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The University of Minnesota
Agricultural Experiment Station

Comparison of First Generation Tomato Crosses and Their Parents

By Richard Wellington
Division of Horticulture

UNIVERSITY FARM, ST. PAUL

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ILLUSTRATIONS

COMPARISON OF FIRST GENERATION TOMATO CROSSES AND THEIR PARENTS

By Richard Wellington[1]

INTRODUCTION

The crossing of closely related varieties of plants and animals is known to produce individuals which are larger and more vigorous and more prolific than either parent. However, little is known as to the frequency of their occurrence and their value in agricultural pursuits. In order to determine whether first generation tomato crosses were superior to their parents, and if so, whether certain crosses were more valuable than others, experiments were carried on from 1909 to 1919, inclusive, at University Farm, St. Paul.

REVIEW OF PREVIOUS STUDIES ON FIRST GENERATION TOMATO CROSSES

Hedrick and Booth (1907) noted that first generation hybrid tomatoes were much more vigorous and productive than their parent varieties and suggested that such crosses might have marketable value. The writer (1912) proved that this assumption was correct in the case of crosses between Dwarf Aristocrat and Hedrick and Stone.

East and Hayes (1912) reported that the cross between Golden Queen and Sutton's Best of All outyielded both parents.

Gilbert (1912) also noted that F_1 hybrids between a standard and a dwarf not only resembled the tall parent, but were a little taller and more vigorous.

Groth (1911), who made an extensive study of the size inheritance of F_1 generation tomato foliage, found that "Practically all characters studied tend to exceed the mean between the values of the parents, in the F_1 of the cross, so that the leaves of the cross tend to be longer, narrower, and possess a greater number of segments than the

[1] The test of first generation crosses was begun at the Minnesota Agricultural Experiment Station in 1909 by A. R. Kohler, and the results of his work from 1911 to 1913, inclusive, have been included in the text, as have also the results reported in 1914 by R. C. Rose in his work on this problem, as a graduate thesis. The work in 1919 was conducted by Miss Hemstead (now Mrs. J. M. Bushnell), who deserves full credit for the results obtained during that season. The author wishes to acknowledge the conscientious and painstaking work of numerous student assistants, and of the horticultural foreman, Fred Haralson, for their assistance in crossing and selfing plants and collecting and collaborating data; and to G. W. Krogh for making graphs, T. W. Horton for photographs, and F. A. Krantz for his assistance in collecting, checking, and tabulating data.

mean between the values for the parents or even than either of the parents themselves. In other words, the crosses tend to be more vigorous than the parents." Later, in his report on the inheritance of size and shape of fruits (1912 and 1915), he states, "The size and shape of the F_1 crosses between ±round fruits are the geometric means of parental sizes and shapes."

Perry (1915) took issue with Groth and states that his explanation would be more tenable if the tomato fruits were perfect spheres, for irregularity of shape is liable to cause considerable error. He thought that the size of fruits could be better obtained from weights than from linear dimensions and in his investigations he found the size of the F_1 generation of the currant-pear cross to be the geometrical mean between the sizes of its parents. This phenomenon was thought to hold only when the fruit of the parents differed greatly in size, for when parents produced fruit of similar size, he thought their progeny would produce fruit approaching the arithmetical mean. As he based his opinions on weights obtained from a small number of plants, and only a portion of the fruit selected from each plant, his conclusions require further confirmation before final acceptance.

Hood (1915) noted seven F_1 standard × dwarf crosses which outyielded their parents in weight and number of fruits. The standard plants of the F_2 and F_3 generations, however, yielded less fruit than those of the F_1 generation. Increased vigor and thriftiness were also noted in the crosses.

Von Tschermak (1916), in discussing tomato breeding investigations, mentioned that in 1914 at Eisgrub an F_1 generation cross between Ficarrazzi and Cooper's First Crop gave over 1 kg. of fruit per plant more than the parents. Other crosses gave no increase, or at least not in this amount. The explanation of the negative results was that they were probably due to the same causes noted by Shull and East in maize, that is, to the lack of heterozygous elements in the crosses.

Stuckey (1916) in his report on blossom-end rot investigation, stated that the first generation cross between Red Cherry and Greater Baltimore gave a higher yield of fruit than any of the fourteen varieties with which it was compared. From the figures given, this cross produced 48.52% more marketable fruit before June 30 than Earliana, the earliest of the varieties.

Hayes and Jones (1916) proved that "Continuous self-fertilization during periods of three and four years in four commercial varieties of tomatoes did not cause any significant decrease in the size or yield of fruit, but merely resulted in isolating, in the first year, types which varied either above or below the original unselected varieties in this character," and further that "Vigor due to crossing as measured by increased yields was not appreciably greater in crosses between artificially selfed strains than in crosses between ordinary commercial varieties." These results were explained as due to the fact that the tomato is almost completely self-fertilized. In the crosses Stone × Dwarf Champion and Lorillard × Best of All there were obtained respectively 8 and 3% average increase in weight per fruit over the parental average. The Stone × Dwarf Champion cross also gave an 8% increase in the the average number of ripe fruits over the average of the parents, and approached the fruit number of the better parent, while the Lorillard × Best of All cross gave no increase.

Through four years the Stone × Dwarf Champion cross gave an increased yield, varying from 11 to 17% over the higher yielding parent. Lorillard × Best of All cross did not, on the other hand, exceed the better parent in yield, altho it did out-yield the average of the parents. The Stone × Dwarf Champion cross ripened its fruit earlier than the earlier parent, and thus the authors concluded that "hybrid vigor effects a result directly opposite to favorable environmental conditions which tend to delay maturity."

EXPERIMENTAL INVESTIGATIONS AND MATERIAL

The comparison of first generation tomato crosses at the Minnesota station was begun in 1909 by A. R. Kohler. Data collected during the first two years were preliminary in nature and are therefore not published; nevertheless they indicated the value of F_1 generation crosses and the advisability of continuing the experimental work on a more extensive and more exact scale. From 1911 to 1913, inclusive, a large number of F_1 crosses were tested, but as only seven plants of each cross were planted and no effort was made to grow the parents from self-fertilized seed or near their crosses, the data for each cross are not given. However, the average performance of all the crosses during each season has been calculated and is discussed under the next topic.

The most promising and unpromising crosses grown in 1913 were selected by R. C. Rose for testing in 1914. Seed of the varieties and crosses was produced during the winter in the greenhouse. About June 1 three rows of thirty plants each of the F_1 crosses and their parents were set out. Wherever possible the F_1 plants and their parents were planted in contiguous rows. Similar methods of procedure in securing seed and planting were followed from 1915 to 1919, except that most of the crosses and selfed plants were produced from known individuals and that fewer plants were grown, about twenty-five of each cross and parent being grown from 1915 to 1918 and six in 1919.

The method of growing the plants each year was similar to that practiced by many commercial growers in the northern states, that is, the seed was sown about the first week in April in flats in the greenhouse, and when the seedlings began to develop their true leaves, they were potted in two-inch pots. Later the plants were transferred to four-inch pots and after danger of frost, about May 30, were set in the field. A guard row was always planted around the entire field in order to give each plant the same amount of space, 5 by 5 feet.

PRELIMINARY WORK FROM 1911 TO 1913, INCLUSIVE

From 1911 to 1913, inclusive, 130 first-generation tomato crosses were grown and compared with their parents, but for reasons already stated the performance of each individual cross is not given. The results obtained during this period are given in Table I.

TABLE I

COMPARISON OF YIELDS OF F_1 GENERATION CROSSES AND THEIR PARENTS, 1911-1913, INCLUSIVE

Year	No. of crosses tested		Average yield per plant of parents, lbs.		Average yield per plant of F_1 crosses, lbs.		Per cent increase in yield of F_1 crosses over average yield of parents		
	D.×S.*	S.×S.	D.	S.	D.×S.	S.×S.	D.×S.	S.×S.	All crosses
1911	19	..	6.39	13.44	16.24	....	63.63	....	63.63
1912	18	13	6.81	12.04	18.75	20.77	98.83	95.49	97.43
1913	18	62	13.95	26.24	31.21	31.03	44.13	11.57	18.89

*D=Dwarf. S=Standard.

