions in 1932 at College Park. The percent of the crop cracking is seen to increase during August 9th to 12th, and fall off appreciably from August 13th to 18th, except in the case of the dry-wet series. On August 19th to 20th an enormous increase in cracking occurred. These decided fluctuations were the result of showers on August 8th, 9th, 11th, and 18th. In

TABLE X -- DAILY RAINFALL, IN INCHES, FOR COLLEGE PARK DURING JULY AND AUGUST, 1932.

Date.	Rainfall.	Date.	Rainfall.	Date.	Rainfall.
July 1	--	July 25	--	Aug. 18	.39
2	T.	26	--	19	.03
3	--	27	.40	20	--
4	.62	28	--	21	--
5	--	29	T.	22	--
6	.13	30	--	23	--
7	T.	31	--	25	--
8	.40	Aug. 1	--	25	--
9	--	2	T.	26	--
10	--	3	.59	27	--
11	--	4	.10	28	--
12	--	5	--	29	T.
13	--	6	--	30	T.
14	--	7	T.		
15	--	8	.29		
16	.93	9	.60		
17	--	10	--		
18	--	11	.29		
19	--	12	--		
20	T.	13	--		
21	T.	14	--		
22	T.	15	--		
23	.04	16	--		
24	--	17	--		

graph 2 the number of fruits cracking in dry plots is plotted against two-day intervals of time. If the percentage of fruits cracking on these dates, in terms of total crop, is used instead of actual numbers, it is found that the curves are very similar. The graph indicates a tendency, on August 18th to 20th, for the enormous increase in cracking to follow a day later than the rain. Such a conclusion would be erroneous because light rain occurred throughout the day on August 18th, up until mid-afternoon. This prevented a counting of cracked fruits for most of the plots on that date. A thorough inspection of the plots at that time, however, showed that severe cracking of the fruits had actually occurred the same day of the rain. Thus under these conditions, rain prolonged over a few hours, was at once effective in inducing cracking. This fact must be borne in mind in an interpretation of the graphs. Figures 3 and 4 show the behavior of fruits in the dry-wet, and wet treatments for the Gulf State Market. The influence of rain is pronounced in each case. It will be shown later that significant differences in amount of cracking are caused by irrigation treatments, signifying that, although these rains did occur, and although their effect on cracking is evident, they did not mask the effect of water applied to the soil in which wetting of the above ground parts was not a factor.

Influence of Irrigation on Cracking; College Park, Field, 1932: The first fruits had begun to set on the field grown plants about June 22nd. Tagging was begun June 19th, and since the high water treatment was begun July 10th, the fruits on these high water plots were given an abundant moisture supply throughout their growth period. It was desired to keep the plots thoroughly soaked, necessitating irrigation every two or three days during dry, sunny weather. Fruits from one high water plot in series 5 rotted badly, so that data taken on them were disregarded. The trouble did not occur in any of the other plots. The precipitation at College Park during July and August, 1932 was relatively low. (Table X). As a result, by July 30th vines on the high water plots were considerably larger, and of a light green color as compared to those in the dry plots. Prior to the shower on July 27th soil moisture samples were taken, at a five inch depth, showing the soil in high water plots to contain 13.73 percent moisture, and that in dry plots, 4.59 percent. On August 11th, one-half of the dry plots were thoroughly irrigated along with the continued wet series. The average soil moisture for the plots five days later was: Wet series, 13.03 percent. Dry-Wet series, 12.96 percent, and dry series, 5.09 percent. It is realized that these percentages do not indicate the amount of water available to the plant. However they do show that there were appreciable differences in soil moisture between the dry and wet treatments. Subsequent behavior of fruits borne on vines grown under these treatments was the matter of primary importance.

A study of Table III reveals decided differences in the number of red ripe fruits which were cracked. The percentage of fruits cracking in the dry-wet series is greater, in every case, than for the dry series, and larger in most cases than for the wet treatment. It is noted that cracking in the dry-wet Globe plots was extremely high, as compared to dry or wet plots of the same variety. With Gulf State Market the difference between the dry-wet and wet series is not so pronounced. This seems to indicate a greater response of the Globe variety to the change from low to high moisture supply. Although, in general, the continued wet treatment gave a higher percentage of cracked fruits at harvest, it is noted that only in series 4 and 5 are these differences marked. Plants in these plots were larger and more vegetative, than those in series, 1, 2, and 3, due to an apparently richer soil. Is it possible that as the season became extremely dry in August, these larger plants of the dry series were more severely affected?

Cracking indices, as influenced by water treatment, are shown in Tables IV. and VI. Referring to Table IV. we find that cracking indices of the dry-wet treatment are, without exception, much larger than those of the dry series, and, in general, larger than for the wet treatment. Odds obtained from these figures are given in Table XIII. There are tremendous odds showing that the dry-wet treatment caused more cracking than the continued dry treatment, using cracking index as a criterion. Furthermore, the odds, based on

TABLE XIII.- EFFECT OF IRRIGATION ON CRACKING.* FIELD, 1932. COLLEGE PARK.

Series	Odds that Dry- Wet treatment caused more cracking than continued dry treatment		Odds that Dry-Wet treatment caused more cracking than continued wet treatment		Odds that Wet-treatment caused more cracking than continued dry treatment	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
1	Over 20,000:1	Infinite	Infinite	Infinite	1:7	95:1
2	Infinite	4,800:1	4:1	4:1	825:1	65:1
3	8:1	26:1	22:1	15,500:1	1:1	1:11
3	-	-	26:1	19:1	-	-
4	Infinite	Infinite	-	-	-	-
4	Infinite	Infinite	1:1	3:1	Infinite	Infinite
5	Infinite	Infinite	19:1	656:1	415:1	175:1
Total	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite

*Odds calculated from cracking indices, including non-cracked fruits in the calculations. (Red ripe state of maturity) See Table IV for means and probable errors.

all the plots are infinitely significant that the dry-wet treatment causes more cracking than continued wet treatment. Comparing the dry with the wet treatment we note that in two cases there are small odds that fruits from dry plots cracked worse than those from wet ones. However, the odds on the total replicates are infinite that cracking in the wet plots is significantly greater. The above indices, obtained from red ripe fruits, are seen to be larger than those in Table VIII, based on the size and number of cracks at the first occurrence of cracking. This means of course that the longer the fruit is left on the vine, after cracking, the greater becomes the severity of cracking, if conditions are favorable. It is found also that the severity of initial cracking was not as consistently the highest in the dry-wet plots as were the final indices of Table IV. The initial indices, however, are averaged from fruits which cracked through all stages of maturity -- from green to ripe, while the indices of Table IV. are taken from red ripe fruits of more nearly the same physiological age. The indices at the time of first cracking, are low for green fruits, and high for red ripe ones. Therefore fruits from a certain treatment tending to crack earlier than in another treatment show the lower initial cracking indices. The tendency towards a delay in cracking of fruits on dry plots, and towards more severe initial cracking as the fruit becomes older will be shown later.

We have shown definite, significant, differences in cracking of tomato fruits from vines given different water treatments. There are two important factors, however, to be considered in an interpretation of these results, namely, (1) the effect of rainfall, superimposed on the irrigation treatments, and (2) the question as to whether, during the period of maturity of the fruits, the relative number ripening for the two varieties and various treatments, was similar throughout the season. In other words, did a large proportion of the total crop ripen earlier in one treatment or variety than in others? If such were true it is obvious that the fruits of one treatment or one variety might respond differently at the time certain field or weather conditions prevailed because as will be shown, stage of development is an important factor in cracking.

It was possible to find the percent of the total crop turning pink on a given date, in the field treatments, since a record was kept of the time at which tagged fruits first began to show a pink color. Consider column two of Table XII-A. The first figure, 2.60, represents the percentage of the seasonal crop (538 fruits) for this particular treatment and variety, which turned pink on August 5th to 6th. The figures for the three treatments of the Gulf State Market variety show that the percentage of tagged fruits turning pink on a given day present no great fluctuations between treatments, through the period from August 5th

TABLE XIIA — PERCENT OF TOTAL CROP TURNING PINK AND PERCENT OF TOTAL CROP CRACKING FOR GIVEN DATES. FIELD, 1932. COLLEGE PARK.

Date	Percent of total crop turning pink on stated date						Percent of total crop cracking on states dates					
	Gulf State Market			Globe			Gulf State Market			Globe		
	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet
Aug. 5, 6	2.60	2.30	3.31	1.29	2.14	2.84	1.87	2.90	.73	1.03	1.22	.47
Aug. 7, 8	9.29	8.93	7.91	4.65	4.58	3.31	.37	5.72	1.65	1.30	3.97	.94
Aug. 9,10	5.39	6.05	7.73	4.65	4.89	3.79	4.46	7.49	2.60	2.60	4.58	3.55
Aug. 11,12	13.00	12.96	17.31	8.26	8.25	5.46	6.87	3.74	4.60	9.80	6.11	3.79
Aug. 13,14	7.62	10.95	11.23	5.10	7.33	6.87	1.30	2.88	9.02	4.39	6.11	10.42
Aug. 15,16	5.93	7.42	5.16	5.10	7.64	4.50	.00	.00	2.57	.51	.91	6.34
Aug. 17,18	8.36	6.05	6.81	8.26	10.10	6.63	.55	.57	7.91	2.58	3.32	10.42
Aug. 19,20	12.08	9.79	10.31	17.31	14.06	10.90	12.30	14.40	22.83	24.28	26.60	36.72
Aug. 21,22	10.22	9.51	9.57	14.73	13.76	11.61	2.00	2.01	1.10	1.29	2.44	.71
Aug. 23,24	5.76	7.78	6.26	9.81	9.78	13.50	.74	1.72	2.76	2.07	1.83	3.55
Aug. 25,26	6.43	7.20	5.52	10.00	7.03	12.79	4.20	3.74	6.81	1.80	3.05	4.50
Aug. 27,28	6.13	6.34	2.94	7.49	4.89	13.50	1.70	.28	.74	3.35	4.28	2.36
Total fruits in crop	5.38	3.47	5.43	3.87	3.27	4.22	—	—	—	—	—	—
Fruits turning pink between Aug. 5-28	4.99	3.31	5.11	3.75	3.09	4.04	—	—	—	—	—	—
No. fruits cracking between Aug. 5-28	1.96	1.58	3.44	2.13	2.11	3.54	—	—	—	—	—	—
Percent of total crop cracking between Aug.5-28	36.43	45.53	63.35	55.03	64.52	83.88	—	—	—	—	—	—

to August 28th, during which time about ninety-five percent of the tagged fruits had reached maturity. The figures for Globe indicate fewer fruits approaching maturity at an early date, with a trend towards a peak from August 19th to 26th, uniform for the three treatments. The similarity of ripening of each variety among different treatments eliminates the maturity factor as a complication in the interpretation of the data, in so far as differences in treatments are concerned.

It is now necessary to study the possible effect of the delay in maturity of the Globe fruits. Comparing, in Table XII, the two varieties with respect to the percent of the total crop cracking at various dates, we find slightly higher values for Gulf State Market from August 5th to 10th. However, on August 11th and 12th the two are very similar, even though the number of fruits approaching maturity is relatively low in Globe. From August 11th to 28th, cracking of Globe as a percent of the total crop, was always higher, again demonstrating the tendency of this variety to crack more severely. Table XII-B contains the cumulative figures for Table XII-A, showing the percent of the total crop which had turned pink or had cracked up to the several dates.

The reaction of the Globe variety, to rain, is similar to that of Gulf State Market. Figure 5 shows the percentage of Globe cracking for three water treatments.

TABLE XII B -- CUMULATIVE FIGURES FROM TABLE XII A.

Date	Percent of total crop which had turned pink up to stated date. (Cumulative)						Percent of total crop which had cracked up to stated date. (Cumulative)					
	Gulf State Market			Globe			Gulf State Market			Globe		
	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet	Dry	Wet	Dry-Wet
Aug. 5, 6	2.60	2.30	3.31	1.29	2.14	2.84	1.87	2.90	.73	1.03	1.22	.47
Aug. 7, 8	11.89	11.23	11.22	5.94	6.72	6.15	2.24	8.62	2.38	2.33	5.19	1.41
Aug. 9,10	17.28	17.28	18.95	10.59	11.61	9.94	6.70	16.11	4.98	4.93	9.77	4.96
Aug. 11,12	30.28	30.24	36.26	18.85	19.86	15.40	13.57	19.85	9.58	14.73	15.88	8.75
Aug. 13,14	37.90	41.19	47.49	23.95	27.19	22.27	14.87	22.73	18.60	19.12	21.99	19.17
Aug. 15,16	43.83	48.61	52.65	29.05	34.83	26.77	14.87	22.73	21.17	19.63	22.90	25.51
Aug. 17,18	52.19	54.66	59.46	37.31	44.93	33.40	15.42	23.30	29.08	22.21	26.22	35.93
Aug. 19,20	64.27	64.45	69.77	54.62	58.99	44.30	27.72	37.70	51.91	46.49	52.82	72.65
Aug. 21,22	74.49	73.96	79.34	69.35	72.75	55.91	29.72	39.71	53.01	47.78	55.26	73.36
Aug. 23,24	80.25	81.74	85.60	79.16	82.53	69.41	30.46	41.43	55.77	49.85	57.09	76.91
Aug. 25,26	86.68	88.94	91.12	89.16	89.56	82.20	34.66	45.17	62.58	51.65	60.14	81.41
Aug. 27,28	92.81	95.28	94.06	96.65	94.45	95.70	36.36	45.45	63.32	55.00	64.42	83.77

Figure 2 -- Effect of Rainfall on Occurrence of Cracked Tomato Fruits. Dry Plots. Gulf State. Field, 1932. College Park.

