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With Particular Reference to Early Yield, Total Yield, and Fruit Size

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Russell E. Larson and T. M. Currence

INTRODUCTION

THE RESULTS of a number of studies have indicated the possible advantages of utilizing the F_1 generation of hybrids in various crops. Increasing interest in production of hybrid seed suggests that their advantages may be utilized in tomato *(Lycopersicon esculentum)* production if suitable combinations possessing distinct benefits over commercial self-pollinated varieties were obtained. The extent to which hybrid vigor may be manifested in the F_2 generation and the possibility of predicting the behavior of characteristics in the F_1 and F_2 generations have become of interest in the practical utilization of crosses.

Powers *(18)*, reporting on inheritance in crosses of two species of *Lycopersicon*, states that whereas the standard methods of breeding self-fertilized crops should be used for tomato breeding, it is not so apparent that methods developed for the improvement of cross-fertilized crops can be used advantageously in a tomato breeding program. He suggests that, "Information concerning heterosis and dominance of the more important economic characters of tomatoes is essential to the solution of this problem." "In regard to the characters studied, it may be concluded that the greatest benefits due to heterosis will come from increased plant size and increased earliness. Some of the increase in plant size should result in increased plant yields. It seems that increases in plant size and earliness are sufficient to warrant an intensive study of the possibility of utilizing heterosis in the commercial production of tomatoes."

In this report new combinations of parental strains have been studied to determine their ability to develop such characters as earliness, yield, and fruit size in the F_1 generation, and to deter-

mine to what extent these characters were carried into the second filial generation. An attempt is made to evaluate the crosses for combinations of several desirable characters since there are certain combinations that seem quite difficult to obtain in homozygous material. For example, the poor fruit type of early commercial varieties seems to be definitely associated with early ripening. An effort has therefore been made to determine the inherited association among the three characters—earliness, yield, and size of fruit.

REVIEW OF LITERATURE

A number of reports on the effects of hybridization in the tomato have been published since 1900. Wellington *(22)* in 1912 reported a cross of Dwarf Aristocrat x Livingston Stone which yielded an average of 3.25 pounds per plant more than its higher-yielding parent. He concluded that the production of F_1 tomato seed was economically feasible. In a continuation of his studies reported in 1922 *(23)*, he indicated that considerable variation in yield was observed over a period of several years. However, as an average the F_1 exceeded the mean yield of their parents and of the higher parent. He further concluded that crossing hastened the maturity of fruits as compared to the mean of the parents and slightly when compared with the earlier parent.

Gilbert *(7)* made an extensive study of the inheritance of various characters in tomatoes and reported that the inheritance of fruit size in the F_1 was a blend between the parents. In the same year, Groth *(8)* reported that size of F_1 tomato fruits was the geometric mean between the two parents. MacArthur *(16)* also concluded that the F_1 fruit size was the geometric mean between the two parents.

Hadfield and Calder *(9)* reported that in appearance the F_1 tomato fruits were intermediate between the two parents, that in certain crosses the F_1 was higher yielding than either parent, and that certain crosses matured earlier than either parent. The investigations of Selavnov and Alpet as reported by Babcock *(1)* showed that in 35 tomato crosses all were earlier than either parent, many yielded from 20 to 50 per cent more than either parent, and the fruits were of better quality and more disease resistant than their parents.

Recently Burgess *(4)* noted the higher-yielding ability of certain crosses. She also reported that the F_1 material was earlier than one parent and usually than both parents. Similarly Meyer

and Peacock *(17)* reported on the value of F_1 tomato crosses as measured in early and total yield. They also noted certain F_1 strains that produced larger fruit than either parent. However, staking and pruning to one stem was practiced, and it is possible that this may have affected fruit sizes of the various parents and hybrids differently.

Barrons and Lucas *(2)*, having determined that certain advantages were obtained from growing tomato hybrids, made a detailed study of method and technic of F_1 seed production. This included a discussion of the more satisfactory cultural methods, instruments for emasculating and pollinating the flowers, collection of pollen, determination of fruit set on different flowers of the same cluster, and a general discussion of production costs.