DISCUSSION OF TABLE I

In 1911 all the crosses were between dwarf and standard varieties, while in 1912 and 1913 part of the crosses were between dwarfs and standards, and part between standards and standards. Since the dwarfs yielded about half as much fruit as the standards and the first generation cross between dwarfs and standards yielded approximately the same as crosses between standards and standards, the increase in yield of first generation crosses between dwarf and standard varieties over the average yield of their parents was greater than that of crosses between standard varieties over the average yield of their parents. The data obtained in 1912 and 1913 which substantiate this statement are as follows: The percentage increase in 1912 of dwarfs × standards over the average yield of their parents was 98.83%, and of standards × standards, 95.49%; and in 1913, 44.13% and 11.57%, respectively. The total percentage increase of all crosses over the average yield of their parents was 63.63% in 1911, 97.43% in 1912, and 78.89% in 1913.

INFLUENCE OF CROSSING UPON EARLINESS, NUMBER OF FRUITS, SIZE OF FRUITS, AND TOTAL PRODUCTION

From 1914 to 1919, inclusive, 60 first generation tomato crosses were compared with their parents. These crosses were derived from 14 varietal combinations. The number of times each variety was used in the crosses is as follows: Earliana 24, Bonny Best 16, Chalk Early Jewel 14, Stone 13, Beauty 10, My Maryland 10, June Pink 9, Dwarf Aristocrat 6, John Baer 5, Globe 5, Comet 4, Dwarf Champion 2, Buck Tresco and New Globe 1 each.

In 1914 the fruit was weighed but not counted, while in 1915, 1916, 1917, 1918, and 1919 it was both weighed and counted. The date of each picking was recorded, hence it has been possible to divide the crop into early, midseason, and late, and thus determine the effect of crossing upon earliness.

PERCENTAGE OF TOTAL NUMBER OF FRUITS RIPENED PER PLANT OF THE F_1 CROSSES AND THEIR PARENTS

(See first section of Table II.)

In order to determine whether the F_1 crosses ripened a greater proportion of their fruits than their parents, the percentage of the total number of fruits which ripened per plant was calculated. The crosses on the average did not ripen as many fruits as the higher parent, for only 21 out of the 60 surpassed the higher parent. The results obtained each season are as follows: In 1914, 4 out of 13 crosses ripened a greater proportion of their fruit than the higher parent; in 1915, 7 out of 24 surpassed the higher parent; in 1916, none of the crosses surpassed the higher parent; in 1917, 7 of the 9 crosses ripened a greater proportion of their fruit than the higher parent; while in 1918, 1 out of 4, and in 1919, 2 out of 3 ripened a greater proportion of their fruit than the higher parent.

PERCENTAGE INCREASE IN NUMBER OF RIPE AND GREEN FRUITS PRODUCED BY FIRST-GENERATION PLANTS OVER MEAN OF PARENTS AND HIGHER PARENT

(See second section of Table II.)

Crossing of varieties, however, caused a definite increase in the number of fruits produced, that is, when measurement is based upon mean of parents. In 1915, 17 out of 24 of the crosses produced more fruits than the mean of their parents; while in 1916, 1917, 1918, and 1919 the proportions were 7 to 7, 6 to 9, 4 to 4, and 2 to 3, respectively.

TABLE II

Influence of Crossing upon Earliness, Number and Size of Fruits, and Total Production

Cross	Percentage of total number of fruits ripened per plant			Percentage increase in number of ripe and green fruits produced by F_1 plant over		Percentage increase in size of individual ripe fruits of F_1 plants over		Percentage increase in total productivity by weight of F_1 plants over	
	Female	Male	F_1	Mean of parents	Higher parent	Mean of parents	Higher parent	Mean of parents	Higher parent
1914									
Beauty × Chalk Early Jewel*	82.7	86.6	88.7	...	...	...	...	19.2	12.1
Beauty × June Pink	82.7	97.4	93.8	...	...	...	...	29.7	15.5
June Pink × Beauty	97.4	82.7	97.5	...	...	...	...	33.0	17.6
Bonny Best × Globe	89.7	66.4	82.3	...	...	...	...	31.6	16.5
Chalk Early Jewel × Earliana	86.6	97.1	96.6	...	...	...	...	28.0	21.7
Earliana × Chalk Early Jewel	97.1	86.6	97.3	...	...	...	...	8.5	7.6
Chalk Early Jewel × Stone	86.6	60.6	78.8	...	...	...	...	14.8	1.4
Dwarf Aristocrat × Earliana	66.5	97.1	91.2	...	...	...	...	99.6	25.1
Dwarf Champion × Stone	68.8	60.6	67.0	...	...	...	...	44.3	3.5
Earliana × Dwarf Champion	97.1	68.8	96.0	...	...	...	...	83.0	18.3
Earliana × My Maryland	97.1	62.2	94.8	...	...	...	...	30.7	15.7
My Maryland × Bonny Best	62.2	89.7	83.7	...	...	...	...	—0.7	—16.0
My Maryland × Globe	62.2	66.4	79.7	...	...	...	...	38.0	9.6
1915									
Beauty × Chalk Early Jewel†	26.0	24.1	26.8	4.6	—1.3	9.4	—1.2	13.5	4.1
Chalk Early Jewel × Beauty	24.1	26.0	33.1	—7.4	—11.4	—3.8	—15.0	4.1	—4.6
Beauty × Earliana	20.7	73.2	71.0	11.4	—5.6	—13.6	—32.8	0.9	—35.8
Beauty × June Pink	32.4	21.5	24.1	—19.7	—27.2	8.2	4.6	—5.4	—11.1
Beauty × My Maryland	16.4	20.1	21.5	—2.3	—16.0	9.6	—13.6	16.3	13.4
Bonny Best × June Pink	65.6	74.9	84.9	28.1	24.7	—22.8	—45.4	5.9	—6.1
Bonny Best × My Maryland	56.8	16.9	34.2	21.6	—1.8	16.3	1.8	32.2	6.8

Bonny Best × Stone	67.9	17.5	42.2	4.1	—6.8	—8.2	—75.2	9.3	—10.5
Stone × Bonny Best	17.5	67.9	31.0	13.1	0.2	—3.2	—18.8	12.0	—7.9
Chalk Early Jewel × Bonny Best	21.7	76.7	49.3	12.6	4.4	12.7	1.8	19.0	10.7
Chalk Early Jewel × Earliana	24.6	71.3	70.1	31.5	11.8	—6.1	—6.9	24.7	—2.0
Chalk Early Jewel × June Pink	29.3	21.5	32.1	—4.1	—9.8	7.5	0.7	6.5	1.9
Chalk Early Jewel × My Maryland	22.4	14.9	15.9	—9.4	—12.0	1.3	—5.6	—0.1	—7.3
Dwarf Aristocrat × Stone	20.8	17.5	17.7	19.8	8.6	3.7	—26.9	53.1	23.5
Dwarf Aristocrat × Bonny Best	34.0	83.4	56.8	64.6	30.2	21.0	5.9	79.9	25.6
Earliana × Dwarf Aristocrat	71.3	29.4	65.4	89.6	56.5	—8.3	—25.6	74.8	13.8
Earliana × Globe	65.0	16.2	68.2	—5.6	—9.2	18.7	52.2	—4.1	—10.2
Earliana × My Maryland	80.0	20.1	58.5	30.3	10.8	—17.8	—50.6	26.5	4.3
Globe × Dwarf Aristocrat	25.6	33.0	39.9	55.6	15.0	3.1	—24.3	75.9	15.9
My Maryland × Dwarf Aristocrat	17.0	26.3	17.9	52.5	28.7	4.3	—23.0	73.3	24.3
Stone × Beauty	20.4	70.0	60.7	49.8	14.5	15.5	—39.2	44.6	6.2
Stone × Earliana	30.4	86.4	76.7	56.0	23.8	—21.9	—42.2	31.0	5.5
Stone × June Pink	19.4	74.9	59.0	61.6	26.8	—17.0	—40.3	49.6	15.1
Stone × My Maryland	—21.4	39.2	30.2	—20.5	—25.0	1.3	2.6	—18.9	—48.2
1916									
Bonny Best × Earliana†	51.3	76.4	55.9	40.6	32.2	—14.0	—31.3	15.0	8.2
Bonny Best × June Pink	45.4	70.8	54.9	54.5	39.8	—27.1	—55.2	12.8	8.5
Chalk Early Jewel × Bonny Best	37.9	48.0	38.9	14.7	2.4	9.2	3.6	10.6	—0.1
Chalk Early Jewel × Earliana	27.2	63.9	48.4	59.8	59.4	—16.3	—27.0	37.3	20.5
John Baer × Earliana	51.9	76.4	59.9	58.8	63.8	—27.6	—49.7	13.3	11.3
Stone × Earliana	28.3	71.8	49.2	99.4	77.9	—24.2	—37.9	44.3	14.9
Stone × June Pink	11.1	70.8	43.5	73.4	51.8	—19.8	—42.8	43.8	11.2
1917									
Bonny Best × Comet†	62.6	46.4	54.8	19.9	7.6	0.0	—12.7	19.3	13.9
Bonny Best × Earliana	77.4	57.4	87.2	—7.2	—23.5	—13.6	—17.0	—8.5	—20.5
Bonny Best × Earliana	61.3	57.4	94.3	5.2	—15.0	—26.8	—43.5	—3.5	18.1
Buck Tresco × Earliana	14.6	54.2	67.1	50.7	31.0	—17.4	—59.4	55.0	24.0