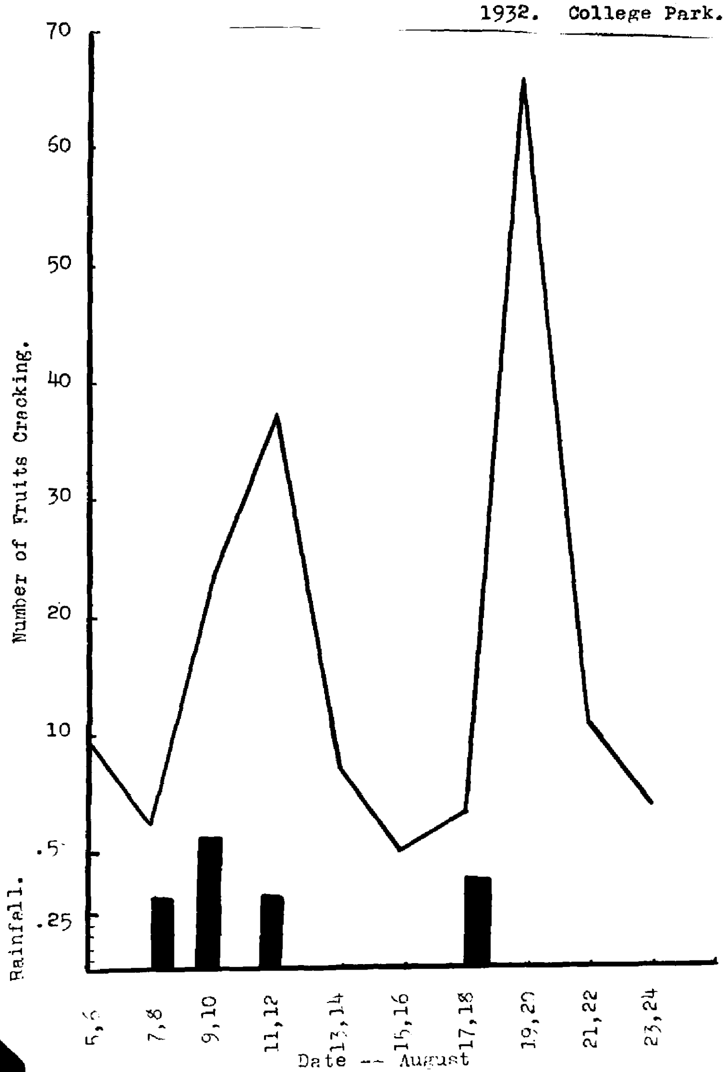


Figure 3 -- Effect of Rainfall on Occurrence of Cracked Tomato Fruits. Dry-Wet Plots. Gulf State Market. Field, 1932. College Park.

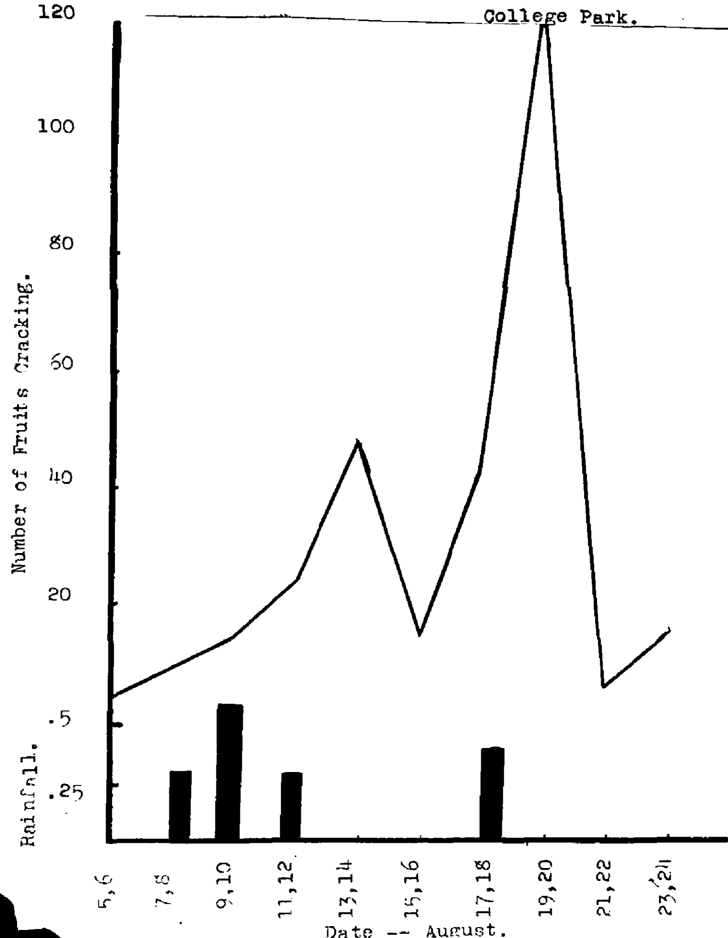


Figure 4. Effect of Reinfall on Occurrence of Cracked Tomato Fruits. Wet Plots. Field, 1933. Gulf State Market Variety.

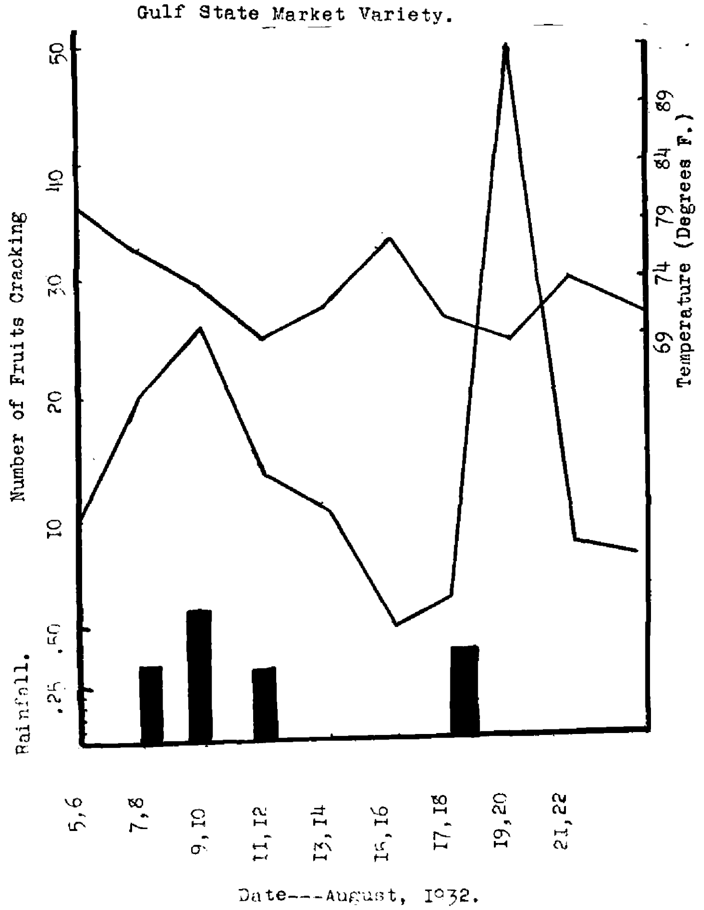
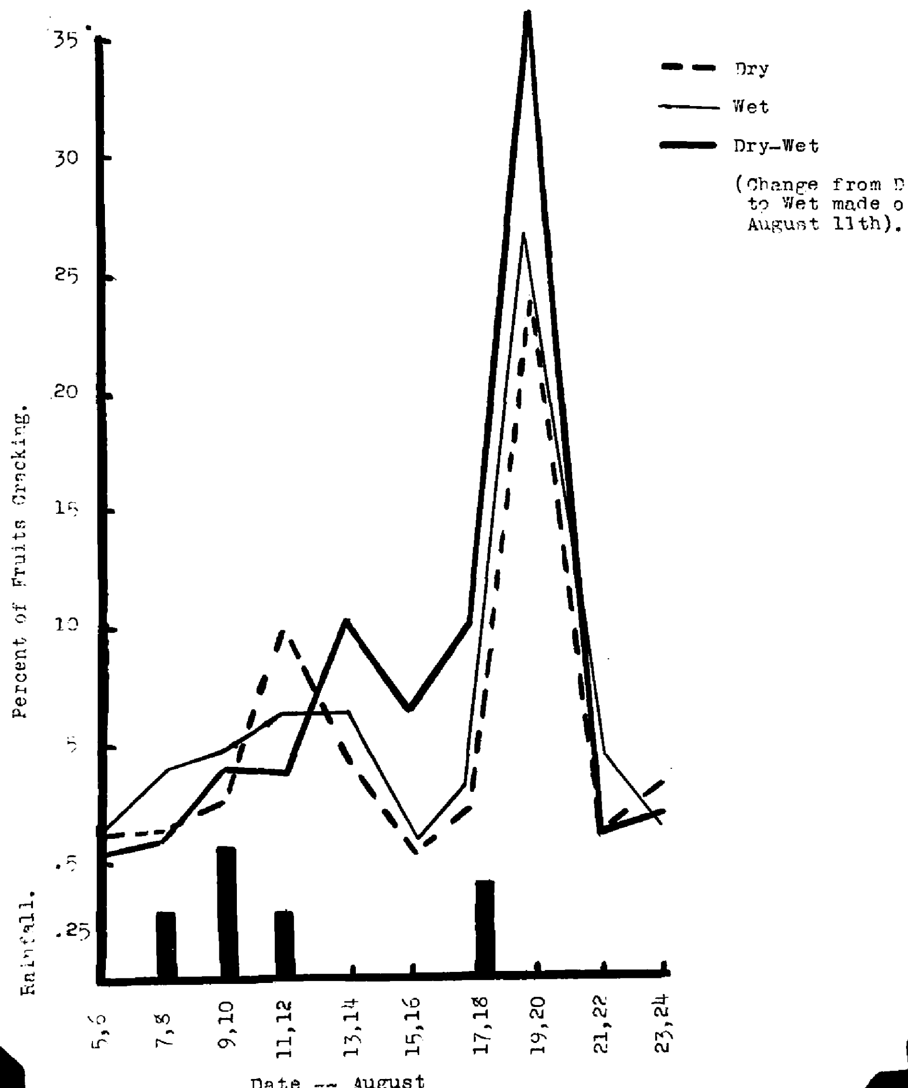


Figure 5 -- Influence of Rainfall and Irrigation on Cracking of Tomato Fruits. Globe Variety. College Park, 1932.



Studying now the effect of the various treatments, we note that the peak of cracking during the rainy period of August 8th to 12th was on August 11th and 12th for the dry plots. No decided peak, during this period is noted for the wet series. Cracking in both the dry and wet treatments sharply declines from August 14th to 17th. Such is not the case with the dry wet treatment, which had been changed from dry to wet on August 11th. A peak in cracking is noted for these plots on August 13th and 14th and cracking remains relatively high for several following days. Comparisons of the general shape of graphs in figures 2, 3, and 4, show a similar behavior in the Gulf State Market variety, with the exception of a more pronounced early peak in the wet series. Here again the cracking of the dry-wet series becomes high on August 13th and 14th, and remains so. Thus, only three days after a thorough irrigation an increase in cracking is apparent. Before going into a discussion of the way in which rainfall induces cracking, and the way in which cracking is brought about by a change from dry to wet treatment, the results obtained with greenhouse grown fruits will be discussed.

<u>Cracking of Greenhouse Crop, Winter of 1931-1932</u>: The plants of this crop, grown in an infertile soil in shallow benches, produced few fruits on the third clusters. The water treatments were not begun until the oldest fruits on the first cluster were mature green. The vines had been kept growing at a medium rate up to that time. Since these water treatments were begun relatively late in the growth

period of the fruits, differences in cracking between treatments, if they occur, must be assigned to an effect of water on plant or fruit, induced in the later phases of development. In the field it is remembered dry and wet treatments were begun soon after the first fruits had set. The two varieties were planted in separate plots so that for reasons stated earlier, a direct varietal comparison could not be made. No mature green or green fruits cracked in the greenhouse in 1931-1932, although the 1932-1933 greenhouse crop showed considerable cracking of fruits before they reached the pink stage. Fruits of the 1931-1932 greenhouse crop were left on the vines, after turning red ripe, until they cracked or began to decay. It was found that if the fruits were left on the vines long enough, after turning ripe, practically all of them would crack. This is of little practical importance, however, and for this reason a period three days after the fruit turned red ripe was taken arbitrarily as a limiting point. Figures in Table XIV show that more fruits cracked on the high water plots.

TABLE XIV -- EFFECT OF WATER SUPPLY ON PERCENTAGE CRACKING OF RED RIPE FRUITS IN GREENHOUSE. 1931-1932

Water Treatment	Percent of Total Fruits Cracking in Greenhouse within 3 days After Turning Red Ripe.	
	Gulf State.	Globe.
Dry	15.8	3.1
Medium	25.7	3.8
Wet	33.7	17.9

Vines of the 1932-1933 crop were kept vigorous by additions of fertilizer. A full set of fruit was obtained on the three clusters. After most of the fruits on the first two clusters had been harvested, the vines showed signs of extreme vegetativeness. Growing tips originated along midribs of many leaves, especially in the wet and dry-wet treatments. Dry and wet treatments were begun with these plants when the first fruits on cluster one were a little over half grown, thereby more nearly approximating the field treatments. Though the fruits were not allowed to remain on the vine as long as the previous season's crop, all were allowed to remain for at least seven to ten days after turning ripe. Again the tendency was for a large proportion of the fruits of all treatments to crack if allowed to remain on the vine long enough. In view of the fact that appreciable cracking had occurred up to the red ripe stage, it was possible to use an earlier stage of maturity at which to compare the tendency to crack. The percent of fruits which had cracked up to and including a period three days after turning pink, is shown in the following table (Table XV). The percentage of fruits cracking in dry plots was small, while the wet treatment was higher than the dry-wet. The latter fact does not coincide with field results, though we cannot directly compare field grown with greenhouse grown fruits. It is important to note that the change from dry to wet treatment

TABLE XV -- EFFECT OF WATER SUPPLY ON CRACKING OF TOMATO FRUITS GROWN IN THE GREENHOUSE 1932-1933.

Water Treatment.	Percent of Total Fruits Cracking in Greenhouse Within Three Days After Turning Pink.	
	Gulf State Market.	Globe.
Dry	23.40	28.84
Wet	38.77	59.09
Dry-Wet	29.20	40.35

did cause an increase in cracking over continued dry treatments. Moreover, if we were to find the percentage cracking for each cluster instead of the three combined, would we not be more likely to note the effect of the dry-wet treatment on the third cluster? It would seem reasonable to suppose that the occurrence of cracks on the third cluster would be a better indication of the effect of treatment on cracking because sufficient time had elapsed for the plant to react to the changed water application. In fact, since the high water application was not begun on the "dry-wet" series until after most of the fruits on the first cluster had matured, it would be unfair to include such fruits in an analysis in which the effect of the changed water treatment was being studied. The following table (Table XVI) includes the percentage cracking on the three clusters separately, and shows, as well, an appreciable influence of position of the fruit on cracking.

TABLE XVI -- PERCENT OF FRUITS CRACKING UP TO AND INCLUDING THREE DAYS AFTER PINK STAGE OF MATURITY, AS INFLUENCED BY WATER TREATMENT, POSITION OF CLUSTER ON VINE, AND POSITION OF FRUIT ON CLUSTER.