MATERIALS AND METHODS

Parent strains listed in table 1 were selected on the basis of characters which would be desirable in the first generation. Included with the named varieties are several unnamed strains developed at the University of Minnesota Agricultural Experiment Station. Earliana, selection 3-38, and selection 10-38 were chosen for their early-yielding ability. Selections 3-38 and 10-38 along with Valiant, Scarlet Dawn, Redcap, Pritchard, Red River, and Marglobe were also selected for the desirable fruit shape and smoothness which they might impart to the hybrids. Valiant, Scarlet Dawn, 11-38, and Redcap are considered somewhat late maturing, but approach the desired fruit type and size. Strain 6-38 is an early ripening, large, rough-fruited selection. Its combination of early maturity and large fruit size warranted testing it in combination with other strains. The variety Allred had none

Table 1. Characteristics of 12 Tomato Strains Used as Parents of Crosses

Strain	Character				
	Earliness	Yielding ability	Fruit size	Shape	Smoothness
3-38	Early	Fair	Small	Round	Smooth
10-38	Early	Poor	Small	Round	Smooth
Valiant	Late	Good	Large	Semiround	Smooth
Scarlet Dawn	Late	Good	Large	Semiflat	Smooth
Redcap	Late	Fair	Large	Semiround	Smooth
Pritchard	Midseason	Good	Medium large	Semiround	Smooth
Red River	Midseason	Fair	Medium large	Semiround	Smooth
Marglobe	Late	Fair	Large	Round	Smooth
11-38	Late	Good	Large	Flat	Rough
Allred	Late	Poor	Medium large	Flat	Rough
Earliana	Early	Good	Medium large	Semiflat	Rough
6-38	Early	Fair	Large	Flat	Rough

of the desirable characters mentioned, but was included to test its combining ability.

In 1939, 26 crosses and 14 parental strains were grown for field investigation in a randomized block arrangement having three replicates. Each plot contained 11 plants spaced 6 feet between rows and 3 feet between plants within the rows. Seven reciprocal crosses were grown individually. It was found that they did not differ significantly from one another in any character, and therefore data on reciprocal crosses were combined.

A similar randomized block arrangement having three replicates of 10 plants each was used in 1940 to test the F_1 of nine different hybrids and to retest three of the better crosses grown in 1939.

The records of the two years were analyzed by the analysis of variance. Simple correlations were used to determine the association between characters. Regression coefficients have been used in an effort to predict the behavior of certain characters in the F_1 generation from parental data.

A split plot planting arrangement *(24)* was grown in 1941 to obtain the yield, earliness, and fruit size of parent varieties and progenies from F_1 and F_2 seed. This design is adapted for tests when the degree of emphasis on different factors is not the same. It was desired especially to emphasize differences between strains and the interaction of strains by generations. This interaction was expected to show the response of the strains in the F_1 and F_2 generations. Eight parental strains, six of which were duplicated, and 14 hybrids were planted in rows of 11 plants, using three plants each of parents and F_1 of the hybrids, but because of segregation, five plants of the F_2 of the hybrids were grown. The order of the strains was at random and the parents and two generations were planted in 84-foot strips crosswise of each block. However, the parents and two generations were randomized in the different blocks. The plants were spaced 6 feet by 6 feet, making each main block 66 by 84 feet. The subplots of parents and F_1 generation measured 18 by 84 feet each, whereas the F_2 generation subplots measured 30 by 84 feet. Seven replicates or blocks were grown. The records were analyzed for early yield, total yield, and fruit size.

Yield records were recorded from July 28 to September 25, 1939; from July 30 to September 26, 1940; and from July 30 to October 2, 1941. Early yield, for all three years, was based on the weight of fruit picked during the first three harvests. The average fruit size was determined by counting and weighing all fruits

through August 29, 1939; August 26, 1940; and through the entire season of 1941.

In addition, a study was made on the interrelation of hybrids and spacings to determine whether or not significant differences existed among certain hybrids when planted at various spacings or whether superior hybrids would be so under any spacing arrangement. If hybrid vigor as indicated by total yield of fruit is the result of an increase in plant size, the yields from high-yielding hybrids should be more adversely affected by close spacing than those of low-yielding strains.