TABLE II—*Continued*

INFLUENCE OF CROSSING UPON EARLINESS, NUMBER AND SIZE OF FRUITS, AND TOTAL PRODUCTION

Cross	Percentage of total number of fruits ripened per plant			Percentage increase in number of ripe and green fruits produced by F_1 plant over		Percentage increase in size of individual ripe fruits of F_1 plants over		Percentage increase in total productivity by weight of F_1 plants over	
	Female	Male	F_1	Mean of parents	Higher parent	Mean of parents	Higher parent	Mean of parents	Higher parent
Comet × Earliana	40.8	67.5	71.4	21.5	—2.6	—17.5	—45.5	4.2	—0.3
Globe × Comet	53.1	34.4	56.6	22.8	—16.5	—13.6	—61.2	29.4	19.7
John Baer × Earliana	71.2	70.4	91.7	23.6	—4.2	—17.7	—68.0	9.7	0.2
John Baer × Earliana	77.4	70.4	88.5	0.0	—10.6	—17.3	—42.9	—0.5	—0.7
John Baer × Comet	84.2	30.4	69.5	—6.4	—71.4	—8.4	—37.6	—3.3	—7.9
1918									
My Maryland × June Pink†	16.8	66.3	41.2	51.8	24.2	—1.9	—3.4	46.8	20.8
Beauty × Stone	58.7	12.4	32.6	62.2	41.9	—1.0	—11.1	47.3	29.3
Chalk Early Jewel × Stone	35.1	14.6	23.9	13.9	—11.5	6.4	3.0	22.7	0.1
John Baer × Earliana	35.7	45.7	58.7	11.9	12.1	—29.1	—38.4	3.7	4.5
1919									
Bonny Best × Chalk Early Jewel‡	76.5	82.2	86.5	—12.3	—38.1	20.8	9.2	12.5	1.7
Bonny Best × Earliana	94.0	96.0	96.6	17.6	13.8	—16.7	—33.3	—0.1	—6.9
New Globe × Earliana	36.8	96.0	81.4	22.2	—2.7	—26.4	—52.1	1.5	—17.7

* Thirty plants each of the F_1 plants and their parents were set out.

† Twenty-five plants each of the F_1 plants and their parents were set out.

‡ Data taken on 6 plants of the F_1 plants and their parents.

The increase over the higher parent was less consistent, altho over half the crosses produced more fruits than the higher parent. The proportion of the crosses which have produced more fruit than the higher parent for the respective years is as follows: 1915, 13 to 24; 1916, 7 to 7; 1917, 2 to 9; 1918, 3 to 4; and 1919, 1 to 3.

PERCENTAGE INCREASE IN SIZE OF INDIVIDUAL RIPE FRUITS OF F_1 PLANTS OVER MEAN OF PARENTS AND HIGHER PARENT

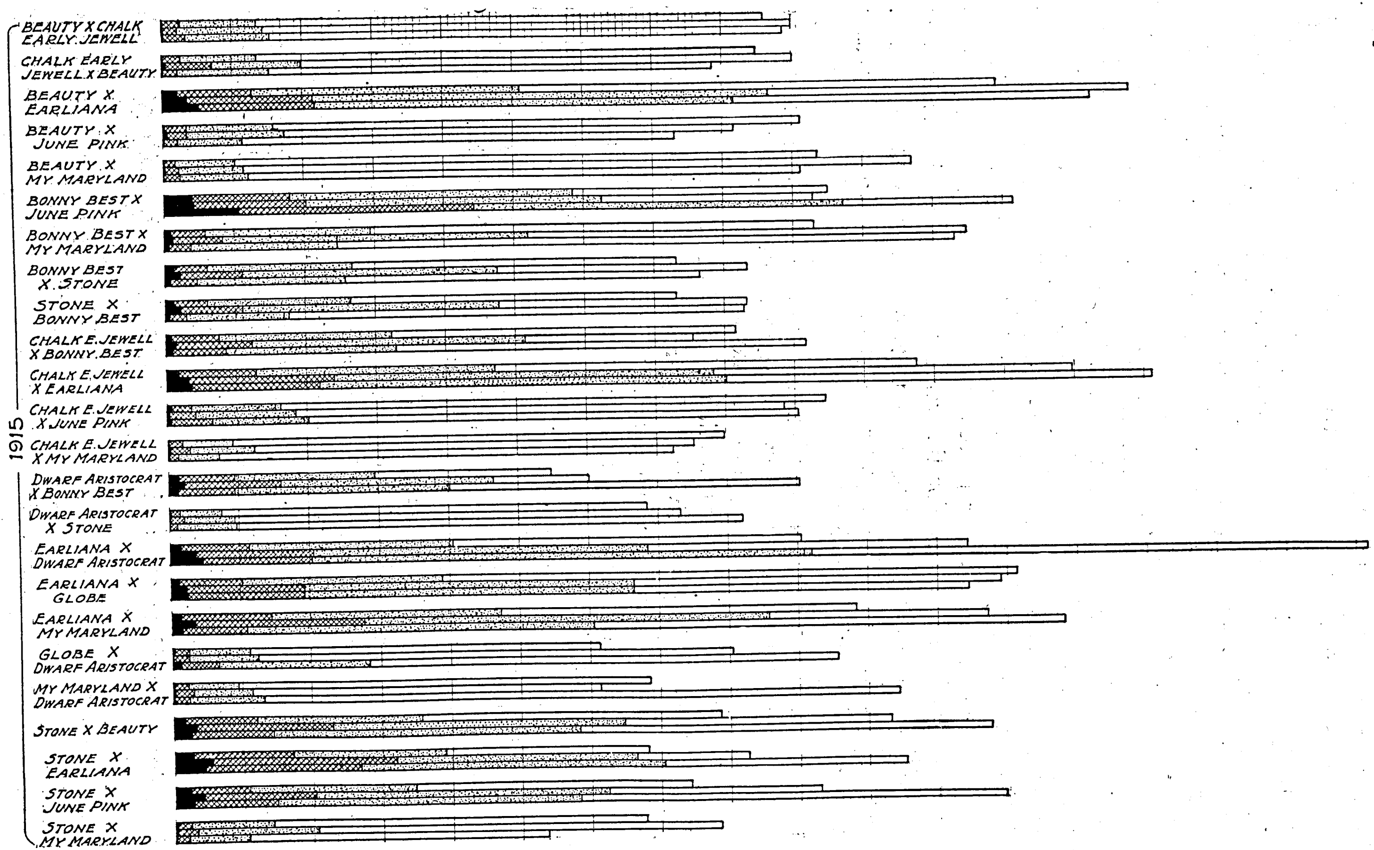
(See third section of Table II.)