Treatment.	Cluster Number.	First Fruit on Cluster.		Third Fruit on Cluster.	
		Gulf State Market.	Globe	Gulf State Market	Globe
Dry	1	35.00	45.45	20.00	11.11
	2	35.29	38.88	6.66	18.75
	3	28.57	35.00	8.33	10.00
Wet	1	37.50	44.44	27.77	31.57
	2	44.44	82.60	33.33	37.50
	3	43.75	85.71	38.46	61.53
Dry-Wet	1	26.31	21.73	16.67	19.04
	2	42.10	45.45	31.81	46.66
	3	45.45	84.31	.00	28.57

The first fruits on the first clusters of the dry plots show as severe cracking as fruits in a similar position on plants in the wet treatment. Cracking of these fruits in the dry-wet series, which, in reality was dry at the time, was low. On the second cluster, however, cracking of first fruits in the dry plots shows no increase, whereas in the dry-wet series, cracking has become more prevalent. On the third cluster marked differences occur between dry and dry-wet treatments, with cracking decreasing in the dry plots and increasing in the dry-wet ones. In the wet plots of Gulf State Market the percentage cracking of the first fruits remains about the same for the three clusters. Cracking of Globe is higher, in the wet series, on clusters two and three.

The dry-wet series of Globe shows a greater increase in cracking on the third cluster than does Gulf State Market, indicating again, as was noted in the field plots, a more marked response to the change in water supply.

With reference to the third fruits of the three clusters, it is noted that in not a single instance do these fruits, situated furtherest from the main stem of the plant, show as high percentage cracking as the first fruits. The greatest decrease, with a single exception, is in the dry plots. This effect of position of fruit is shown more clearly in Table XVII, summarized from Table XVI. Note the marked decrease in percentage cracking of third fruits in the dry treatment. There is no question but that there is a relationship between water intake through the root system of the plant and the occurrence of cracking. In no case

TABLE XVII -- PERCENT OF FRUITS CRACKING UP TO AND INCLUDING THREE DAYS AFTER PINK STAGE OF MATURITY AS INFLUENCED BY WATER TREATMENT AND POSITION OF FRUIT ON CLUSTER.

Treatment.	No. 1 Fruits *		No. 3 Fruits **	
	Gulf State Market.	Globe	Gulf State Market.	Globe
Dry	32.69	40.00	11.90	13.63
Wet	43.13	72.58	34.04	41.66
Dry-Wet	36.06	48.43	19.23	30.00

* Average of No. 1 fruits for clusters 1, 2, 3.
** Average of No. 3 fruits for clusters 1, 2, 3.

was moisture on above ground portions of the plant a complicating factor in the greenhouse, yet fruits from vines given a continued high soil water treatment and those changed from low to high water showed consistently a higher percentage of cracking. The evidence for such a relation is strengthened by the appearance of more severe cracking on those fruits adjacent to the main stem. In individual clusters, there are exceptions, of course, to this behavior. It is a matter of common knowledge that the first fruits on the cluster are the larger ones. A size factor thus enters into a comparison of the first and third fruits on the cluster. Observations in this study indicate that size of fruit, though it may play some part, is not a major factor in cracking. Diameters of field-grown fruits show (Table XVIII), as would be expected, consistently larger fruits from the wet treatments. Yet a much smaller percentage

TABLE XVIII -- DIAMETER * OF TOMATO FRUITS FIELD, 1932. COLLEGE PARK.

Series.	Dry		Wet		Dry-Wet.	
	Gulf State Market.	Globe	Gulf State Market.	Globe	Gulf State Market.	Globe
1	5.94	5.87	6.51	6.47	5.84	6.13
2	6.28	6.46	6.52	6.76	6.35	6.18
3	6.09	6.35	7.12	6.51	6.29	7.12
3	--	--	6.80	6.81	6.06	6.05
4	6.35	6.75	--	--	5.97	6.37
4	6.23	5.99	6.70	6.68	6.50	6.65
5	6.49	6.71	7.22	6.82	6.32	6.82
5	6.82	6.90	--	--	--	--
Total	6.36	6.47	6.58	6.68	6.23	6.48

* Diam. in centimeters, at time of harvest (red ripe) of tagged

of these fruits cracked than did those of the dry-wet series, which were no larger than those from dry plots. It was apparent too that within a given treatment, size of fruit was not of great importance.

The total number of fruits borne per vine, (a seasonal total) is presented in Table XIX. The numbers are

TABLE XIX -- NUMBER OF FRUITS BORNE PER VINE*

FIELD, 1932. COLLEGE PARK

Series.	Dry.		Wet.		Dry-Wet.	
	Gulf State Market.	Globe	Gulf State Market.	Globe	Gulf State Market.	Globe
1	23.5	20.9	19.0	26.0	20.7	26.8
2	31.1	26.0	35.2	26.4	26.2	29.3
3	23.5	20.4	33.7	32.6	26.3	31.7
3	--	--	34.6	24.5	26.0	27.3
4	26.1	29.3	--	--	22.2	20.6
4	29.6	28.0	32.9	25.1	24.7	26.1
5	29.7	22.2	27.0	26.5	25.3	29.0
5	30.0	33.7	--	--	--	--
Total	27.7	26.1	31.1	26.9	24.6	27.3

quite variable, and seem to bear no relation to the treatments with which the severity of cracking has been shown to be closely associated. The possibility of set of fruit as affecting cracking must not be taken too lightly however. The known differences in percentage cracking as affected by position of fruit on the cluster would indicate that such a relation may exist.

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*Figures represent average number of fruits borne per vine, throughout the season.

Cracking Indices of Greenhouse Fruits: Severity of cracking of greenhouse fruits, as measured by cracking indices, depends upon soil water supply. Table XX shows that wet treatment gave higher indices than dry, while dry-wet indices were higher than those of the wet treatment. This is in accord with the behavior of the varieties under field conditions. In the greenhouse, a comparison of the two varieties as to cracking indices shows a remarkable similarity, especially for indices at time of cracking. Under

TABLE XX -- CRACKING INDICES OF SIZE AND NUMBER OF CRACKS GREENHOUSE FRUITS, 1932-1933.*

Variety and Treatment.	Index at Time Cracking Occurred.	Index at Time of Harvest.
Gulf State Market, Dry	1.37	2.43
Gulf State Market, Wet	1.50	2.83
Gulf State Market, Dry-Wet	1.67	3.27
Globe, Dry	1.36	2.10
Globe, Wet	1.46	3.33
Globe, Dry-Wet	1.59	3.55

field conditions, Globe showed higher indices than Gulf State Market. A possible cause for this difference will be discussed under concentric and radial cracking. It is important

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*Each small crack was given a value of 1; medium sized crack a value of 2, and each large crack a value of 3.

to note that in the greenhouse, as in the field, indices are appreciably larger when the fruits are harvested than when cracking first occurred. Cracking of green or mature green fruits in the greenhouse crop of 1932-1933 originated, as a rule, as small radial cracks near the corky layer, which grew larger as the fruit matured.

Effect of Stage of Maturity of Fruit on Cracking Indices.

Are green fruits less likely to crack severely, when cracking does occur, than red ripe ones? The severity of initial cracking does increase with age. That is, the longer a fruit is allowed to remain on the vine, especially after it reaches the mature green stage, the greater is the possibility that if it does crack, the cracking will be rather severe. Cracking indices for fruits which are cracked at different ages are presented in the following table (Table XXI). For about ten days there was a small and similar degree of cracking at each daily time interval prior to the attainment of the pink stage. A discrepancy is apparent between Tables XX and XXI in that the relative severity of initial cracking in the wet and dry treatments does not agree. This is due to the omission of data for several days on either end of the range of development shown in the first column of the latter. The tables are not comparable. This tendency towards more severe cracking

TABLE XXI -- EFFECT OF STAGE OF MATURITY OF FRUIT ON CRACKING INDEX. FIELD, 1932. COLLEGE PARK. GULF STATE MARKET.

Maturity.	Cracking Indices*		
	Dry	Wet	Dry-Wet
7 days before pink,	1.0	1.6	1.4
6 days before pink,	2.0	1.3	1.6
5 days before pink,	1.7	1.4	1.7
4 days before pink,	1.4	2.1	1.9
3 days before pink,	1.3	1.3	2.2
2 days before pink,	2.2	1.2	1.5
1 day before pink,	1.6	1.7	1.5
Pink,	1.8	1.2	2.1
1 day after pink,	1.7	1.9	2.4
2 days after pink,	2.4	1.9	3.1
3 (red ripe),	2.2	2.5	3.4
4 (red ripe),	3.1	1.6	3.7
5 (red ripe),	3.0	3.5	4.5
6 (red ripe),	3.6	2.7	4.2
7 (red ripe),	3.1	1.9	4.9

as the fruit becomes older, was first studied in the greenhouse crop of 1931-1932. The red ripe fruits, if they remained on the vine two or three weeks, before cracking, would finally rupture severely. On the wet plots large cracks appeared earlier (Table XXII). In fact the appearance of large cracks on fruits grown in the high water plots was earlier than the appearance of small ones in the dry plots. Again the effect of water applied to the soil is well defined in its influence on cracking of the tomato fruit.

There remains an important question relating to

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*Indices at time of cracking (Initial index)

TABLE XXII -- INFLUENCE OF STAGE OF MATURITY ON SIZE OF CRACK WHEN CRACKING FIRST OCCURS, 1931-1932. GLOBE AND GULF STATE MARKET VARIETIES.

Treatment.	No. Days From Red Ripe Stage Until Cracking Occurred.	
	Large Cracks.	Small Cracks.
Dry	12.0	6.8
Medium	9.4	6.6
Wet	5.6	3.6

the association between cracking and physiological age of the fruit. Though the size of the rupture at the time of its occurrence increases with age, are a larger number of these mature fruits more likely to crack? At what age of the fruit does the largest percentage of cracked fruits occur?

Percentage Cracking in Relation to Maturity.

In Table XXIII are shown the percentages of fruits which cracked when they reached a given age. It is not a percentage based on the total number of fruits produced, but upon the number of sound fruits of a given age in days as 100.

Practically all of the fruits turned red ripe between two and three days after the pink stage. It is at once noticed that a very smallpercentage crack up to within three days of the pink stage, at which time an appreciable increase in cracking occurs, becoming especially noticeable at the pink stage. Red ripe fruits show a still further

TABLE XXIII -- PERCENTAGE CRACKING IN RELATION TO MATURITY -- (Figures Represent Percent of Fruits Cracking on the Day They Reached the Stated Stage of Maturity). Greenhouse, 1932-1933.

Maturity.	Percent Fruits Cracking.
14 days preceding pink,	.31
13 days preceding pink,	.31
12 days preceding pink,	.00
11 days preceding pink,	.95
10 days preceding pink,	.00
9 days preceding pink,	.79
8 days preceding pink,	.64
7 days preceding pink,	.80
6 days preceding pink,	.65
5 days preceding pink,	.32
4 days preceding pink,	.32
3 days preceding pink,	1.32
2 days preceding pink,	2.17
1 day preceding pink,	1.88
Pink,	5.40
1 day after pink,	7.73
2 days after pink,	7.18
3 (ripe),	10.32
4 (ripe),	8.63
5 (ripe),	9.44
6 (ripe),	12.46
7 (ripe),	12.25

increase in frequency of cracking.

What is the effect of water treatment and position of the fruit on the cluster on cracking? Table XXIV shows plainly that the first fruit on the cluster cracks at an earlier stage than the third one. It is interesting to note too that fruits from plants grown in high water plots

TABLE XXIV -- PERCENT CRACKING IN RELATION TO MATURITY. FIGURES REPRESENT PERCENT FRUITS CRACKING ON THE DAY THAT THEY REACHED THE STATED STAGE OF MATURITY. GREENHOUSE, 1932-33.

Maturity	Dry Treatment				Wet Treatment				Dry-Wet Treatment			
	Gulf State Market		Globe		Gulf State Market		Globe		Gulf State Market		Globe	
	* No.1 fruit	No.3 fruit	No.1 fruit	No.3 fruit	No.1 fruit	No.3 fruit	No.1 fruit	No.3 fruit	No.1 fruit	No.3 fruit	No.1 fruit	No.3 fruit
14 days preceding pink	.0	.0	.0	.0	.0	.0	1.61	.0	1.63	.0	.0	.0
13 days preceding pink	.0	.0	.0	.0	1.96	.0	.0	.0	.0	.0	1.56	.0
12 days preceding pink	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
11 days preceding pink	.0	.0	.0	.0	2.00	.0	6.55	2.08	.0	.0	.0	.0
10 days preceding pink	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
9 days preceding pink	1.92	.0	.0	.0	6.12	.0	.0	.0	.0	.0	1.58	.0
8 days preceding pink	.0	.0	1.66	.0	.0	.0	1.75	.0	.0	.0	1.61	2.0
7 days preceding pink	.0	.0	.0	.0	2.17	.0	3.57	.0	.0	.0	3.28	.0
6 days preceding pink	.0	.0	.0	.0	2.22	.0	1.85	.0	.0	.0	3.38	.0
5 days preceding pink	.0	.0	.0	.0	.0	.0	.0	2.12	.0	.0	1.75	.0
4 days preceding pink	.0	.0	.0	2.27	.0	.0	1.88	.0	.0	.0	.0	.0
3 days preceding pink	1.96	.0	.0	.0	2.27	2.12	1.92	6.52	5.00	.0	.0	4.15
2 days preceding pink	.0	.0	1.69	2.32	2.32	2.15	3.92	2.32	.0	.0	5.35	6.52
1 day preceding pink	2.00	.0	3.44	.0	4.75	4.44	18.36	2.38	.0	.0	5.66	2.32
Pink	4.08	2.38	14.28	.0	2.50	9.30	17.50	9.75	1.70	.0	3.84	4.87
1 day after pink	12.76	.0	10.41	.0	7.69	7.69	24.24	13.51	3.44	1.92	16.32	2.50
2 days after pink	4.87	7.31	4.65	4.76	13.88	8.33	20.00	3.12	10.71	3.92	4.87	7.69
3 days after pink	10.25	2.64	12.15	5.00	6.45	6.06	15.00	9.67	24.00	1.43	12.82	5.55
4 days after pink	8.57	5.40	8.33	10.52	13.79	.0	5.88	7.15	21.05	4.76	17.64	2.94
5 days after pink	25.00	8.57	6.05	.0	12.00	12.90	6.25	11.53	18.75	2.50	7.14	11.00
6 days after pink	16.66	6.25	9.67	.0	13.63	7.40	13.33	4.34	34.61	15.38	15.38	23.33
7 days after pink	15.00	6.66	14.28	5.88	10.00	8.00	.0	18.18	17.64	21.21	18.18	17.39

* No. 1 fruit - refers to the first fruits on the cluster - adjacent to the stem.
No. 3 fruits refer to those fruits borne on the cluster three fruits from the stem.

cracked earlier than those on dry plots. The probability that a tomato fruit will crack early in the mature green or green stage depends, therefore, upon its environment and position on the plant as does the index of cracking. The older the fruit becomes the greater is the probability that it will crack.