EXPERIMENTAL RESULTS

Early Yields of the F_1 Generation

As shown in tables 2, 3, and 6 the varieties and strains used as parents varied for time of fruit ripening. The extremes were selection 6-38 which produced early yields of 0.49 and 0.76 tons per acre for the 1939 and 1941 tests, respectively, and the variety Redcap which over the three-year period produced early yields of 0.01, 0.00, and 0.12 tons per acre.

Analyses of variance computed for each of the three years indicate that significant differences occurred between the means. In tables 2, 3, and 6 are presented the early yield data for the

Table 2. The 1939 Means of 19 F_1 Tomato Lines and Their Parents for Early Yield in Tons per Acre

Number	Cross	Parents		F_1
		♀	♂	
1	3-38 x Valiant	0.20	0.04	0.10
2	3-38 x Earliana	0.20	0.18	0.19
3	3-38 x 11-38	0.20	0.10	0.12
4	3-38 x Allred	0.20	0.02	0.07
5	3-38 x 6-38	0.20	0.49	0.16
6	11-38 x Valiant	0.10	0.04	0.02
7	11-38 x Allred	0.10	0.02	0.03
8	11-38 x Earliana	0.10	0.18	0.17
9	Valiant x 10-38	0.04	0.43	0.13
10	Valiant x Allred	0.04	0.02	0.02
11	Valiant x Earliana	0.04	0.18	0.01
12	Earliana x Scarlet Dawn	0.18	0.01	0.10
13	Earliana x 10-38	0.18	0.43	0.26
14	10-38 x Allred	0.43	0.02	0.40
15	10-38 x 6-38	0.43	0.49	0.55
16	Scarlet Dawn x 6-38	0.01	0.49	0.08
17	6-38 x 11-38	0.49	0.10	0.12
18	6-38 x Valiant	0.49	0.04	0.31
19	Redcap x Allred	0.01	0.02	0.07

Significant difference—0.18 tons.
Highly significant difference—0.24 tons.

Table 3. Early Yield and Total Yield in Tons per Acre and Fruit Size in Ounces per Fruit of 12 F_1 Tomato Lines and Five Parental Strains Tested in 1940

Number	Cross	Early yield	Total yield	Fruit size
		Tons	Tons	Ounces
1	Pritchard x Scarlet Dawn	0.13	25.38	5.28
2	Scarlet Dawn x 11-38	0.50	27.70	4.96
3	Scarlet Dawn x Red River	0.76	23.51	4.16
4	Redcap x Earliana	0.65	22.48	3.20
5	3-38 x Marglobe	0.67	25.93	4.16
6	3-38 x Valiant	1.27	28.55	4.48
7	Pritchard x 6-38	0.80	26.66	3.36
8	Scarlet Dawn x 6-38	0.92	26.60	3.84
9	Redcap x 10-38	0.86	24.30	2.72
10	Redcap x Valiant	0.41	25.81	4.32
11	Redcap x Scarlet Dawn	0.15	23.02	5.12
12	Redcap x Allred	0.18	25.79	4.00
13	Earliana	1.39	24.07	3.84
14	Redcap	0.00	23.84	4.48
15	Red River	0.69	22.75	4.96
16	Marglobe	0.30	18.94	4.80
17	Valiant	0.36	22.75	5.12
Significant difference		0.43	5.17	0.86
Highly significant difference		0.60	.....	1.17

three-year period. One F_1, 10-38 x Allred, of the 19 tested in 1939, was significantly earlier maturing than its parental average but only equaled the yield of its earlier parent. Hybrids 3-38 x 6-38, Scarlet Dawn x 6-38, and 6-38 x 11-38 as shown in table 2 were significantly later maturing than their parental average, although none yielded significantly less early fruit than their later-maturing parent. The F_1 yield of these three hybrids together with hybrids Valiant x 10-38, Earliana x 10-38, and 6-38 x Valiant was significantly lower yielding of early fruit than the higher parent. The F_1 of 10-38 x Allred and 6-38 x Valiant was significantly higher in early yield than their lower parent. The early yields of the remaining hybrids did not differ significantly from the early yields of the early parent, late parent, or parental average.