As would naturally be expected the increase in number of fruits per plant caused a decrease in size of the ripe fruit. This decrease in size was most marked in those years when the increase in number of fruits was the greatest, namely 1916 and 1917. The proportion of crosses which gave a higher percentage increase in size of ripe fruits over the mean of parents for the years 1915 to 1919, inclusive, was respectively as follows: 14 to 24, 1 to 7, 0 to 9, 1 to 4, and 1 to 3. With the exception of 1915, these proportions held when the crosses were compared with the higher parent.

PERCENTAGE INCREASE IN TOTAL PRODUCTION OF RIPE AND GREEN FRUITS BY WEIGHT OF F_1 PLANTS OVER MEAN OF PARENTS AND HIGHER PARENT

(See fourth section of Table II.)

The increase in productivity of F_1 crosses over their parents has been marked during the whole experiment. In 1914, 12 of the 14 crosses gave more fruit than the mean of their parents and the higher yielding parent; in 1915, 20 of the 24 crosses gave more fruit than the mean and 14 more than the higher parent; in 1916, all 7 crosses produced more fruit than the mean and 6 more than the higher parent; in 1917, 5 of the 9 crosses gave more fruit than both the mean of parents and higher parent; in 1918, all the crosses outyielded the parental mean and higher parent; while in 1919, 2 outyielded the mean of the parents and 1 the higher parent. The percentage of increase for the same cross has fluctuated more or less during different seasons and within the same season. For example, Chalk Early Jewel × Earliana gave increases over the mean of parents and higher parent of 28.0% and 21.7%, respectively, in 1914; of 24.7% and —2.0% in 1915; and 37.3% and 20.5% in 1916; while the reciprocal cross gave increases of 8.5% and 7.6% in 1914. Again, John Baer × Earliana gave increases of 13.3% and 11.3% in 1916; 9.7%, and 0.2%, and —0.5% and —0.7% in 1917; and 3.7% and 4.5% in 1918. These variations may have been partly due to a difference in varietal strains used in the production of the crosses and partly to experimental error that is bound to occur in field experiments. It is evident that the merit of a first generation cross must be determined by its performance over a series of years.


1915
BEAUTY X CHALK EARLY JEWELL
CHALK EARLY JEWELL X BEAUTY
BEAUTY X EARLIANA
BEAUTY X JUNE PINK
BEAUTY X MY MARYLAND
BONNY BEST X JUNE PINK
BONNY BEST X MY MARYLAND
BONNY BEST X STONE
STONE X BONNY BEST
CHALK E. JEWELL X BONNY BEST
CHALK E. JEWELL X EARLIANA
CHALK E. JEWELL X JUNE PINK
CHALK E. JEWELL X MY MARYLAND
DWARF ARISTOCRAT X BONNY BEST
DWARF ARISTOCRAT X STONE
EARLIANA X DWARF ARISTOCRAT
EARLIANA X GLOBE
EARLIANA X MY MARYLAND
GLOBE X DWARF ARISTOCRAT
MY MARYLAND X DWARF ARISTOCRAT
STONE X BEAUTY
STONE X EARLIANA
STONE X JUNE PINK
STONE X MY MARYLAND

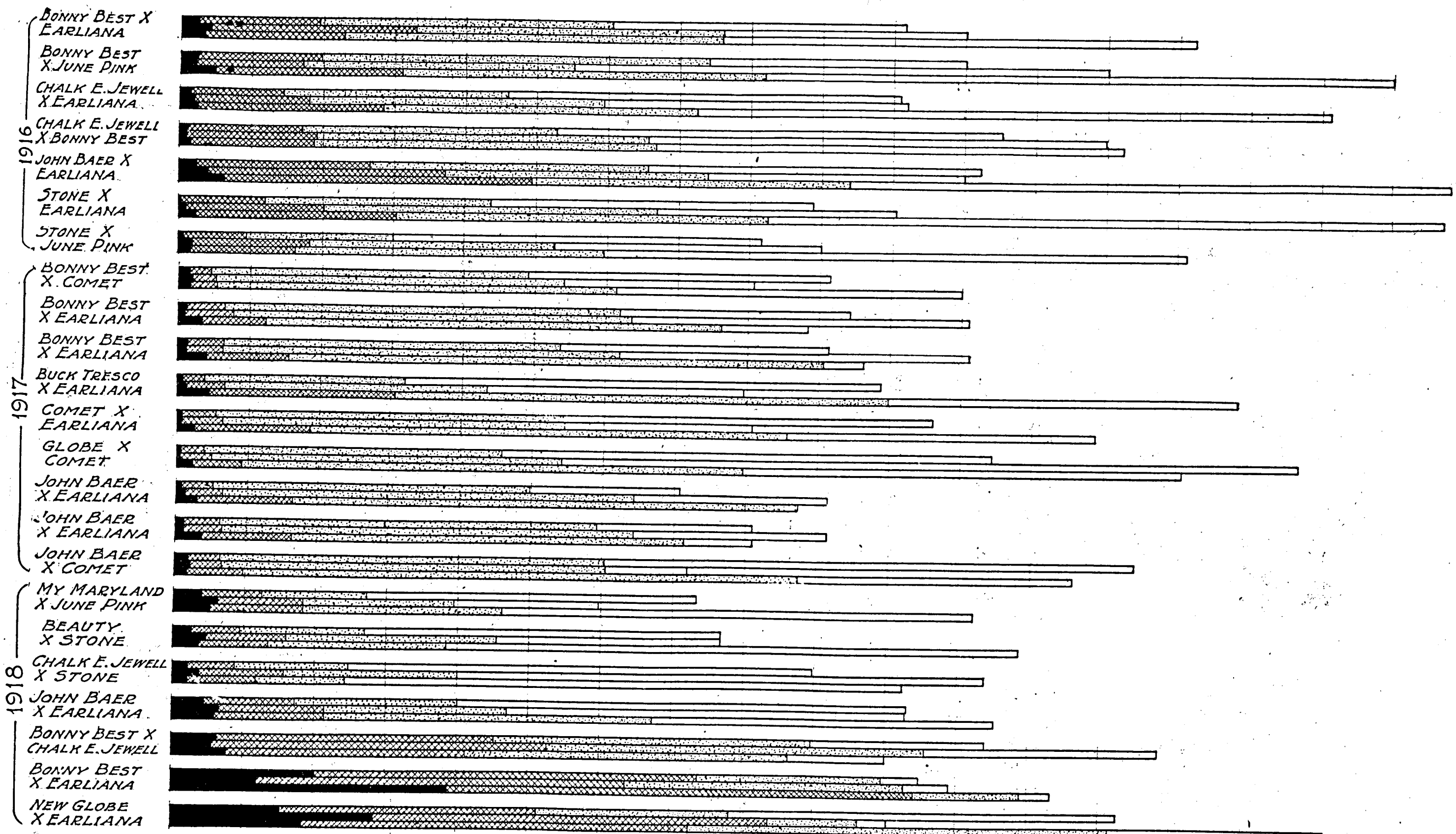


Fig. 1. Number of Ripe and Green Fruits Produced per Plant by Means of Parents, Higher Yielding Parents, and F_1 Cross

The fruits ripening in the early part of the season are designated by a solid marking, in midseason by cross-hatching, in late season by stippling, and green fruits by blank bars. The upper line of each cross represents the mean of the parents, the middle line the higher yielding parents, and the lower line the first-generation cross. It is readily seen that the first-generation crosses having Earliana or its close relative, June Pink, for one parent, have made the most marked increase over the mean of the parents and the higher yielding parent.

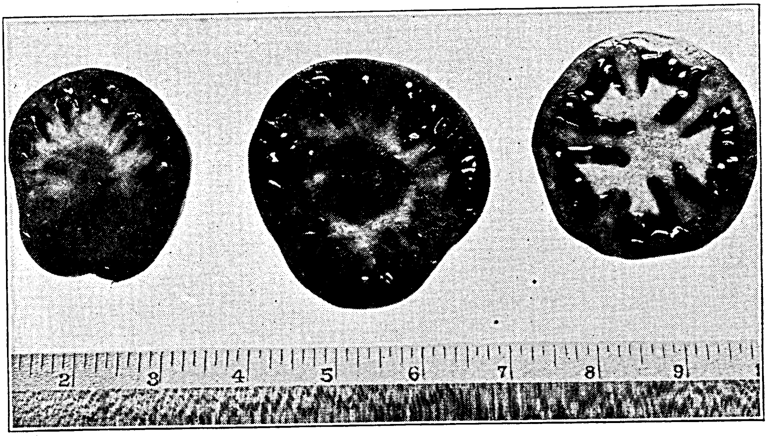


Fig. 2. Fruit of Earliana

Few or no seed in cells of the two Earliana fruits to the left are correlated with their irregular shape.