Results with field-grown fruits (Table XXV) corrobrate the above conclusions. The percentage of cracking increases up to the red ripe stage, and shows a slight tendency to decrease after that time, in the Globe variety. Again the relatively early cracking of fruits on wet plots, as compared to those on dry plots, is seen. The Globe variety, in the field, not only cracks more severely, but is more susceptible at all stages of maturity.

Types of Cracking and Region of Fruit Most Susceptible to Cracking.

It is commonly observed that tomato fruits crack most frequently at the stem end. Two types of cracking may occur: (1) radial, or (2) concentric. The former is the more common, as a rule, and appears at the attachment of the stem, in most cases, although deep splits may occur along the sides of fruits, without reaching to the corky layer of the stem end. Data in Table XXVI were taken at Arlington Farm October 2nd to October 19th, 1931 during a relatively dry period, and represent a field run of mature green, pink, and red-ripe fruits. Column one shows that an average of 82 per-

TABLE XXV -- PERCENT CRACKING IN RELATION TO MATURITY. FIGURES REPRESENT PERCENT CRACKING OF THE FRUITS ON THE DAY THAT THEY REACHED THE STATED STAGE OF MATURITY. FIELD, 1932. COLLEGE PARK.

Maturity	Dry		Wet		Dry - Wet	
	Gulf State Market	Globe	Gulf State Market	Globe	Gulf State Market	Globe
10 days preceding pink	.18	.26	2.31	.93	.00	2.86
9 days preceding pink	.37	1.31	1.18	1.56	.56	4.91
8 days preceding pink	.75	2.39	2.10	2.54	2.42	7.49
7 days preceding pink	.57	3.54	4.29	6.20	2.67	5.58
6 days preceding pink	1.53	3.95	4.80	4.52	2.74	11.83
5 days preceding pink	1.75	2.05	5.38	7.66	3.22	6.37
4 days preceding pink	2.17	4.20	3.55	9.09	4.12	10.75
3 days preceding pink	2.63	5.95	6.64	12.17	3.22	8.83
2 days preceding pink	3.93	5.33	8.30	13.36	5.76	19.38
1 day preceding pink	3.82	8.09	5.17	14.28	4.94	13.11
Pink	6.25	11.87	6.81	14.66	9.40	22.01
1 day after pink	5.45	8.70	3.90	12.50	5.46	16.93
2 days after pink	7.05	7.14	10.80	8.92	9.82	26.21
3 days after pink	8.96	6.66	6.66	5.88	9.61	14.47
4 days after pink	6.81	5.49	7.79	9.37	12.76	18.46

cent of the total cracks occur within the creases radiating from the stem end. These creases lie immediately above or along the septal or interlocular walls. Only 7.67 percent

TABLE XXVI -- PLACE ON THE FRUIT MOST SUSCEPTIBLE TO RADIAL CRACKING. FIGURES EXPRESSED AS PERCENTAGES OF TOTAL NUMBER OF CRACKS OCCURRING. ARLINGTON, 1931.

Variety.	Percent of Total Cracks Occurring on Crease.	Percent of Total Cracks Occurring on Locule.	Percent of Total Cracks Connected With Corky Ring.	Average Number Cracks Per Fruit.
Gulf State	72.06	13.44	94.44	2.21
Globe	75.66	10.21	88.64	2.63
Marglobe.	93.73	2.34	98.59	2.63
Average	82.42	7.67	94.64	2.51
Number Fruits.	4.81			

(column 2) occurred on the locule between these creases. The remaining 10.33 percent were either concentric cracks or could not be definitely placed in the above two groups. Column three shows that 94.64 percent of the total cracks on the fruits were connected with the corky ring of the stem end. Greenhouse grown fruits of the winters of 1931-1932, and 1932-1933, showed with the exception of only two or three fruits out of a thousand, cracks radiating from the stem end. It was often observed, however, that the initiation of cracking was not at the corky layer with subsequent increase in size of the crack towards the shoulder of the fruit, but that very small ruptures would originate just outside of the corky area. (Figure 6). The crack would then increase in size and become connected with the corky ring of the stem end. The initiation of radial cracking is usually from the corky ring itself.

It was found that under field conditions of 1932, concentric cracking may become prevalent. This type of cracking was slight, however, until relatively late in the season, when a high percent of the fruits cracked concentrically (Figure 7). Table XXVII shows the behavior of the two varieties between August 5th and August 20th. The third column in the table shows the precent of cracked fruits, between August 5th and 11th, having concentric cracks. At that time the percentage was low. Between August 12th and 17th concentric cracking became more frequent, and from August 18th to 20th was very high.

It is interesting to note that Globe fruits consistently showed a higher percent of concentric cracking. It was found earlier that cracking in the dry-wet series was increased between August 12th and 17th by the change to high soil water on August 11th. The concentric type of cracking (column four of the table) was increased, and remained high thereafter, for these plots.

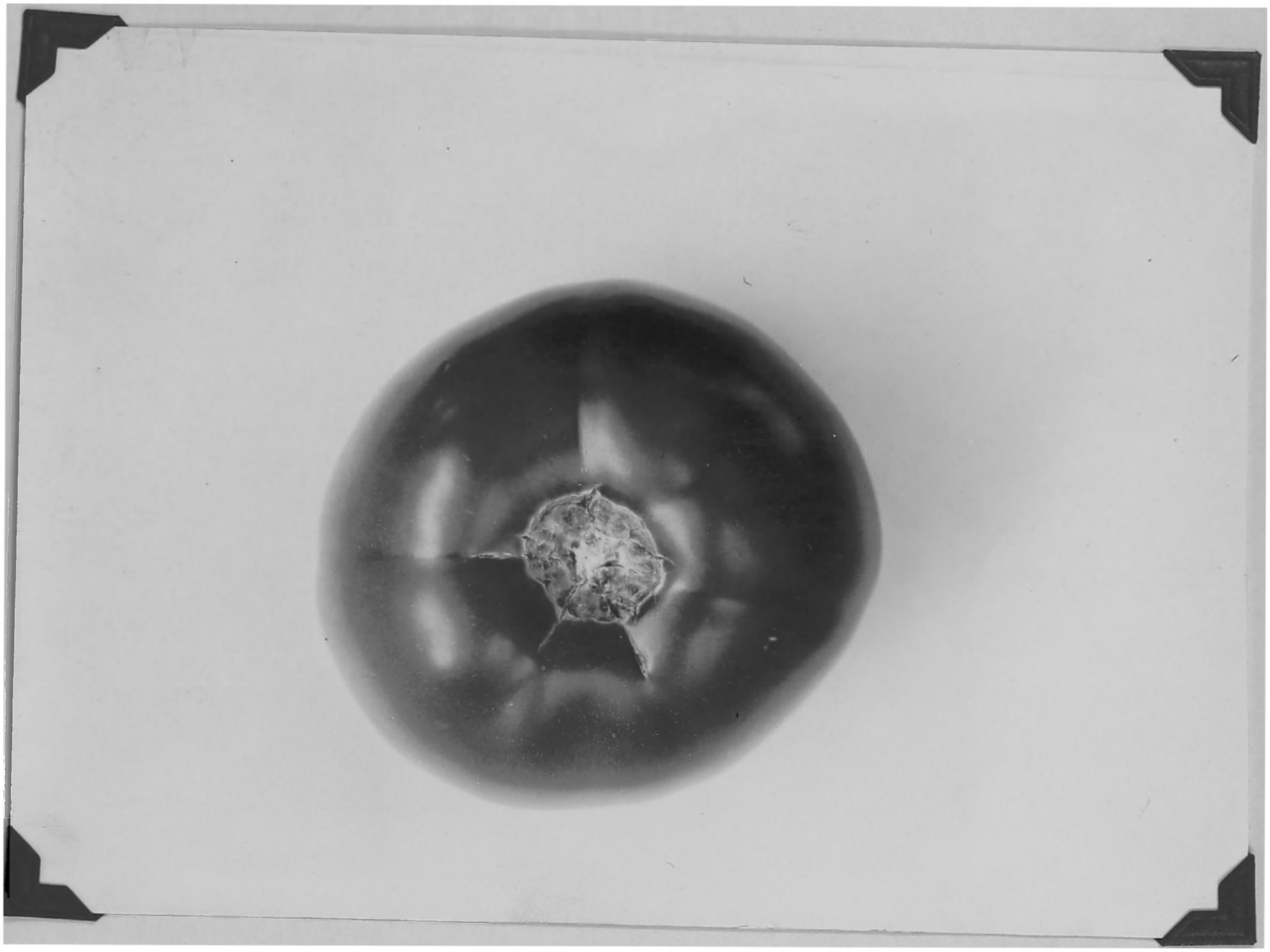

Figure 6 -- Gulf State Market fruit. Note that very small cracks are originating within the creases, and just outside the corky layer. The usual origin of these radial cracks, however, is from the corky ring itself.

Figure 7 — Severe concentric cracking of Globe Tomato fruit from field plots. College Park, 1932.

TABLE XXVII -- CONCENTRIC CRACKING OF GLOBE AND GULF STATE MARKET TOMATO FRUITS.*

(Figures Represent Percent of Total Fruits Within the Stated Dates)

Treatment.	Variety.	Period Over Which Cracking Occurred (Inclusive) Aug. 5 - 11: Percentage Concentric Cracks.	Aug. 12 - 17: Percentage Concentric Cracks.	Aug. 18 - 20: Percentage Concentric Cracks.
Dry	Gulf State Market	6.77	7.40	33.83
	Globe	17.94	26.19	71.34
Wet	Gulf State Market	.00	.00	41.50
	Globe	6.97	28.88	55.17
Dry-Wet	Gulf State Market	2.39	15.13	50.80
	Globe	7.14	46.40	81.29

One of the reasons for the high cracking indices of the Globe variety, under field conditions, is its decided tendency towards concentric cracking.

The cause of concentric cracking in the field crop, and its absence in greenhouse crops, is not definitely known. The observation that the field grown fruits, especially of the Globe variety, often possessed numerous corky dots on the green

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*Those fruits showing both concentric and radial cracks were included as concentric.

area of the stem end, must not be overlooked as bearing a possible relation to concentric cracking. The immersion of such spotted fruits in dye solutions and water will be discussed later.

It was apparent, in making counts of cracked fruits, that red ripe ones were less susceptible to the concentric type of cracking. This is shown in Table XXVIII. Inasmuch as concentric cracking appears to be confined to

TABLE XXVIII — CONCENTRIC CRACKING AS RELATED TO STAGE OF MATURITY OF THE FRUIT. GULF STATE MARKET. FIELD, 1932. COLLEGE PARK.

Treatment.	Percent of Fruits of Pink Stage or Earlier Which Cracked Concentrically.	Percent of Fruits of Later Than Pink Stage Which Cracked Concentrically.
Dry	83.33	6.82
Wet	72.00	14.28
Dry-Wet	82.80	22.39

certain growing seasons, and to certain ages of fruit, there is reason to believe that it is caused by factors other than those responsible for the radial type of cracking.

Inherent Weakness of the Fruit in the Creases: Since it was found that most of the radial cracks of Gulf State Market and Globe varieties normally occur in the creases radi-

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* Calculated on fruits cracking between August 18th and 20th inclusive.

ating from the stem end, it was desirable to find whether the resistance to puncture in this area might be less than that on other portions of the fruit. A common corn pressure tester, with plunger .514 mm. in diameter was used. Numerous tests were made throughout the course of the experiments. Punctures were made in three regions of the fruit: (1) in the crease one-fourth inch from the corky ring, (2) on the locule, one-fourth inch from corky ring, and (3) on the flower end, one-fourth inch from the stylar scar. A low puncture test in the creases, where a high percentage of the cracks occur, would indicate an inherent structural weakness at this point. Table XXVIII gives a typical example of the results. In every case tremendous odds have been obtained showing that the resistance of the crease to puncture is much less than that of regions between the creases or at the flower end. Puncture tests of mature green fruits from the 1931-1932 greenhouse crop show similar differences (Table XXIX). In no case were less than eight fruits used, nor less than thirty tests made for a single figure. Though the weakness of the creases was established beyond doubt, the high coefficients of variability of punctures of fruits of the same age and treatment (from 15 - 30 percent) and the lack of consistent differences in a given direction, have indicated that no differences in resistance to puncture could be shown between varieties or water treatments.

TABLE XXVIII -- PUNCTURE TESTS OF GULF STATE AND GLOBE TOMATO FRUITS, IN DIFFERENT REGIONS OF THE FRUIT FROM HIGH AND LOW WATER TREATMENTS. PINK FRUITS. GREENHOUSE, Nov. 27th, 1932.

Variety and Water Treatment.	Grams Resistance to a Piston .514 mm. in diameter.*		
	(1) Crease	(2) Locule	(3) Flower End
Gulf State, High water	77.03	127.37	183.62
Gulf State, Low water	76.09	143.50	199.87
Globe, High water	85.93	146.62	174.62
Globe, Low water	74.12	140.70	174.50

Puncture tests of field-grown fruits are shown in Table XXX. In all cases, care was taken to hold the puncture tester at an angle, within the bottom of creases, that provided flat contact of the piston and skin. It is realized that these are not true tests of the resistance to puncture of the skin alone, but that underlying tissue, as well as skin, combine to offer resistance to the pressure. This should not be considered objectionable, because the tissue beneath the skin must certainly play some part, as well as the skin itself, in resistance to cracking. Red

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*Eachfigure is the average of 32-40 puncture tests made on sample of 8-12 fruits.
(1) Puncture made 1/4 inch from corky ring.
(2) Puncture made 1/4 inch from corky ring.
(3) Puncture made 1/4 inch from Flower End Scar.

TABLE XXIX — PUNCTURE TESTS OF GULF STATE MARKET AND GLOBE TOMATO FRUITS, IN DIFFERENT REGIONS OF THE FRUIT FROM HIGH, MEDIUM, AND LOW WATER TREATMENTS. GREENHOUSE, DEC. 16th, 1931. MATURE GREEN FRUITS.

Variety and Treatment.	Grams Resistance to a Piston .514 mm. in diameter		
	Crease.	Locule.	Flower End
Gulf State, High Water Market.	106.45	133.54	180.00
Gulf State Market, Low Water.	104.81	140.63	182.22
Gulf State Market, Medium Water.	102.55	135.55	176.22
Globe, High Water.	100.42	144.02	169.73
Globe, Low Water.	98.56	167.12	194.09
Globe, Medium Water	101.44	150.25	195.75

ripe fruits give much less resistance, as can be seen by Table XXX. This is an indication that underlying tissue is important. Rosenbaum and Sando (1920) using a Joly balance with a needle 78 microns in diameter, found that the pressure in grams necessary to puncture the fruit increased up to the pink stage.