Data for 1940 were incomplete owing to the loss of several parental strains and hybrids. However, of the two hybrids in which comparison with parents was possible, neither differed significantly from its parental average.

With one exception the early yields of F_1 families tested in 1941 were superior to their parental average. In table 6 are shown crosses 3-38 x Allred, Earliana x 10-38, 10-38 x Allred, and 10-38 x 6-38 which produced early yields significantly exceeding the average of their respective parents. Earliana x 10-38 and 10-38 x Allred also significantly exceeded the early yield of the earlier parent.

The data suggest intermediate inheritance of earliness in the F_1 generation. A high correlation was obtained between the aver-

age early yield of the parents and early yield of their F_1 progenies. The r values are 0.606 and 0.666 for the 1939 and 1941 data, respectively. The fact that there were two crosses (table 6) that produced significantly greater early yields than the earliest variety, certain crosses definitely superior to the parental average, and certain crosses definitely inferior to the parental average suggests that there were certain favorable and unfavorable combinations depending on the interaction of gene combinations.

It is possible that significant increases in early yield of the F_1 generation of certain crosses may be due to the interaction of genes for yield which increase the yield throughout the harvest season. For example, in Earliana x 10-38, as shown in table 4, the per cent increase in total yield of the F_1 over the parental average is similar to the increase in early yield. However, it is possible that genes for maturity also influence the quantity of early yield either independently of, or together with, total yield; e.g., in hybrids 3-38 x Allred and 10-38 x Allred (table 4), genes for earliness must be operative, as the per cent increase in early yield of the F_1 over the parental average was 41 per cent greater than the increase in total yield. Considering the relationship of early yield and total yield in the F_1, it will be noted that there were no significant correlations between these two characters. This is a further suggestion that genes for time of fruit ripening may act independently of those for yield.

Using the amount of early yield as a criterion, selection 10-38 appears to have good combining ability. Of the two crosses producing superior early yields of the F_1 generation in 1939, the three crosses producing superior early yields of the F_1 in 1940, and the four crosses producing superior early yields of the F_1 in 1941, selection 10-38 was present in six. It is interesting to note that the late-maturing variety Allred was a common parent for three of these crosses. Hybrid 10-38 x Allred, shown in table 6, significantly exceeded the early yield of all other hybrids and varieties.

Table 4. A Comparison of Four F_1 Lines Whose Early Yields Significantly Exceeded Their Parental Averages with Their Respective F_1 Increases in Total Yields over the Parental Averages in 1941

Hybrid	Early yield				Total yield			
	Mean of parents	F_1	Diff.	Per cent increase	Mean of parents	F_1	Diff.	Per cent increase
3-38 x Allred	0.31	0.74	0.43	58	12.14	14.66	2.52	17
Earliana x 10-38	0.73	1.15	0.42	36	15.49	22.03	6.54	30
10-38 x Allred	0.56	1.54	0.98	64	11.68	15.25	3.57	23
10-38 x 6-38	0.73	1.09	0.36	35	14.58	19.52	4.94	25

Table 5. Observed and Estimated Days to Ripening of 19 F_1 Tomato Lines—Prediction Equation Obtained from Regression of the F_1 on Mean of Parents