INFLUENCE OF CROSSING UPON EARLINESS AS INDICATED BY INCREASE IN PRODUCTION OF RIPE FRUIT

(Calculated in pounds per acre for early, midseason, and late season varieties.)

In order to determine the effect of crossing upon earliness, as the crosses seemed often to ripen earlier than either parent, the season was divided into three parts: early, midseason, and late, and the crop was calculated separately for each part. (See Table III.) The data are arranged in two main sections in order to show (1) the increased yield over the mean of parents and (2) the increased yield over the higher parent. The second section is of particular interest to the grower, for if the cross is less productive than the higher parent its value is nil, that is, from the yield standpoint. Yield, however, is not the only character of a commercial fruit. Smoothness is also a desirable character of first generation crosses, as is indicated later.

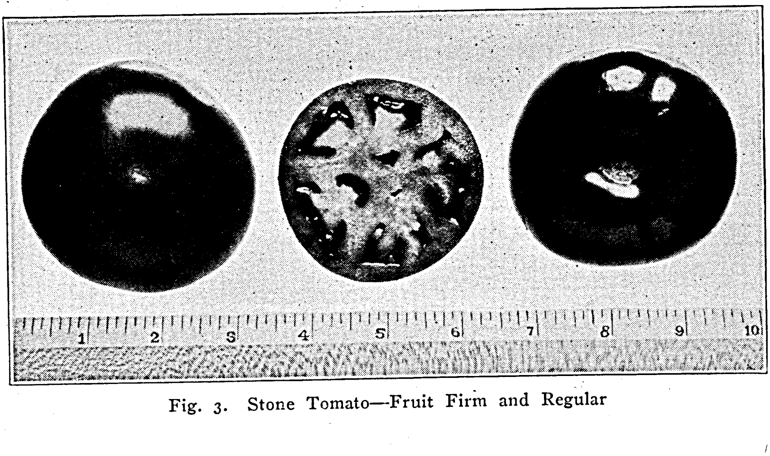


Fig. 3. Stone Tomato—Fruit Firm and Regular

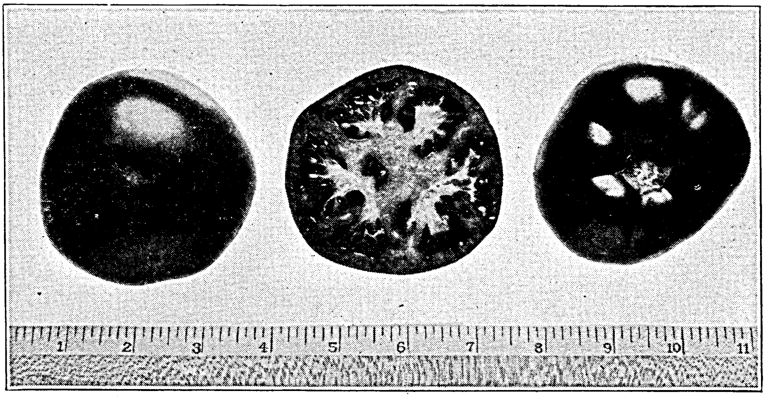


Fig. 4. Stone × June Pink F_1
The fruit is firmer and more regular than the male parent.

In 1915, the crosses ripened more fruit than the mean of the parents in the following proportions: 14 to 20 in early season, 17 to 24 in mid-season, 19 to 24 in late season, and 18 to 24 in the total season. In 1916, the proportions for the same respective seasons were 5 to 6, 6 to 7, 5 to 7, and 7 to 7. In 1917, the proportions were 8 to 9, 9 to 9, 7 to 9, and 9 to 9. In 1918, the proportions were 3 to 4, 4 to 4, 3 to 4, and 4 to 4; while in 1919 the proportions were 3 to 3, 2 to 3, 2 to 3, and 3 to 3. Summarizing the performance of the crosses for the five years, we find 33 gave an increase and 9 a decrease in the early part of the season, 38 an increase and 9 a decrease in midseason, 36 an increase and 11 a decrease in late season, and 41 an increase and 6 a decrease in the season as a whole. The evidence thus strongly supports the statement that crossing tomatoes hastens the maturity of the fruit.

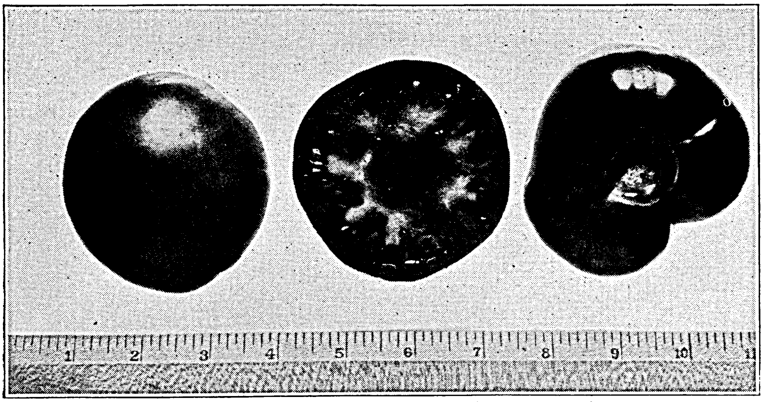


Fig. 5. June Pink—Fruit Soft and Irregular

TABLE III

Influence of Crossing upon Earliness as Indicated by Increase in Production of Ripe Fruit, Calculated in Pounds per Acre for Early, Mid-Season, and Late

Cross	Increase in pounds per acre of F_1 plants over mean yield of parents				Increase in pounds per acre of F_1 plants over yield of higher parent			
	Early	Mid-season	Late	Total	Early	Mid-season	Late	Total
1915								
Beauty × Chalk Early Jewel	—17.4	348.5	906.1	1,237.1	17.4	69.7	871.2	958.3
Chalk Early Jewel × Beauty	87.1	1,568.2	505.3	2,160.6	122.0	1,289.4	470.5	1,881.8
Beauty × Earliana	731.8	1,324.2	4,024.9	5,993.9	—69.7	—2,387.1	—9,199.9	—11,656.7
Beauty × June Pink	—156.8	—209.1	—453.0	—818.9	—226.5	—453.0	—1,324.2	—2,003.8
Beauty × My Maryland	0.0	383.3	1,533.3	1,916.6	—17.4	278.8	1,132.6	1,393.9
Bonny Best × June Pink	1,951.5	5,453.7	—331.1	7,074.1	1,690.1	3,850.7	—3,362.8	2,178.0
Bonny Best × My Maryland	87.1	—522.7	1,603.0	1,167.4	156.8	—1,725.0	—5,854.5	—7,736.3
Bonny Best × Stone	—104.5	—592.4	156.8	—540.1	—522.7	—2,317.3	—7,684.0	—10,524.1
Stone × Bonny Best	—191.7	—1,341.7	—2,334.8	—3,868.1	—609.8	—3,066.6	—10,175.6	—13,852.1
Chalk Early Jewel × Bonny Best	—122.0	296.2	2,596.2	3,014.4	—87.1	—1,237.1	—2,247.7	—3,571.9
Chalk Early Jewel × Earliana	993.2	2,909.8	9,252.1	13,155.1	331.1	—1,254.5	—383.3	—1,306.8
Chalk Early Jewel × June Pink	0.0	1,515.9	906.1	—2,421.9	—69.7	1,272.0	—191.7	1,010.6
Chalk Early Jewel × My Maryland	0.0	—261.4	—453.0	—714.4	0.0	—557.6	—1,428.8	—1,986.3
Dwarf Aristocrat × Bonny Best	122.0	—139.4	5,384.0	5,366.6	—52.3	2,700.7	1,341.7	—1,411.3
Dwarf Aristocrat × Stone	52.3	156.8	1,411.3	1,620.4	69.7	87.1	1,150.0	1,306.8
Earliana × Dwarf Aristocrat	801.5	1,637.9	13,311.9	15,751.3	52.3	—1,846.9	3,781.0	1,986.3
Earliana × Stone	644.7	3,903.0	7,143.8	11,891.5	278.8	1,080.3	479.5	1,829.5
Earliana × My Maryland	0.0	—1,289.4	7,544.6	6,255.2	—784.1	—5,889.3	1,446.2	—5,227.2
Globe × Dwarf Aristocrat	278.8	1,272.0	5,540.8	7,091.6	296.2	1,132.6	3,937.8	5,366.6
My Maryland × Dwarf Aristocrat	87.1	52.3	1,986.3	2,125.7	104.5	87.1	1,533.2	1,725.0
Stone × Beauty	418.2	1,446.2	8,834.0	10,698.3	—278.8	—2,387.1	435.6	—2,230.3
Stone × Earliana	487.9	2,875.0	6,377.2	9,740.0	—836.4	—2,178.0	1,219.7	—17,994.7
Stone × June Pink	296.2	1,097.7	9,600.6	10,994.5	—662.1	—2,526.5	975.7	—2,212.9
Stone × My Maryland	—32.9	17.4	—2,300.0	—2,317.4	—87.1	—453.0	—6,046.1	—6,586.3