It has been observed that sometimes the skin lying in the bottom of the crease tends to become separated from underlying tissue, forming a small cavity underneath. This

TABLE XXX -- PRESSURE TEST OF GULF STATE MARKET AND GLOBE TOMATO FRUITS FROM HIGH AND LOW WATER PLOTS, IN THE FIELD. MATURE GREEN FRUITS. July 27th, 1932.

Variety and Water Treatment.	Pressure Tests.		
	Crease.	Locule.	Flower End.
Gulf State, High Water.	118.1	167.8	186.3
Gulf State, Low Water.	121.3	167.1	187.9
Globe, High Water.	126.7	169.7	196.4
Globe, Low Water.	132.5	177.7	184.6

TABLE XXXI -- PUNCTURE TESTS OF GULF STATE MARKET RED RIPE TOMATO FRUITS, IN DIFFERENT REGIONS OF THE FRUIT, FROM DRY AND WET PLOTS. GREENHOUSE 1931.

Treatment.	Grams Resistance to a Piston .514 mm. in diameter.		
	Crease.	Locule.	Flower End.
High Water.	20.25	60.56	104.65
Low Water.	28.3	77.57	90.71

may partially explain the low resistance of this region to puncture. There is, however, an obvious need for study of skin thickness and type of underlying cells in attempting to explain the reasons for the inherent weakness of the creases.

Differential Growth of Regions of the Fruit

The usual occurrence of cracks near the stem end of fruits as they approach maturity led to the question as to whether this region might not at this stage, show a relatively high growth rate as compared to the stem end or to the middle portion of the fruit. Accordingly, as a measure of increase in expansion of the skin, small lines of uniform length were measured off: (1) one-fourth inch from the corky layer, concentrically across a crease, (2) one-fourth inch from the flower end, lying concentrically, and (3) on the middle of the fruit, running radially. Several blossoms on vines of each variety were tagged July 26th. On August 3rd, lines 6.4 mm. long were placed on six fruits of each variety in the positions noted above. A small pen was used, with India ink, to mark the fruits. Though the ink largely disappeared, the scars left by the pen point served as lines. The increase in length of the lines was measured at from three to five day intervals, until the fruits turned pink, which was September 3rd. The vines were on high water plots. Figures 8 and 9 show the average increase in mms. of the marked areas. The shape of the curves are

Fig. 8. Differential Growth Rates of Different Regions Of the Tomato Fruit. Gulf State Market Variety. (I) Stem End. (2) Side (3) Flower End.

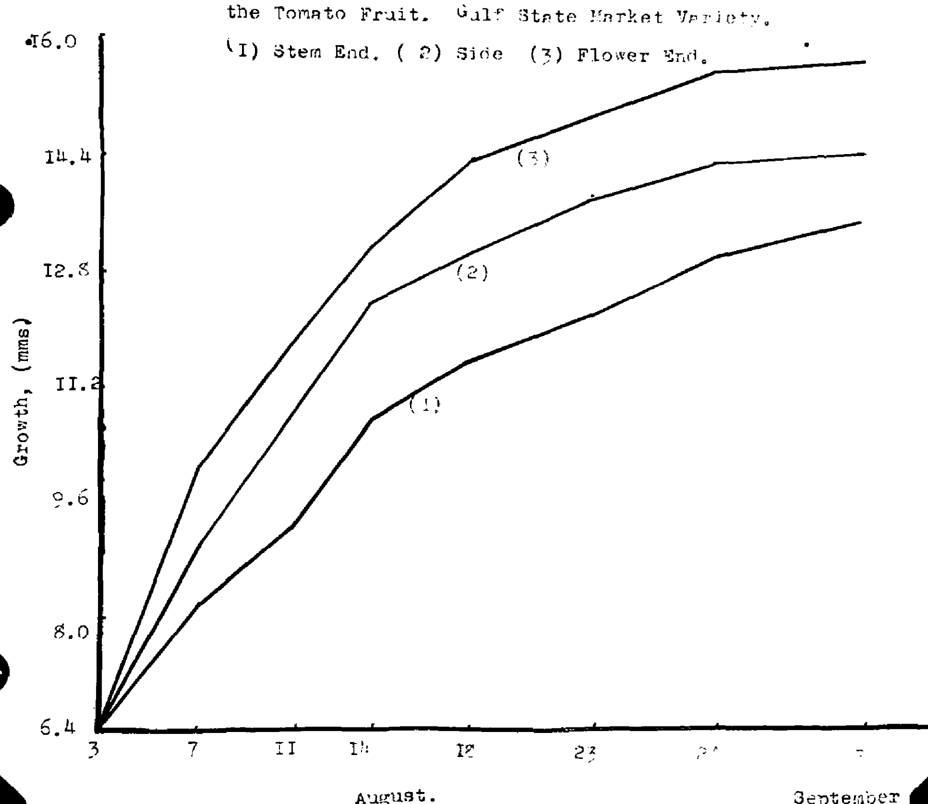
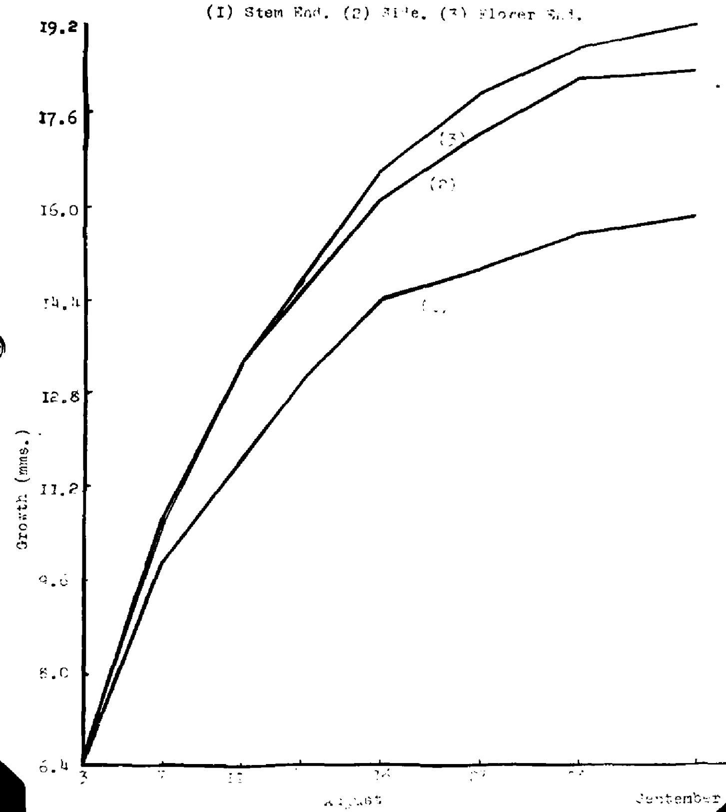


Fig. 9. Differential Growth Rates of Different Regions of the Tomato Fruit. Globe Variety.
(I) Stem End. (2) Side. (3) Flower End.



similar in all cases. The average increase of the stem end is less than that of flower end. Nor does the stem end show a sudden growth increase towards maturity. Two Globe fruits and one Gulf State Market fruit cracked concentrically on the stem end on September 3rd, but there was no greater increase in growth of these fruits at the stem end than with non-cracked fruits. It is possible, however, that a measurable increase in swelling would occur only where the skin gave way, being entirely local.

A difference in growth rates of different parts of fruits must take place in order that they may assume their inherent shape. The formation of creases at the stem end of the tomato fruit must undoubtedly be due to varying growth rates of cells of the ovary wall above the locules, and those lying above septae. Red ripe fruits are smoother -- the creases as a rule less pronounced -- than less mature fruits. This "smoothing out" effect must be the result of a differential in growth, and may be concerned with the rupture of fruits in the crease areas.

Immersion of Fruits in Water

It was found, in the fall of 1931, that red ripe fruits, if placed in water bath at room temperature, would often crack within a few minutes. Mature green or pink fruits, however, were much more resistant. The immediate increase in cracking brought about by rain in the field crop of 1932 suggested that certainly the passage of water through the roots and conducting system of the plant, thence into the fruit, could not be sufficient to account for the immediate effect of rain. In order to determine whether rain might be taken in through the skin or corky layer, fruits were immersed in water at room temperature and carefully weighed after definite intervals of time. The results were clear cut. If the stem was removed and the corky ring and stem scar paraffined, no increase in weight of the fruits occurred. (Table XXXII). When the stem was left on and the corky ring not paraffined (a coat of paraffine was put on the end of the stem itself) there was absorption of water. In sixteen hours, an average of over one gram of water was absorbed through the corky ring in this way. That these fruits were capable of absorbing very large amounts of water is shown in the case in which the stem was removed, leaving the entire corky ring and place of attachment of the stem free to take up water. None of the fruits used for the above experiment had corky spots in the skin.

By using solutions of Methylene blue (1:1000) it was possible to demonstrate that stain was absorbed by the small corky dots on shoulders of fruits and could be seen diffusing into the tissue immediately beneath. Figure 10 shows a red ripe fruit with the corky spots appearing on the stem end. After immersion of the fruit in methylene blue for ten hours, dye solution had been absorbed through these spots. The same fruit (slightly reduced) is shown in figure 11, after

TABLE XXXII.-- WATER INTAKE OF INDIVIDUAL TOMATO FRUITS IMMERSED IN WATER. CUMULATIVE INCREASE IN WEIGHT IS GIVEN. MATURE GREEN GLOBES FROM FIELD PLOTS, 1932.

Treatment	Initial Weight of fruit in grams	Gain in weight after indicated intervals of time				
		40 min.	2 hrs.	4 hrs.	16 hrs.	27 hrs.
Stem removed and corky ring paraffined. Avg. of 6 fruits	113.93	-.017	-.011	-.023	-.039	-.063
Stem left on. Corky ring not paraffined.	127.244	+.233	+.304	+.356	+.736	+1.187
Stem left on. Corky ring not paraffined.	111.957	+.555	+.785	+.938	+1.554	+2.019
Stem left on. Corky ring not paraffined	132.054	+.259	+.373	+.429	+1.017	+1.513
Stem removed. Corky ring not paraffined.	126.297	+3.534	+ 4.915	+6.790	+10.250	+13.203
Stem removed. Corky ring not paraffined	134.912	+3.191	+ 4.571	+6.288	+9.530	+11.875
Stem removed. Corky ring not paraffined	101.902	+2.413	+ 3.523	+4.695	+7.975	+10.257

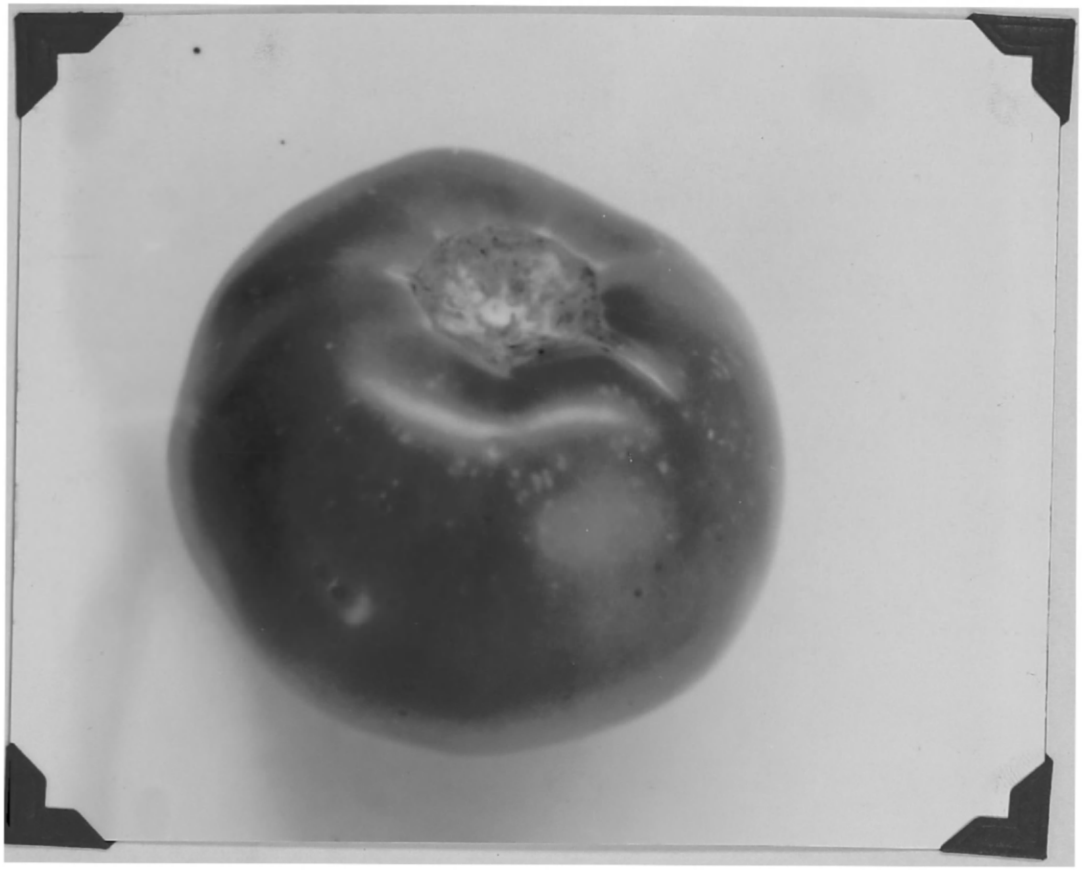


Figure 10 -- Globe tomato fruit, showing numerous
corky dots on stem end.
(See Figure 11).