Number	Cross	Actual	*Estimate	Deviation
1	3-38 x Valiant	114	113.9	0.1
2	3-38 x Earliana	109	110.5	—1.5
3	3-38 x 11-38	111	110.8	0.2
4	3-38 x Allred	113	114.2	—1.2
5	3-38 x 6-38	110	109.5	0.5
6	11-38 x Valiant	120	113.9	6.1
7	11-38 x Allred	114	114.2	—0.2
8	11-38 x Earliana	111	110.5	0.5
9	Valiant x 10-38	113	112.2	0.8
10	Valiant x Allred	119	117.2	1.8
11	Valiant x Earliana	119	113.5	5.5
12	Earliana x Scarlet Dawn	112	113.9	—1.9
13	Earliana x 10-38	107	108.8	—1.8
14	10-38 x Allred	106	112.5	—6.5
15	10-38 x 6-38	105	107.8	—2.8
16	Scarlet Dawn x 6-38	114	112.8	1.2
17	6-38 x 11-38	115	109.5	5.5
18	6-38 x Valiant	107	112.5	—5.5
19	Redcap x Allred	113	117.2	—4.2
20	11-38	110	.....	.....
21	10-38	105	.....	.....
22	Earliana	109	.....	.....
23	Valiant	119	.....	.....
24	Allred	120	.....	.....
25	Scarlet Dawn	120	.....	.....
26	Redcap	119	.....	.....
27	6-38	106	.....	.....
28	3-38	110	.....	.....

* Estimated number of days $= 0.6766\ M + 36.39$.

This was a cross between an early and a late strain in which the cumulative effect of genes for earliness and possibly genes for yield produced a superior early hybrid.

From a practical viewpoint several F_1 progenies significantly exceeded the early yield of Earliana which may be considered a standard variety for early market purposes. These were 10-38 x Allred and 10-38 x 6-38, as shown in table 2, and Earliana x 10-38, 10-38 x Allred, and 10-38 x 6-38, as shown in table 6. However, small fruit size and low total yield would eliminate most of these from a practical consideration. Further information pertaining to this will be considered later.

The association existing between the average early yield of the parents and early yield of their F_1 progenies makes it possible to compute a regression of the F_1 mean on the parental average and to calculate a prediction equation. To facilitate handling of the material, however, data on early yield in 1939 were converted to number of days from seeding to ripening of one fruit per plant, or 11 fruits per plot. It was found that early yield of the F_1 generation could be predicted with reasonable accuracy. As seen in

table 5, the average deviation of the estimated from the actual was 2.5 days or 2.3 per cent. The formula derived was, estimate equals 0.6766 M + 36.39, where M equals the average of the two parents.

Early Yields of F_1 and F_2 Generations

For 1941 the early yields in tons per acre are presented in table 6. The combined analysis of variance for early yield is presented in table 7. A significant F value for generations and highly significant F values for hybrids and for the interaction hybrids by generations are indicated. The interaction of hybrids by generations furnishes comparisons to determine the relative earliness of different hybrids in the F_1 and F_2 generations. Since the interaction was significant, it appears that the differences in early yield of F_1 and F_2 were not the same for all hybrids. Several examples of this may be noted in table 6. For instance, the early yield of the F_2 hybrid 10-38 x Allred was significantly inferior to the early yield of the F_1 generation. The early yield of the F_1 of 10-38 x 6-38 was slightly larger than the average early yield of the parents, and that of the F_2 generation was significantly greater than the F_1. The difference between the generations of the first cross is 0.80 in favor of the F_1, but in the latter cross the difference is 0.57 in favor of the F_2 so that the cross difference is 0.80 + 0.57 or 1.37 tons.

Of the three F_2 progenies of hybrids whose early yield was

Table 6. Early Yields in Tons per Acre of the Parental, F_1, and F_2 Generations of 14 Tomato Crosses Grown in 1941

Number	Cross	♀ Parent	♂ Parent	Mean of parents	F_1	F_2
1	3-38 x Valiant	0.20	0.29	0.25	0.39	0.13
2	3-38 x Earliana	0.20	0.74	0.47	0.57	0.47
3	3-38 x 11-38	0.20	0.51	0.36	0.56	0.30
4	3-38 x Allred	0.20	0.41	0.31	0.74	0.21
5	3-38 x 6-38	0.20	0.76	0.48	0.60	0.35
6	11-38 x Valiant	0.51	0.29	0.41	0.16	0.36
7	Valiant x 10-38	0.29	0.72	0.48	0.56	0.29
8	Valiant x Allred	0.29	0.41	0.35	0.43	0.35
9	Valiant x Earliana	0.29	0.74	0.53	0.80	0.37
10	Earliana x 10-38	0.74	0.72	0.73	1.15	0.97
11	10-38 x Allred	0.72	0.41	0.56	1.54	0.74
12	10-38 x 6-38	0.72	0.76	0.73	1.09	1.66
13	6-38 x 11-38	0.76	0.51	0.63	0.64	0.63
14	Redcap x Allred	0.12	0.41	0.27	0.42	0.28
Mean of generations		.....	.....	0.47	0.69	0.51
Significant difference within generations		0.35	0.35	0.23	0.42	0.30

Interaction of strains x generations: Significant difference = 0.36 tons.