1916								
Bonny Best × Earliana*	—32.9	—52.3	2,369.7	2,282.5	—871.2	—3,101.5	1,585.6	—2,387.1
Bonny Best × June Pink	714.4	2,543.9	—243.9	3,014.4	714.4	1,167.4	—3,641.6	—1,759.8
Chalk Early Jewel × Bonny Best	0.0	679.5	2,997.0	3,676.5	17.4	—1,080.3	3,206.0	2,143.2
Chalk Early Jewel × Earliana	331.1	5,837.0	4,547.7	10,715.8	34.9	4,164.3	—1,899.2	2,300.0
John Baer × Earliana	1,167.4	4,512.8	—2,770.4	2,909.1	278.8	4,042.4	—4,180.8	139.4
Stone × Earliana	505.3	5,262.1	4,512.8	10,280.2	17.4	1,515.9	—2,543.9	—1,010.6
Stone × June Pink	313.6	2,073.5	8,415.8	10,802.9	—139.4	—2,491.6	—418.2	—3,049.2
1917								
Bonny Best × Comet*	34.9	139.4	3,397.7	3,624.6	—122.0	—209.1	1,341.7	1,010.6
Bonny Best × Earliana	749.2	540.1	—522.7	766.7	697.0	17.4	—906.1	—191.7
Bonny Best × Earliana	731.8	1,533.3	1,968.9	4,303.7	883.7	836.4	191.7	1,916.6
Buck Tresco × Earliana	1,045.4	1,446.2	10,419.6	12,911.2	836.4	383.3	5,610.5	6,830.2
Comet × Earliana	697.0	1,846.9	2,857.5	3,669.0	662.1	1,010.6	453.0	2,125.7
Globe × Comet	435.6	1,115.1	6,725.7	8,276.4	453.0	697.0	4,077.2	5,227.2
John Baer × Earliana	697.0	2,896.1	2,090.9	5,593.1	505.3	2,474.2	1,463.6	4,443.1
John Baer × Earliana	958.3	2,265.1	—348.5	2,875.0	1,010.6	2,265.1	—1,550.7	1,725.0
John Baer × Comet	—139.4	784.1	4,669.6	5,314.3	—435.6	278.8	1,202.3	1,045.4
1918								
My Maryland × June Pink*	104.5	2,143.2	6,185.5	8,433.2	—1,184.8	—17.4	3,571.9	2,369.7
Beauty × Stone	87.1	765.7	6,063.6	6,917.3	—1,289.4	1,498.5	1,585.6	—1,202.3
Chalk Early Jewel × Stone	243.9	1,637.9	—1,028.0	853.8	—679.5	—975.7	—5,349.2	—7,004.5
John Baer × Earliana	—209.1	122.0	5,959.0	5,871.9	—557.6	—400.8	5,784.8	4,826.5
1919								
Bonny Best × Chalk Early Jewel†	2,968.9	2,125.7	3,484.8	8,102.2	2,753.0	383.3	1,184.8	4,321.2
Bonny Best × Earliana	5,401.4	—993.7	—4,199.2	209.1	993.2	—5,227.2	975.7	—3,432.5
New Globe × Earliana	209.1	3,223.4	8,119.6	11,552.1	—6,115.8	—5,540.8	18,521.7	6,865.1

* Twenty-five plants each of the F_1 plants and their parents were set out.

† Data taken on 6 plants each of the F_1 plants and their parents.

In summarizing the performance of the crosses as compared with the higher yielding parent, a positive increase is found, altho its margin is small. During the five years, 24 crosses gave an increased yield and 22 a decreased yield in the early part of the season, 24 an increased and 23 a decreased yield in midseason, 28 an increased and 19 a decreased yield in late season, and 25 an increased and 22 a decreased yield in the entire season.

EFFECT OF CROSSING ON SMOOTHNESS OF FRUITS

In 1914, 1915, 1916, 1917, and 1918, the fruit when picked was graded into No. 1 and No. 2, according to smoothness, size, and condition. Invariably the first generation crosses made between rough types, as Earliana and June Pink; and smooth types, as Bonny Best and Chalk Early Jewel, were found to have a much higher percentage of first-grade fruit than the rough parent; or, in other words, the smooth surface of one parent dominated to a high degree the rough surface of the other. In 1916, a dry hot season, a large number of smooth fruits were thrown out of grade 1 on account of their small size, and since the F_1 crosses produced proportionately more small fruits than their parents, the percentage of grade 1 fruit in that season is not an accurate index of smoothness.

The cause of the increased smoothness has not been determined, but it seems probable that the surface character, like the size character, is dependent upon numerous factors and therefore is inherited apparently as an intermediate character. The assumption is further supported by the fact that no simple splitting of smoothness of fruit surface occurs in the second generation. Roughness may be accentuated by excessive moisture, type of soil, and imperfect fertilization of the ovules. At least the shrunken areas of rough fruits like those of Earliana are frequently deficient in seed (see Fig. 1) and certain regions produce rough types of Earlianas. The cause of the irregularity often arises earlier than the fertilization stage, as the ovary previous to fertilization may be markedly irregular. Strange to say, no tomato with smooth fruit, except first generation crosses, ripens its fruit as early as Earliana—a bearer of more or less irregular fruits.

RELATION OF CLIMATIC CONDITIONS TO NUMBER AND SIZE OF FRUITS

EFFECT OF WEATHER ON YIELD

The variations in the yield of fruit which occurred during eight years of investigation must have been due largely to the variations in climatic conditions, since the soil type, and amount of manure applied was fairly uniform each year. In Figure 6 is shown the relation of the average yield per plant of the standard varieties for each season to the mean rainfall and temperature of the growing months, namely, June, July, August, and September. The maximum yield was obtained in 1913 when the plants received sufficient moisture and heat during the months of June and July to produce an optimum growth, and sufficient dry weather and heat during August to cause the setting and ripening of a large number of fruits. The mean temperature for June and July, 1913, was 70° and 69.9° F. and of August and September 72.2° and 60.8° F., respectively, while the rainfall of these months was 3.05, 6.11, 1.59, and 3.34 inches, respectively. In 1916, when the second highest yield of the varieties was obtained, the mean temperature of June, July, August, and September was respectively, 63°, 76.6°, 70.4°, and 58.4°, and the rainfall 1.0, 0.72, 1.57, and 2.33 inches. Abnormally low rainfall throughout the season must have reduced the yield, and the low mean temperature of June must have checked the growth of the plants.