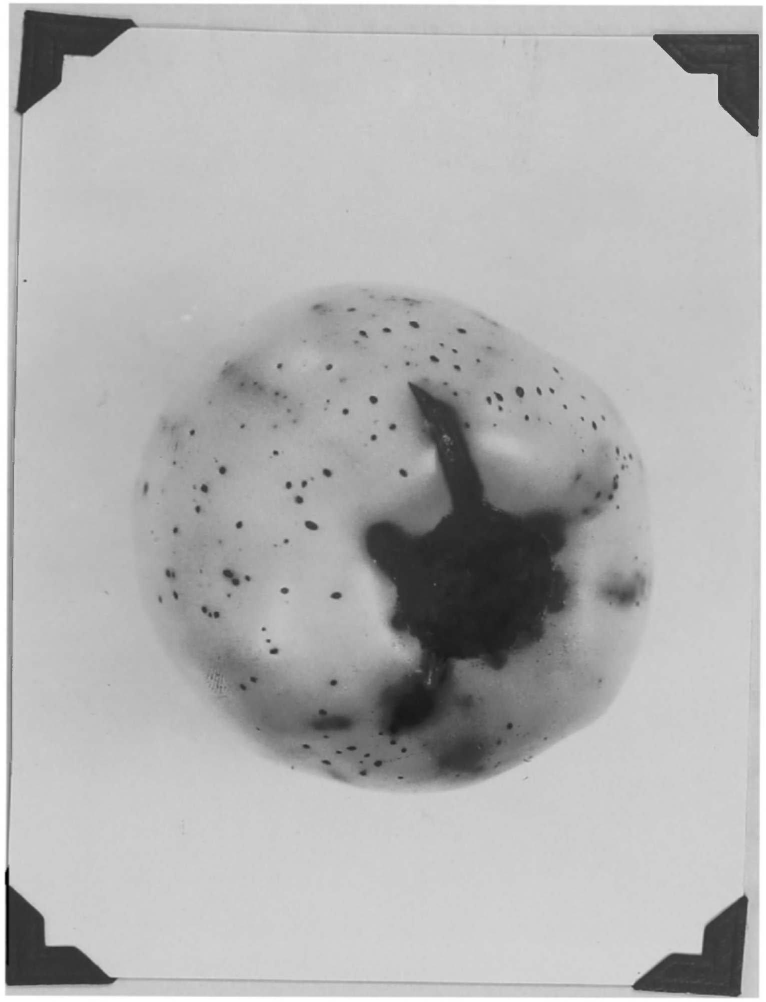


Figure 11 — Same fruit as in Figure 10 (slightly reduced) after 10 hours immersion in 1:1000 methylene blue solution. Note that stain has been absorbed in the corky areas. Fruit in Figure 10 taken with green filter; fruit below taken with red filter.

the ten hour immersion. The photograph in figure 10 was taken with a green filter, while in order to show the stain, a red filter was used for figure 11.

The fruit in figure 12, having a rough skin, but no cracks, was left in 1:1000 methylene blue over night. Note that the stain had been absorbed and small cracks had occurred in the shoulder area. There seems little doubt but that rain water is absorbed in this way in the field, accounting for some concentric cracking.

Dye is absorbed by many fruits mainly along the septae. Such fruits, after remaining in the solution for two or three hours, then allowed to dry, present a distinct pointed pattern radiating from the corky layer. Practically all of these points lie on septae, which have been shown to be the most likely place for cracking to occur. (See figure 13)

To what extent cracking is influenced by absorption of external moisture through the corky layer, which has been shown possible, or through rough, corky areas in the skin, cannot be told. Suffice it to say that both certainly play some part.

Temperature

Verner and Blodgett (1931) found that high temperature increased the rate of cracking of cherries immersed in water. What, however, is the effect of temperature on fruits growing on the vine or tree? High temperature might theoretically induce cracking of fruits

Figure 12 -- Gulf State Market fruit which was left in methylene blue solution (1:1000) for ten hours. The fruit, when placed in the dye had numerous corky spots on the shoulder area. Note that stain was absorbed through these spots, and small cracks occurred.

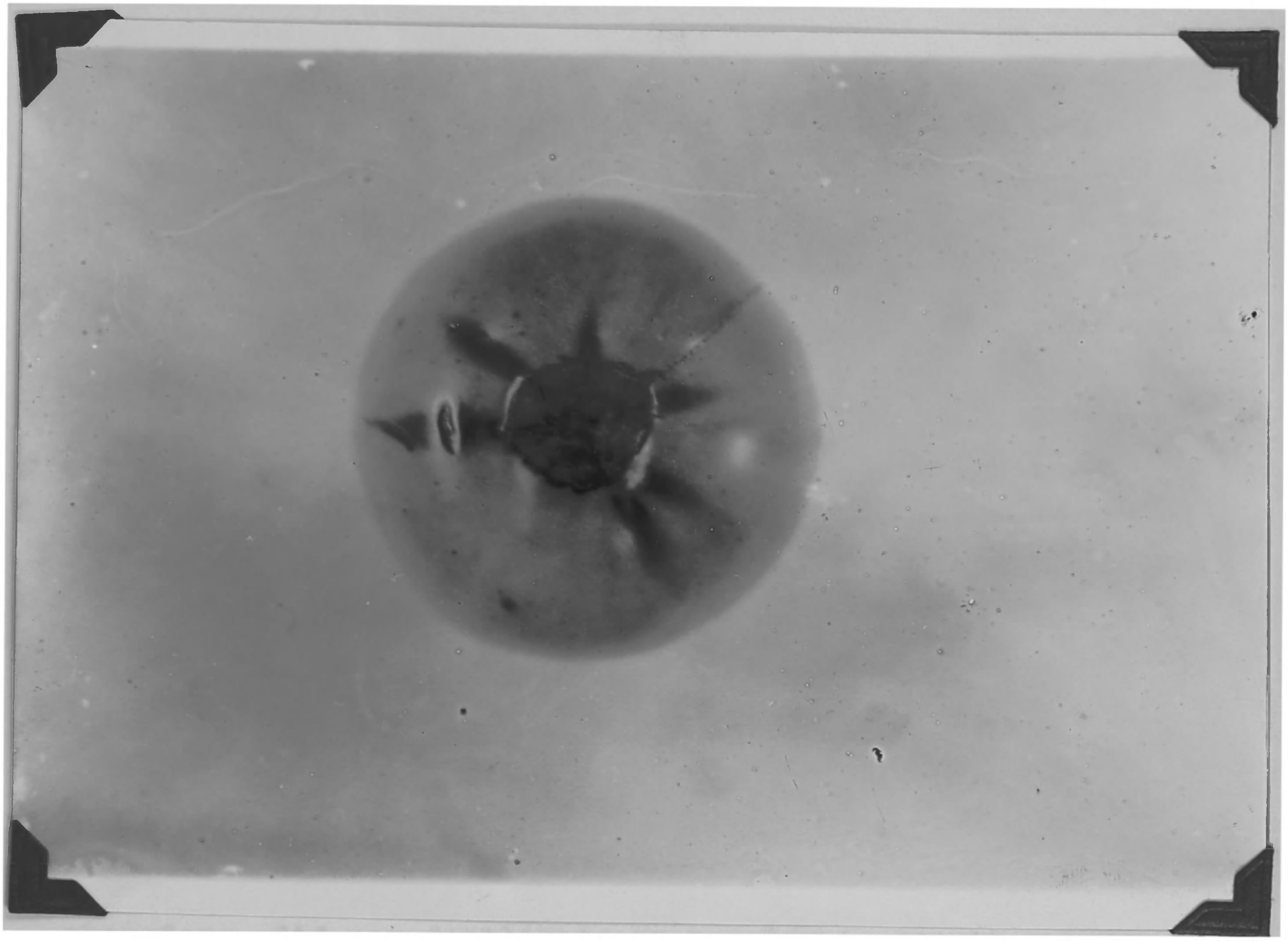


Figure 13 -- Gulf State Market fruit, after remaining in 1:1000 methylene blue solution two hours. The stain has diffused most rapidly into the crease areas, giving a pointed pattern.

on the vine by promoting more rapid growth and maturity. Imbibition is more rapid at high temperatures. Thermal expansion of the fruit may possibly be important. However, it is to be remembered that high temperatures also promote rapid transpiration -- not only from the fruit, but from other plant parts which may draw upon the fruit for water. An ideal condition for promoting cracking would, no doubt, be warm, rainy, weather. Periods of high temperature did not correspond with periods of cracking in fruits grown in the field. (Figure 4). As a rule, the high temperatures were accompanied by dry weather, and cracking was greatly decreased. MacDougal (1920) in studying growth of tomato fruits by means of an auxograph states "as the daily temperatures of the fruits rose from 12°C. and 14°C to 26°C. and 28°C., acceleration (of growth) ensued up to a point where the rise caused a water-loss overbalancing the gain by hydration. Higher temperatures, therefore, did not facilitate or accelerate growth unless accompanied by high relative humidity." He found that as a result highest growth rates were those of mid-day and afternoon, provided the high temperature was accompanied by fog or showers. An actual shrinkage in volume of tomato fruits was noted on days with low humidity and high temperature, conducive to high transpiration.

Many cases have been observed in these studies in which those fruits attached to the plant and which were exposed to the sun appeared to be the ones cracking most severely. The writer was enabled to study the effect of shading the entire plant on cracking in the Marglobe variety in the summer of 1932. The treatments were designed to study the influence of sunlight on tomato color. Differences in degree of cracking were so apparent between fruits from shaded and non-shaded plants that data were taken on the last three harvests which would show their relative cracking indices. The plants had been pruned to a single stem, and the shading treatments begun July 5th, 1932. The fruits studied were, therefore, at the time of beginning the treatment, just setting. Cracking indices were arbitrarily determined as described earlier. Table XXXIII shows that

TABLE XXXIII — EFFECT OF SHADING ON DEGREE* OF CRACKING OF THE TOMATO FRUIT. MARGLOBE VARIETY. 1932.

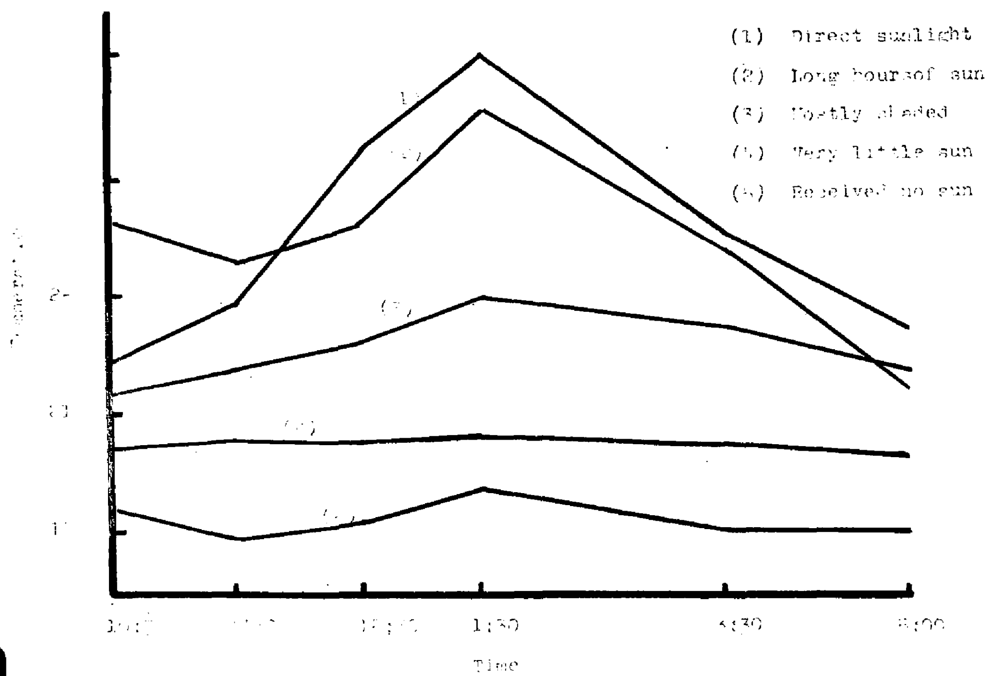
Harvest Date.	Fruits exposed to sun (on untreated plants)	Fruits partly shaded from sun (untreated plants)	Fruits mostly shaded from sun (on untreated plots)	Single Muslin	Double Muslin
August 15th	12.0	8.4	8.6	7.1	4.9
August 20th	9.0	9.6	---	6.3	2.7
August 25th	10.6	10.5	11.7	5.9	3.5

* Each figure is averaged from 10-25 fruits.

plants shaded by single thicknesses of muslin produced fruits which were much less severely cracked, while double muslin was even more effective in preventing cracking. The severity of cracking of unshaded fruits may be neither the result of high temperatures, nor of the direct effect of sun on the cutin of the fruit. Its action may be indirect by influencing photosynthesis, and ultimately the chemical composition of the fruit. That the temperature of fruits in the sun is very high compared to shaded ones, was found by inserting the bulbs of thermometers into the ovary wall tissue of such fruits. Figure 14 shows that very great differences in the temperature of the tissue of individual fruits may occur on sunny days with fruits grown in the same greenhouse. Fruits located on the vine so that they receive sunlight throughout most of the day, were at mid-day at a temperature almost twice as high as that of well shaded fruits. Fruits borne on the third cluster were the ones, in the greenhouse, most directly exposed to the sun. We have shown, however, that these fruits did not crack more severely, on dry plots, than did those on the first or second clusters. In wet plots of Gulf State Market, third cluster fruits did not crack appreciably more. It would seem that under these conditions, temperature was not of prime importance. It was found that in the dry-wet treatments, cracking was more prevalent on the third cluster, yet this is related definitely to water supply. Temperature, at least, did not appear to greatly retard cracking.

Figure 1. -- Temperature of Individual Tomato Fruits.

Dec. [illegible], 19[illegible]. [illegible] Day. Greenhouse.



Chemical and Bio-Physical Studies

Methods:

1. Moisture Determinations: Finely sliced tissue was placed in a forced drought oven for sixty hours at 65°C. Samples of from twelve to twenty grams green weight were used. Duplicate determinations were always made.

2. Hydrogen-ion Concentration: pH determinations were made with a portable type potentiometer, using a saturated calomel cell, and quinhydrone electrode. Freshly expressed juice was used, and duplicate determinations made.

3. Freezing Point Depression: The sap, immediately after being expressed with a small hand press, was placed in an ice bath, and determination of the freezing point made at least within forty-five minutes. Duplicate determinations on different lots of fruits run in this way agreed very closely.

4. Pectin and Protopectin: These pectic constituents were determined essentially as outlined by Appleman and Conrad (1927). Their method of purification of pectin and protopectin from the tomato fruit, was closely followed. Duplicate determinations on duplicate samples were made for both pectin and protopectin. Lots of eight to twelve fruits were used for each of the two samples. After finely grinding in a large meat chopper, a fifty gram sample of the tissue was immediately dropped into enough

cold alcohol to leave the final concentration at eighty percent. .2 grams of calcium carbonate was added to each sample.

5. Carbohydrates: Sampling: Duplicate one-hundred gram samples of the tissue, after being cut into small pieces, were dropped into wide mouth Erlenmeyer flasks containing .4 grams of calcium carbonate and sufficient alcohol to leave a final concentration of eighty percent. The flask was immediately placed in a hot water bath and the alcohol allowed to boil for five minutes. The flasks were then removed, cooled, stoppered and sealed with paraffine until used. Tissue from twelve to eighteen fruits was used for each sample.