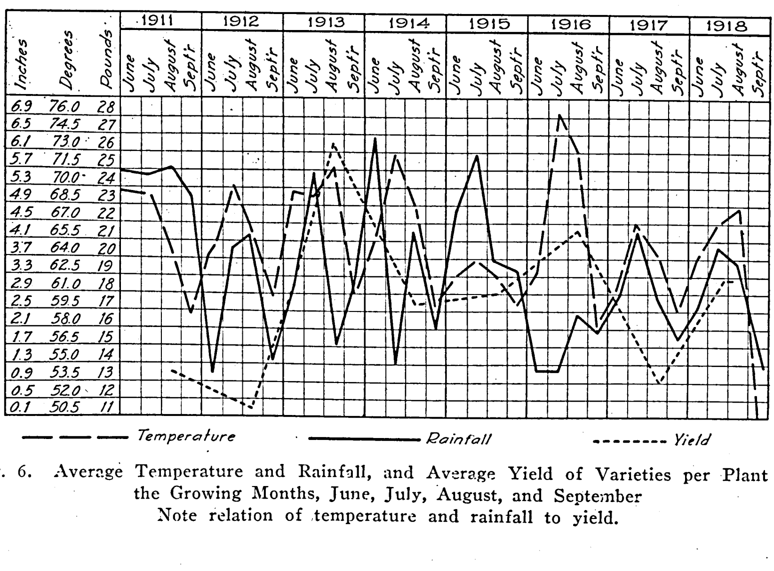


Fig. 6. Average Temperature and Rainfall, and Average Yield of Varieties per Plant for the Growing Months, June, July, August, and September
Note relation of temperature and rainfall to yield.

In 1911, 1912, 1914, 1915, and 1917, when the yields were comparatively low, the mean temperature, particularly during August, was uniformly low. The yield in 1914 was also probably affected by the drouth in July which checked the growth of the plants. The cause of high and low yields each year can thus be explained satisfactorily by the amount of rainfall and the temperature during the months of June, July, August, and September. In other words, a maximum tomato crop is dependent upon sufficient moisture and heat to produce large vigorous plants, and sufficient dry weather and heat after the plant has reached its critical period (the time of setting first fruits) to cause the setting and development of a large number of fruits.

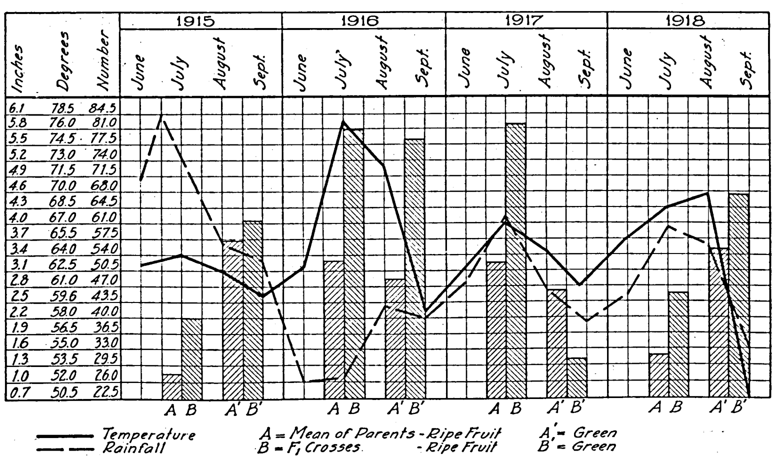


Fig. 7. Amount of Rainfall, Average Temperature, and Average Yield per Plant by the F_1 Generation Crosses and Their Parents

Note (1) that the crosses produced more ripe fruits in 1916 and 1917, when the mean temperature was greater, and (2) that most fruit set in 1916 when the temperature was high and the rainfall was low in the early part of the season.

A curious reversal in yield took place in 1915 and 1916. The low and high-yielding strains of Bonny Best, Chalk Early Jewel, Earliana, and Stone grown in 1915 reversed their positions the following year. As the soil conditions were similar, the variations must have been due to climatic conditions, as 1915 was a cold wet season and 1916 a hot dry one. If this assumption is correct, then the conclusion may be drawn that certain strains are better adapted to certain climatic conditions than others and further that one-year tests of strains are of value only for that particular season.

EFFECT OF SEASONAL CONDITIONS ON NUMBER OF RIPE AND GREEN FRUITS PRODUCED, 1915 TO 1918, INCLUSIVE, BY F_1 CROSSES AND THEIR PARENTAL MEANS

The number of fruits and the proportion of ripe and green fruits produced by the F_1 crosses and the mean of their parents fluctuated markedly during the years 1915 to 1918, inclusive. Figure 7 shows these variations as correlated with rainfall and temperature. Undoubtedly wide variation also occurred during the seasons from 1911 to 1914, but no data were taken in these years on the number of fruits.

The low average number of ripe fruits produced in 1915 and 1918 was undoubtedly due to cold weather. In 1915 the cool weather was fairly uniform throughout the season, while in 1918 it occurred during August and September when the fruits should have been ripening. in 1916 and 1917 the temperature averaged higher throughout the season and the number of ripe fruits was markedly greater. The green fruits, however, were much more numerous in 1916 than in 1917. This variation might have been due to the high temperature and low rainfall in the early part of 1916, which caused an extra heavy setting of fruit.

EFFECT OF RAINFALL ON SIZE OF FRUITS

In 1916 the rainfall was exceptionally low, and as it came mainly at distinct periods it was easy to determine its effect on the size of fruits. To illustrate this effect, which was similar in all varieties and crosses, Earliana, Stone, and their F_1 cross were selected. (See Fig.

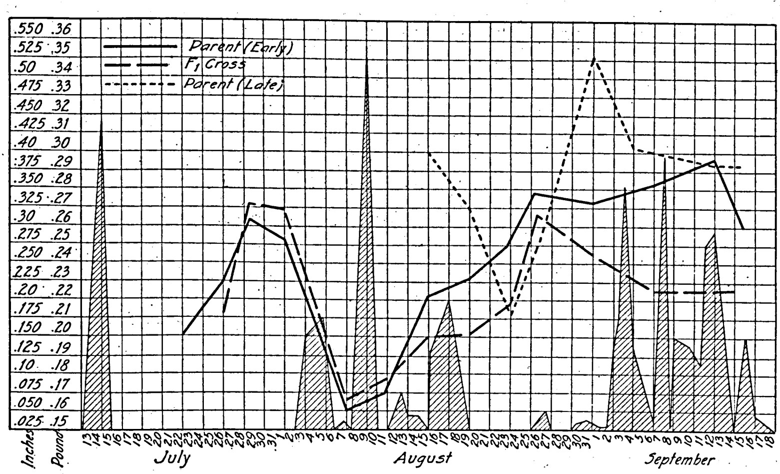


Fig. 8. Amount of Rainfall, Time of Occurrence, and Average Size of Fruits of Earliana, Stone, and Their First-Generation Cross

Note the length of time required after each rainfall for the fruits to reach their maximum size. The decrease in size could have been prevented by irrigating about every two weeks.

8.) On July 2 and 3 the rainfall recorded was 0.2 inch, and no more rain was noted until the 15th. From the 15th to the 19th of July 0.51 inch of rain was recorded, 0.43 of it falling on the 15th. Traces of rain were noted at intervals during the rest of the month and the first part of August, but no water of consequence fell until August 9, when 0.54 inch was recorded. A small amount of rain was again recorded on August 17 and 19, but no appreciable amount was recorded until September 4. Thus there were three distinct periods of rainfall in 1916, namely, the middle of July, August 9, and September 4.

Fruit of Earliana began to ripen July 23; of the F_1 cross, July 27; and of Stone, August 16. About July 29 the fruit of Earliana and the cross had reached its maximum size, and from then on it rapidly declined in size until August 9, when the second heavy rainfall appeared. Immediately after this the size of the fruit increased until about August 26, when it began to decrease until rain appeared on September 4.

Thus on the clay loam soil at University Farm, St. Paul, a rainfall of 0.5 inch exerted a beneficial influence on the size of the tomato fruits for approximately two weeks, and then its influence began to decline. From the practical standpoint, these results indicate approximately when and how much water should be applied artificially in order to maintain the size of tomato fruits. Where the soil is less retentive of moisture and the heat more intense, more frequent waterings would naturally be required.

INHERITANCE OF DECUMBENT HABIT IN PLANTS OF EARLIANA AND JUNE PINK VARIETIES

The dominance in tomatoes of the standard habit of plant growth over the recessive dwarf condition has been known for many years, but no mention has been made of the difference in the habit of standard plants. Earliana and June Pink varieties, which are apparently identical except in the color of the fruit, have a more decumbent habit of growth than Bonny Best, Chalk Early Jewel, Buck Tresco, Comet, Beauty, Globe, My Maryland, John Baer, and Stone. The behavior of this decumbent habit has been observed in nine F_1 crosses between Earliana and normal standard varieties, one F_1 cross between Earliana and a dwarf variety, and one F_1 cross between June Pink and a normal standard, and in every case it has shown complete dominance. For results obtained in 1915-1917, inclusive, see Table IV.

TABLE IV

INHERITANCE OF DECUMBENT HABIT IN THE TOMATO, 1915-1917, INCLUSIVE

Cross	♀	♂	F_1 cross
Beauty × Chalk Early Jewel	N*	N	N
Chalk Early Jewel × Beauty	N	N	N
Beauty × Earliana	N	D	D
Beauty × My Maryland	N	N	N
Bonny Best × Comet	N	N	N
Bonny Best × Earliana	N	D	D
Buck Tresco × Earliana	N	D	D
Chalk Early Jewel × Earliana	N	D	D
Chalk Early Jewel × My Maryland	N	N	N
Comet × Earliana	N	D	D
Dwarf Aristocrat × Stone	U	N	N
Earliana × Dwarf Aristocrat	D	U	D
Earliana × Globe	D	N	D
Earliana × My Maryland	D	N	D
Globe × Comet	N	N	N
Globe × Dwarf Aristocrat	N	U	N
John Baer × Earliana	N	D	D
Stone × Earliana	N	D	D
Stone × June Pink	N	D	D
Stone × My Maryland	N	N	N

* N=Normal standard; D=Decumbent standard; U=Upright or dwarf.

From the practical standpoint the knowledge of the dominance of this decumbent habit has a value, for it furnishes a check to the accuracy of crossing when either the Earliana or June Pink is used in crosses. Further, the decumbent habit may exert an effect on the earliness of ripening, as the fruits on such plants are more exposed to the sun's rays.

COMMERCIAL POSSIBILITIES OF FIRST-GENERATION CROSSES

Whether or not first generation crosses will be used for commercial purposes depends primarily upon whether the returns will compensate for the use of such seed. First generation seed must necessarily be expensive, as crossing naturally entails much labor—the buds must be emasculated in the proper stage, that is, before sufficiently mature to shed pollen; and the pollen must be applied artificially. For commercial purposes it may not be necessary to cover the emasculated flower-clusters with paper sacks to prevent undesirable cross- or self-fertilization, since according to Jones (1916), only a small percentage of crossing takes place in a field of mixed varieties.

Considering the fact that only 1742.4 plants are required to an acre when the plants are set 5 feet apart each way, that one ounce contains from 3000 to 4000 seed, and that one tomato may contain several hundred seed, the cost per plant should be comparatively low. One extra bushel of early fruit should cover all extra expense of such seed for an acre. Growers who cater to early markets and who farm high-priced land; and greenhouse men, who have to make as great a profit as possible from every square foot of space, can well afford to use such seed.

ADVANTAGES OF FIRST-GENERATION CROSSES

The commercial assets of first-generation tomato crosses may be briefly summarized as follows: (1) They are often more productive than either parent, and (2) they are often earlier and smoother, especially when Earliana, a very early variety which bears rough fruit, is crossed with a smooth type as Stone or Chalk Early Jewel.

The seedsman can take advantage of the fact that segregation of characters occurs in the second generation, for the grower must return each season if he wishes to secure the same kind of seed. In other words, the seed grower can hold a trade secret by not publishing the parentage, which would be difficult if not impossible to discover.

DISADVANTAGES OF FIRST-GENERATION CROSSES

The chief disadvantages of F_1 crosses are that their seed must necessarily be expensive and that their fruits are likely to average smaller than standard kinds.

FIRST-GENERATION CROSSES WORTHY OF TRIAL

The tests to date have been somewhat unsatisfactory. For instance, one cross will make a particularly fine showing one season and a poorer one the next, that is, the results have not been as consistent as desired. Whether the variation is partly due to a different reaction toward different climatic changes is unknown, but such an explanation is probable, for it is known that the different varietal strains respond differently to such changes. Without actual trials it is impossible to predict what combinations will give good results. In analyzing the performance of the F_1 crosses grown from 1915 to 1919, it will be found that as a rule crosses between the early varieties, Earliana and June Pink, and the slightly later varieties, Bonny Best, Chalk Early Jewel, and John Baer, have been very productive and in fact have usually produced more fruit than the earlier parent. Since the fruits of these crosses can be classed as smooth, they are more valuable than the

Earliana. As Earliana and June Pink are apparently identical except in color, and Bonny Best, John Baer, and Chalk Early Jewel are of similar type, such crosses are, practically speaking, simply a combination of two types. Since crosses between June Pink and red varieties give red fruits in the first generation, it makes no difference whether this variety or Earliana is used. Another desirable combination, that is, if an early Stone type is wanted, is a cross between Stone and Earliana or June Pink.

Other crosses have done exceptionally well, such as Buck Tresco × Earliana and Comet × Earliana, but as they were tested only one season, it is advisable simply to recommend them for further trial.

For greenhouse purposes, a cross between Bonny Best and Globe proved in one season to be especially valuable. The fruit was smooth and red like Bonny Best, and at least one week earlier. This earliness was probably due partially to the fact that the first blossom cluster set numerous fruits on the cross, and few or none on the parents.

The performance of each cross tested is given in the preceding tables, where its productiveness as well as that of its parents may be learned.

SUMMARY

(1) This bulletin covers a nine-year comparison of first generation crosses with their parents.

(2) The percentage increase of all F_1 crosses, grown each season from 1911 to 1913, over the mean of parents, was respectively 63.62%, 97.43%, and 18.89%.

(3) Sixty F_1 crosses were tested from 1914 to 1919, inclusive, and twenty-one of them ripened a higher percentage of their fruit than their higher parent.

(4) The F_1 crosses on the average ripened more fruits than the mean of their parents and also of their higher parent.

(5) The F_1 crosses on the average produced smaller fruits than the mean of their parents and the higher parent.

(6) The F_1 crosses on the average outyielded the mean of their parents and the higher parent.

(7) The percentage increase for the same cross has fluctuated for the same and different seasons, yet on the average it has given a consistent gain.

(8) Crossing hastened the maturity of the fruits decidedly, that is, when compared with the mean of parents and slightly when compared with the higher parent.

(9) The number of ripe and green fruits produced per plant by mean of parents, higher yielding parent, and F_1 cross is graphically illustrated in Figure 1.

(10) The F_1 fruits derived from crosses between smooth and rough fruited varieties are superior to the fruits produced by the rough fruited parent and are generally classed as smooth.

(11) The yield of tomato varieties and crosses was closely correlated with climatic conditions. The highest yield was obtained in 1913 when the mean temperature of the two growing months, June and July, averaged nearly 70° F. and the rainfall was ample to produce good growth; and the third or ripening month, August, was sufficiently dry and hot to cause a good setting and ripening of fruit.

(12) The high and low yielding strains of Bonny Best, Chalk Early Jewel, Earliana, and Stone, in the cold wet year of 1915, reversed their positions in the hot dry year of 1916.

(13) The number of ripe and green fruits produced from 1915 to 1918 by the mean of parents and F_1 crosses fluctuated directly with the weather conditions of the respective seasons.

(14) In 1916, a hot and dry season, the rainfall came periodically. After a heavy rainfall the size of the fruit increased for approximately two weeks and then decreased in size.

(15) Two types of standard tomato plants, decumbent and normal, were noted, the former behaving as a dominant to the latter.

(16) At least two tomato F_1 crosses could be grown to advantage, namely, (a) a cross between Earliana, or its near relative June Pink, and Bonny Best, John Baer, and Chalk Early Jewel, which are similar in season and appearance; and (b) a cross between the Earliana type and Stone. The former would be very early and smooth and the latter early, smooth, and solid, like Stone.

(17) The increased yield of superior early fruit should more than offset the extra cost of F_1 seed.

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