Total sugars, reducing sugars, acid hydrolyzable materials, sucrose -- these constituents were determined by the methods described by Boswell (1923). Duplicate analyses on duplicate samples were made.

In all of the chemical and bio-physical measurements which are to be described below, the septum and locule tissues of the fruits were discarded. Unless otherwise indicated only the stem end one-third of this ovary wall tissue was used. Inasmuch as cracking normally occurs in this region, and in the ovary wall tissue, there would seem to be no reason for including the other portions of the fruit. There is, of course, the possibility that the tissue within the locule may exert sufficient pressure, under favorable conditions, to split the surrounding ovary wall tissue. This is certainly not the case, however, with many fruits, for "puffy" tomatoes have been observed in the greenhouse that cracked (at the stem end) even though the locular cavity was only partly filled with seeds, pulp, and juice. On the other hand, the only fruits which have cracked severely enough along the side to expose locular tissue, which bulged into the open crack, was in the dry-wet plots in the field. It may have been that water intake, following the dry period, was great enough in the pulp vesicles to break open the ovary wall.

Water Content of the Tomato Fruit.

<u>Water Content of Stem and Flower End Ovary Wall Tissue:</u> The extremely important role which soil moisture plays in the occurrence of cracks in the tomato fruit,

suggests the necessity for making a thorough study of the water content of the fruit tissue. Is the stem end, where cracking is most frequent, high in water? Numerous determinations on the ovary wall tissue have shown that it is higher in moisture than the stylar end. Stem end tissue has varied from .3 to 1.0 percent higher, both in field grown and greenhouse-grown fruits. The following table shows these small, though consistent differences.

TABLE XXXIV -- WATER CONTENT OF STEM AND FLOWER END OVARY WALL TISSUE OF GULF STATE MARKET, GLOBE, AND MARGLOBE TOMATO FRUITS. ARLINGTON, 1931. MATURE GREEN FRUITS

Date.	Gulf State Market.		Globe		Marglobe	
	Stem End.	Flower End	Stem End.	Flower End.	Stem End.	Flower End.
August 31st.	93.74	93.42	93.61	93.28	94.00	93.51
Sept. 10th.	94.25	93.99	94.14	93.91	93.93	93.56
Sept. 14th.	94.13	93.75	94.10	93.78	94.22	93.69

The fruits harvested August 31st were cracked, while those picked on the two later dates were not. It is interesting to note the striking similarity in water content of the Gulf State Market and Globe varieties. It was at once apparent that differences in susceptibility to cracking between these two varieties could not be explained by the moisture content, or apparent inbibitional capacity.

As a more accurate check on the water content of stem and flower end tissue, determinations on individual fruits were made, in which the skin was carefully removed, and only the parenchymatous cells of the ovary wall used for the moisture determination.

TABLE XXXV -- WATER CONTENT OF STEM AND FLOWER END OVARY WALL TISSUE OF INDIVIDUAL FRUITS OF THE GULF STATE MARKET VARIETY. GREENHOUSE, JANUARY 7, 1933. FRUITS FROM WET PLOTS.

Maturity.	Fruit No.	Water Content.		Increase, Stem End Over Flower End.
		Stem End.	Flower End.	
Red Ripe.	1	95.37	95.06	+ .31
Red Ripe.	2	94.95	94.59	+.36
Red Ripe.	3	95.71	95.21	+ .50
Red Ripe.	4	95.35	94.87	+ .48
Mature Green.	6	94.81	94.17	∓ .64
Mature Green.	7	95.68	95.34	∓ .34
Mature Green.	8	95.02	94.71	∓ .31
Mature Green.	9	94.52	94.25	∓ .27
Mature Green.	10	95.31	94.74	∓ .57

The role which relatively high water may play in the cracking of the fruit near the stem end is a matter of speculation. Since this is the fruit portion in nearest proximity to the stem, it is not surprising that the tissue should be higher in water content.

<u>Water Content of the Fruit as Affected by Soil Moisture:</u> Withholding water from the soil has resulted in low water content of the fruit tissue. Brooks and MacGillivray (1928) found that dry matter in the tomato fruit varied inversely with the percent of soil moisture. In the present study, differences in water content of the tissue have been found in fruits from dry and wet plots in the field and in the greenhouse. In Table XXXVI is shown the effect of water content of the soil on the water content of the fruit.

TABLE XXXVI -- WATER CONTENT OF STEM AND FLOWER END OF GULF STATE MARKET AND GLOBE TOMATO FRUITS FROM HIGH AND LOW WATER PLOTS. SLIGHT PINK STAGE. GREENHOUSE. DECEMBER 8th, 1932.

Variety and Treatment.	Cracked Fruits:		Non-Cracked Fruits.		Percent Increase of Stem End Over Flower End.	
	Stem End.	Flower End.	Stem End.	Flower End.	Cracked	Non-Cracked
Gulf State Market, Wet	94.92	94.37	94.74	93.93	+.55	+.81
Gulf State Market, Dry	—	—	93.74	93.37	—	+.37
Globe, Wet	94.70	94.22	94.65	93.72	+.48	+.93
Globe, Dry	—	—	93.54	93.11	—	+.43

Fruits from these wet plots, relatively high in water, were the ones cracking most severely. Can this high water content explain the susceptibility to cracking? No doubt it plays some part. However, we have found that a heavy irrigation in the field could, within three to six days, cause an appreciable increase in cracking. Can it be shown that, in this space of time, the water content of the fruits on dry plots may be brought to a level of that of fruits in continuously wet plots? Table XXXVII shows that within a period of five days the fruits on the dry-wet series had hot increased in percentage moisture sufficiently to be on a level with fruits from the wet plots. There was an indication

TABLE XXXVII -- WATER CONTENT OF GULF STATE MARKET AND GLOBE TOMATO FRUITS AS AFFECTED BY IRRIGATION. FIELD, 1932. MATURE GREEN FRUITS. STEM END OVARY WALL TISSUE.

Variety and Treatment.	July 27th.	August 16th.	
	Non-Cracked.	Cracked.	Non-Cracked.
Gulf State Market (Wet)	94.37	93.85	93.56
Gulf State Market (Dry-Wet)*	--	92.24	91.67
Gulf State Market (Dry)	93.10	91.90	91.67
Globe (Wet)	94.06	93.49	93.82
Globe (Dry-Wet)	--	92.72	92.81
Globe (Dry)	93.07	92.71	92.00

*Changed from dry to wet on August 11th.

that some additional water had been taken in, since in two cases out of four the water content was higher than for the fruits from dry plots, and in the other two cases the percentages were almost identical. Yet in spite of the relatively low water content of fruits from the dry-wet series, they were then cracking more severely than fruits on the wet plots. Only stem end ovary wall tissue was used in these determinations. There is the possibility that changes may have been greater in other fruit parts, or that only the tissue distinctly local to the rupture itself may undergo an appreciable change in water content.

Further data relative to the water content of the fruit tissue will be presented in the following discussion of freezing point depressions.

Freezing Point Depression of Tomato Fruit Tissue

Since measurable differences in the percentage of water in the tissues have been shown after applying different amounts of water to the soil, it is not surprising that freezing point depression measurements have shown consistent differences. Table XXXVIII presents determinations made eight days after the change to the water treatments indicated.

Although differences are small, water content is high, and freezing point depressions low on ovary wall tissue of fruits from the high water treatments. No varietal comparison is possible here for reasons stated earlier.

TABLE XXXVIII -- EFFECT OF WATER TREATMENT ON WATER CONTENT AND FREEZING POINT DEPRESSION OF THE FRUIT. MATURE GREEN FRUITS. GREENHOUSE. DECEMBER 16th, 1931.

Treatment.	Water Content.		Freezing Point Depression.	
	Gulf State Market.	Globe.	Gulf State Market.	Globe.
Wet.	---	94.95	---	.602
Medium.	95.00	94.02	.606	.652
Dry.	94.59	93.94	.664	.670

Nineteen days following the beginning of the water treatments, more pronounced differences are seen.

TABLE XXXIX -- EFFECT OF WATER TREATMENT ON WATER CONTENT OF THE FRUIT AND FREEZING POINT DEPRESSION. GREENHOUSE. STEM END OVARY WALL TISSUE. EARLY PINK STATE OF MATURITY. DECEMBER 27th, 1931.

Water Treatment.	Water Content.		Freezing Point Depression.	
	Gulf State.	Globe.	Gulf State.	Globe.
High Water.	94.45	94.63	.621	.618
Medium Water.	94.11	92.80	.693	.832
Low Water.	93.16	91.99	.788	.900

The water content of the Globe fruits from medium water and low water treatments has become very low, which is, in turn, responsible for the high freezing point depressions. A comparison of the two varieties shows that the Gulf State Market fruits of the medium and low water treatments were appreciably the higher in water content and lower in freezing point depression. It is to be remembered that it was under these conditions that the Gulf State Market variety showed the greater percentage cracking. It appears that vines of this variety actually did receive more water which, in turn, was responsible for the behavior in cracking.

Regardless of what the water treatments may be, there are some fruits which crack and some which do not. Are the cracked fruits of the dry series relatively low in freezing point depression, as compared to non-cracked ones, and if so is it as low as cracked or non-cracked fruits from wet plots? Table XL shows that <u>cracked</u> fruits from dry plots are much higher in freezing point depression (and lower in water content) than are <u>non-cracked</u> fruits from the high water plots. A comparison of cracked and non-cracked fruits within a given treatment shows only very small differences. This is in line with numerous other moisture determinations on cracked and non-cracked fruits of a given treatment. It must be concluded, from the above table, that merely the presence of high water does not mean that the fruit will crack, nor does low water content necessarily indicate that it will not crack.

TABLE XL -- WATER CONTENT AND FREEZING POINT DEPRESSION OF CRACKED AND NON-CRACKED FRUITS FROM LOW AND HIGH WATER PLOTS. GREENHOUSE, JANUARY 1st, 1932. RED RIPE FRUITS. STEM END OVARY WALL TISSUE. SAMPLED ON DAY OF CRACKING. GULF STATE MARKET VARIETY.

Treatment.	Water Content.		Freezing Point Depression.	
	Cracked.	Non-Cracked.	Cracked	Non-Cracked.
Dry	93.66	93.95	.752	.767
Wet	95.00	94.75	.618	.631

Freezing point determinations on the greenhouse crop of 1932-1933 agreed with the above data as to the effect of soil moisture on water content of ovary wall tissue. (Table XLI). The dry and wet treatments were begun October 19th, and on November 27th, thirty-nine days later, fruits from the wet series were measurably higher in water content and lower in freezing point depression. The change from dry to wet treatment was begun December 5th and on December 12th it is noted that fruits from these dry-wet plots were much lower in water content than those from wet plots, yet slightly higher than those from dry plots. Again on December 21st, determinations show fruits from the wet series to be relatively high in water, as compared to those which had been changed from dry to wet

TABLE XLI -- WATER CONTENT AND FREEZING POINT DEPRESSION OF GULF STATE MARKET AND GLOBE TOMATO FRUITS FROM DRY, WET, AND DRY-WET PLOTS. EARLY PINK STAGE OF MATURITY. GREENHOUSE, 1932-1933.

Variety and Treatment.	Date.	Water Content.	Freezing Point Determinations.
Gulf State Market, Dry,	Nov. 27th	93.93	.658
Gulf State Market, Wet,	Nov. 27th	95.00	.591
Globe, Dry,	Nov. 27th	94.45	.638
Globe, Wet,	Nov. 27th	94.67	.569
Globe, Dry,	Dec. 12th	93.56	.640
Globe, Wet,	Dec. 12th	95.00	.487
Globe, Dry-Wet,	Dec. 12th	93.75	.574
Gulf State Market, Dry,	Dec. 21st	93.56	.688
Gulf State Market, Wet,	Dec. 21st	95.26	.511
Gulf State Market, Dry-Wet	Dec. 21st	94.13	.612
Globe, Dry,	Dec. 21st	93.34	.712
Globe, Wet,	Dec. 21st	94.90	.496
Globe, Dry-Wet	Dec. 21st	94.45	.570

sixteen days earlier. At this date, however, fruits from dry plots are considerably lower than those from the dry-wet treatment.

It is thus seen that fruits on vines given a low water supply, then plentifully supplied with water, cannot be expected to become high in water content of ovary wall tissue within the course of a few days. Yet, as with the field crop, in spite of the intermediate water content of their tissue, these fruits were cracking badly -- more than either of the other two lots. Again we must conclude that high water content (or low freezing point depression) does not necessarily mean that fruits will crack severely. With fruits from continued dry and continued wet treatments, of course, it is closely associated with occurrence of cracked fruits.

Hydrogen-Ion Concentration of Tomato Fruit Tissue

The influence which hydrogen-ion concentration has upon swelling of bio-colloids is well known. MacDougal's (1920) exhaustive studies on swelling of plant tissue and prepared disks of gelatine and agar is an outstanding contribution to the subject. The peculiarities of the tomato fruit, with respect to changes in its hydrogen-ion concentration during maturity, at once suggested the importance of a study of this factor as related to varietal susceptibility to cracking and as a possible explanation for cracking only at the stem end of the fruit.

Preliminary studies on the Bonny Best variety showed that the highest hydrogen-ion concentration is reached in fruits just as they begin to turn pink. As the fruit ripens, hydrogen-ion concentration decreases (p H increases). The green fruit is also relatively low in hydrogen-ion concentration. (Table XLII). If we may suppose that the high H-ion concentration of tomato tissue as it approaches the pink stage is favorable, relative to the iso-electric point, for increased swelling, then we would expect that at the slight

TABLE XLII -- pH OF TOMATO TISSUE (OVARY WALL) FROM STEM END AND FLOWER END OF FRUITS OF DIFFERENT STAGES OF MATURITY. BONNY BEST. COLLEGE PARK, 1931.

State of Maturity.	August 3rd		August 5th		August 9th	
	Stem End.	Flower End.	Stem End.	Flower End.	Stem End.	Flower End.
Green (Immature)	--	--	4.68	4.71	4.56	4.54
Slight Pink	4.39	4.27	4.40	4.26	4.37	4.27
Red Ripe	4.54	4.53	4.59	4.56	4.56	4.56

pink stage growth should be most rapid in the tomato fruit, brought about by the increased imbibition. Might not this, in turn, promote a high degree of cracking in the fruits? Gustafson's (1926) (1927) studies on growth of the tomato, as well as MacDougal's (1920), show it to follow a typical s-shaped curve. There has been no indication, in the present study, that cracking is more severe at the pink stage than in later stages of growth (red ripe), when hidrogen-ion concentration is decreased.

In comparing the hydrogen-ion concentration of the stem end and flower end of ovary wall tissue, it is noted (Table XLII) that for immature, green, and red ripe fruits, the values are similar. However, at the slight pink stage, hydrogen-ion concentration is consistently higher in the flower end. This was found to be invariably true in further determinations on the Gulf State Market and Globe varieties.(Table XLII-A)

Though these fruits are listed as mature green, when they were cut open, a faint pink color was apparent in the locule tissue, showing that they were very near the pink stage of maturity. The differences, though small, are consistent.

TABLE XLII-A -- HYDROGEN-ION CONCENTRATION OF STEM AND FLOWER END OF OVARY WALL TISSUE OF GULF STATE MARKET AND GLOBE TOMATO FRUITS. MATURE GREEN FRUITS. ARLINGTON, 1931.

Date.	Gulf State pH		Globe pH	
	Stem End.	Flower End.	Stem End.	Flower End.
August 31st, Cracked Fruits.	4.21	4.18	4.28	4.00
September 10th, Non-Cracked Fruit	4.27	4.18	4.20	4.18
September 14th, Non-Cracked Fruit	4.54	4.46	4.37	4.20

It is conceivable that this gradient in pH, characteristic of normal fruits as they begin to ripen on the vine, may have some connection with cracking. It results probably from a difference in ripening rate of the two ends of the tomato fruit, for the flower end usually turns pink first. Since no such gradient is present in ripe fruits, and so cannot be a factor in cracking of such fruits, there is doubt as to its value in promoting cracking of mature green or pink ones.

No consistent differences in the pH of fruits from high and low water plots have been found. Table XLIII gives a typical example of determinations made on fruits from the various water treatments. There is also no difference in the pH of the two varieties.

TABLE XLIII -- pH OF TOMATO FRUITS FROM DRY, WET, AND DRY-WET TREATMENTS. FIELD, 1932. MATURE GREEN FRUITS. STEM END OVARY WALL TISSUE.

Variety and Treatment.	pH	
	Cracked.	Non-Cracked
Gulf State Market, Dry	4.44	4.36
Gulf State Market, Wet	4.42	4.40
Gulf State Market, Dry-Wet	4.37	4.40
Globe, Dry	4.39	4.36
Globe, Wet	4.42	4.33
Globe, Dry-Wet	4.54	4.46

The following table gives pH values of red ripe fruits on the same cluster, one of which was cracked, the other one not cracked. There is no dvidence that cracked fruits are higher or lower in hydrogen-ion concentration. The conclusion seems justified that hydrogen-ion concentration of ovary wall tissue is not of importance in cracking of tomato fruits.

TABLE XLIV -- pH OF INDIVIDUAL RED RIPE TOMATO FRUITS. PAIRED FRUITS WERE ON SAME CLUSTER AND RIPENED ON THE SAME DAY.

Comparison Number.	Condition of Fruit.	pH
1	Non-cracked	4.37
	Cracked	4.30
2	Non-cracked	4.35
	Cracked	4.39
3	Non-Cracked	4.44
	Cracked	4.46
4	Non-Cracked	4.32
	Cracked	4.32
5	Non-Cracked	4.33
	Cracked	4.38

Chemical Composition in Relation to Cracking

Carbohydrate analyses: Analyses of field grown fruits of the two varieties are shown in Table XLV. There are no striking differences in total sugars or reducing sugars of fruits from the various water treatments, nor are there appreciable differences between cracked and non-cracked fruits. In most cases the Globe variety, which cracks the worse is slightly higher in total and reducing sugars than Gulf State, if the two are compared within a given treatment. These differences, however, are small.

Fruits from the wet plots are relatively low in acid hydrolyzable materials. This, together with the fact

TABLE XLV -- PARTIAL CHEMICAL COMPOSITION AND pH OF TOMATO FRUITS OF GULF STATE AND GLOBE VARIETIES FROM HIGH, LOW, AND LOW-HIGH WATER TREATMENTS CALCULATED ON DRY WEIGHT BASIS. AUGUST 16, 1932. FIELD COLLEGE PARK.

Variety	Water treatment	Cracking	Percent water	Total sugars	Reducing sugars	Sucrose	Acid Hydrolyzable materials
Gulf State Market	Wet	Cracked	93.58	48.3	45.9	2.4	9.7
Gulf State Market	Wet	Non-cracked	93.22	48.0	46.0	2.0	10.2
Globe	Wet	Cracked	93.54	49.5	47.8	1.7	10.4
Globe	Wet	Non-cracked	93.25	49.1	46.7	2.9	10.8
Gulf State Market	Dry	Cracked	91.82	48.2	45.8	2.4	11.5
Gulf State Market	Dry	Non-cracked	91.31	48.8	43.0	5.8	14.4
Globe	Dry	Cracked	92.63	49.1	46.9	2.2	11.1
Globe	Dry	Non-cracked	92.16	46.5	40.7	5.8	11.9
Gulf State Market	Dry-Wet	Cracked	92.06	44.8	42.3	2.5	13.1
Gulf State Market	Dry-Wet	Non-cracked	91.15	43.5	39.2	4.3	13.8
Globe	Dry-Wet	Cracked	92.45	45.3	41.1	4.2	13.6
Globe	Dry-Wet	Non-cracked	92.71	46.0	43.3	2.7	13.9

that in every case the cracked fruits are lower in acid hydrolyzable materials, suggests a possible relation between cracking and some material, whatever it may be, included in the acid hydrolyzable fraction. The difference, however, is not great enough nor the number of determinations sufficiently large to give very much weight to this relation. It was the primary purpose of the analyses to determine whether the two varieties, known to crack differently, showed appreciable differences in the carbohydrate constituents. They do not.

<u>Pectic Materials</u>: Appleman and Conrad (1927) have shown that as the tomato fruit ripens, protopectin is changed to pectin, with the ratio of $\frac{\text{pectin}}{\text{protopectin}}$ being, as a result, higher as the fruit turns red ripe. This change of protopectin to pectin no doubt plays an important part in the known susceptibility of red ripe fruits to crack more severely. Why, however, does the fruit crack on the stem end? Would it not be logical to suppose that this is the part of the fruit which remains highest in protopectin as ripening advances, since it is the last portion to develop a red color? Analyses for pectin and protopectin were made to determine whether such is the case, and to compare the pectic constituents of the two varieties. Compare, in the last two columns of Table XLVI, the ratio of $\frac{\text{pectin}}{\text{protopectin}}$ for the stem end and flower end of the fruit. Without exception, as we would expect, the ratio is highest for the flower end. Further, in comparing the percent of protopectin for the two ends of the fruit, we note

TABLE XLVI-- PECTIC CONSTITUENTS OF TOMATOES. GREENHOUSE, FALL, OF 1932. EARLY PINK STAGE OF MATURITY. DEC. 8, 1932. PERCENT DRY WEIGHT. OVARY WALL TISSUE.

Cracking and treatment	Variety	Pectin		Protopectin		Total Pectin		Ratio of: pectin / protopectin	
		Stem end	Flower end	Stem end	Flower end	Stem end	Flower end	Stem end	Flower end
High water (cracked)	Gulf State Market	3.43	3.69	3.32	2.04	6.75	5.73	1.033	1.809
	Globe	2.05	2.96	4.12	2.60	6.17	5.56	.498	1.116
High water (non-cracked)	Gulf State Market	2.83	3.03	2.75	2.19	5.58	5.22	1.029	1.383
	Globe	1.87	2.64	4.23	3.07	6.10	5.71	.442	.859
Low water (non-cracked)	Gulf State Market	2.99	2.66	3.61	2.89	6.60	5.55	.829	.920
	Globe	2.75	3.37	3.66	2.93	6.41	6.30	.751	1.150

the highest protopectin in the stem end. Theoretically this high protopectin content should aid in preventing a rupture of the tissue at this end, which is fails to do. Furthermore, there are marked differences in pectic constituents between the two varieties. The variety which cracks the more severely shows the lower pectin, higher protopectin and $\frac{\text{pectin}}{\text{protopectin}}$ ratio, which is just opposite to that one would expect if these constituents played an important part in cracking. In all cases, the total pectin is highest in stem end tissue.

SUMMARY

1. There is a difference in susceptibility to cracking among tomato varieties. Gulf State Market, although very similar in external characteristics to Globe, cracked less than the latter variety. The two varieties were used throughout the experiment.

2. Rain is effective in producing cracking within a few hours. The water is absorbed through the corky layer of the stem end, or may be taken in through small corky areas in the skin.

3. Heavy irrigation throughout the season induced more cracking than occurred in plats left dry. However, dry treatment, followed by continued heavy irrigation, produced more cracked fruits and larger cracking indices than heavy irrigation throughout the season. An increase in cracking was noted within three to six days after applying heavy irrigation to the dry series. It would be expected, therefore, that a prolonged period of rain following a dry spell would be most effective in producing severe cracking.

4. Behavior of fruits in the greenhouse was similar to that of those in the field, relative to water treatments. Cracking, however, is generally less severe under greenhouse conditions. Vigorous, well fertilized vines in the greenhouse produced fruits which cracked more than did fruits on vines grown the previous season with low nutrient supply throughout their growth.

5. A higher percentage of the first fruits on the cluster crack than third fruits. This is further evidence of a water relation. Moreover, less severe cracking of the third fruits on the cluster is most marked on dry plots.

6. Size of fruit, though it may play some part, is not a major factor in cracking. Fruits from continued wet treatments in the field, though larger, did not crack as severely as smaller fruits on the dry-wet plots.

7. Green fruits, at time of cracking, are less likely to crack severely than red ripe ones. Appearance of large cracks in red ripe green house grown fruits was earlier in high water plots.

8. First fruits on the cluster crack at an earlier age than do number three fruits on the cluster. Fruits from plants in high water plots cracked earlier than those on dry plots. The older the fruit becomes the greater is the probability that it will crack.

9, Tomato fruits may crack radially or concentrically. The former is the more common, especially under the greenhouse conditions of these experiments. Most of the cracks in tomato fruits,whether radial or concentric, appear at the stem end. Practically all of the radial cracks are connected with the corky layer of the stem end. Cracks radiating from the stem end are located mostly along creases which lie above or along the septae or interlocular walls. Initiation of radial cracking is usually within the corky ring itself. Under field conditions concentric cracking became prevalent late in the season. This type of cracking was always highest in the Globe variety. Field grown fruits of the Globe variety often possessed corky dots on the green area of the stem end, which through absorption of external moisture, may have promoted concentric cracking of this variety. Concentric cracking is less likely to occur in red ripe fruits than in green ones. Since concentric cracking may occur at different parts of the growing season, and at other ages of fruit than radial cracking occurs, there is reason to believe that it is caused by factors other than those responsible for the radial type of cracking.

10. Puncture tests made in the creases, on the locule, and on the flower end showed that the creases are inherently weak regions. It is within them that most of the radial cracks occur. In order to explain the low puncture test of the crease area, a study of skin thickness and type of underlying cells is needed.

11. Measurement of the increase in length of small lines marked on fruits showed that the stem end actually grew less than the flower end or side of the fruit, in spite of the fact that cracking normally occurs at that end. It is suggested that expansion when cracking occurs is entirely local.

12. Fruits absorbed water through the corky layer of the stem end. If the entire layer and point of attachment of the stem were paraffined, no increase in weight of fruit occurred, showing that water is not taken in through the

fruit skins. By using solutions of methylene blue it was possible to demonstrate that water is absorbed by the ovary wall through the small corky dots on the shoulders of fruits and the dye could be seen diffused into the tissue immediately beneath the skin. Dye is absorbed by many fruits mainly along the septae, and after remaining in the solution for two or three hours presents a distinct pointed pattern radiating from the corky layer. The points of the pattern lie on septae, along which cracking normally occurs.

13. It is probable that high temperatures, unless accompanied by rain, have little effect on cracking, since transpiration would tend to offset any gain in growth (or swelling) brought about by the increase in temperature. Fruits from plants shaded for long intervals show much smaller cracking indices than fruits from plants fully exposed to the sun, Whether the causal factor is temperature, direct effect of sun on cutin (photochemical effect) or is indirectly related to chemical composition as influenced by shading, is a matter of conjecture. Fruits exposed to the sun attain a much higher temperature than those shaded by the leaves of the plant.

14. Only ovary wall tissue was used in making chemical and bio-physical studies, since this is the tissue in which cracking occurs. The water content of stem end ovary wall tissue is generally from .3 to 1.0 percent higher than flower end tissue. This higher water content may partially explain the usual cracking at the stem end. Withholding water from the soil resulted in low water content

of the fruit tissue. Fewer of these fruits on dry plots, having low water in their tissues, cracked.

Though it was shown that cracking increased within three to six days after a change from dry to wet treatment, there was, in this space of time, only a very small change in water content of stem end ovary wall tissue. It was shown, in field and greenhouse grown fruits, that a sudden increase in water content of fruit tissue could not be expected by changing from low to high soil water. High water content of the fruit tissue does not necessarily mean that a fruit will crack, nor does a low water content mean that it will not crack.

Freezing point depressions were lowest in fruits from high water plots. No sudden lowering of freezing point depression is brought about by a change from low to high water treatment.

15. Highest hydrogen-ion concentration occurs in fruits just as they are beginning to turn pink. This sudden increase in hydrogen-ion concentration is accompanied by the first really marked tendency of fruits to crack. Although the hydrogen-ion concentration subsequently declines as the fruits attain red ripeness the tendency to crack does not decline, but rather becomes more severe. As the fruit begins to ripen, the hydrogen-ion concentration of stem end ovary wall tissue is consistently lower than that of the flower end ovary wall tissue. No appreciable difference in hydrogen-ion concentration is found between fruits from

high and low water treatments. The hydrogen-ion concentration of the two varieties studied was very similar. It was concluded that the pH of tomato tissue was not of great importance in cracking of the fruit.

16. The globe variety, which cracks the more badly, is slightly higher in total and reducing sugars than Gulf State Market. The differences appear too small to be of great importance, however.

Fruits from high water plots were low in acid hydrolyzable materials, as were cracked fruits of a given treatment. Although insufficient data were obtained to explain the significance of the high negative correlation between cracking and percentage of acid hydrolyzable substances, the very consistent and striking results appear to merit further consideration.

17. Protopectin is higher in ovary wall stem end tissue than in the stylar end when the fruit begins to ripen. In spite of this fact, cracking normally occurs at the stem end. The breaking down of protopectin, as the fruit ripens, is suggested as one of the reasons why cracking indices of red ripe fruits are relatively larger than of less mature fruits.

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Approved Victor R. Boswell

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