Table 7. Combined Analysis of Variance of Early Yields of 14 Strains in Two Generations

Variance due to	D.F.	Mean square	S.E.	F.
Blocks	6	.....	.....	.....
Strains	13	4.5085	.....	14.53**
Error a. (B x S)	78	0.3102	0.5569	.....
Blocks	6	.....	.....	.....
Generations	1	4.5303	.....	10.97**
Error b. (B x G)	6	0.4128	0.6424	.....
Strains x Generations	13	0.9838	.....	3.07**
Error c.	78	0.3199	0.5656	.....
Total	195	.....	.....	.....

** Highly significant.

distinctly less than their corresponding F_1's, Allred was a common parent for two, and strains 3-38, Valiant, Earliana, and 10-38 were present in one combination each. It appears that these strains, and particularly Allred, contained fewer of the dominant genes for early maturity, and the F_2 therefore segregated a greater number of late-maturing plants. In contrast to this, the F_2 of 10-38 x 6-38 contained a number of early-maturing segregates and possibly resulted from parents having numerous partially dominant or dominant genes for earliness.

The average increase in early yield of the F_1 generation over the parental average was 47 per cent, whereas the average increase of the F_2 generation early yield over the parental was only 8 per cent. This is a reduction of 39 per cent from F_1 to F_2.

Total Yields of the F_1 Generation

The analyses of variance for total yields gave significant F values, indicating that definite differences occurred between strains for each of the three years. The total yields in tons per acre of the various hybrids and parents are listed in tables 3, 8, and 9. It is evident that the F_1 generation of certain crosses shows definite increases in yield over the mean of the parents, and in a few cases the yields in the F_1 are significantly greater than that of the higher-yielding parent. This is in agreement with results obtained by other workers *(9, 17, 22, 23)*. Of the hybrids tested in 1939, six were significantly greater than their parental average. Crosses 3-38 x Valiant, 10-38 x 6-38, and Scarlet Dawn x 6-38 significantly exceeded the yield of their greater-yielding parent. The first and third of these hybrids produced yields of 32.67 and 33.21 tons per acre, respectively. The highest-yielding parental

variety in the test was Earliana which produced an average of 28.04 tons per acre. Since Earliana was planted in four randomized locations in each block, it was necessary to divide the standard error by $\sqrt{12}$ in calculating the standard error of the mean of this variety. Thus a difference of 2.70 tons represents significance between Earliana and other strains. The F_1 of Scarlet Dawn x 6-38 produced a yield of 33.21 tons per acre which was 5.18 tons per acre more than the mean of Earliana. The mean of 3-38 x Valiant was 4.63 tons per acre greater than the mean of Earliana. This hybrid was also tested in 1940 and again appeared superior in yield. It exceeded the mean for Earliana, which again was the highest-yielding variety by 4.48 tons per acre, giving odds of 12:1 that the difference was significant.

Fifteen of the hybrids tested in 1939, and the two in which comparison with parents was possible in 1940, were not significantly different from the higher-yielding parent. One cross in the 1939 trial, although significantly lower than its greater-yielding parent, did not differ significantly from its parental average.

No F_1 strain tested in 1941 yielded less than its higher-yielding parent. Ten of the 14 strains significantly exceeded the average yields of their respective parents. The remaining four exceeded the average of their parents but the differences were not significant. Nine hybrids significantly exceeded the yield of either par-

Table 8. The 1939 Means of 19 F_1 Tomato Lines and Their Parents for Total Yield in Tons per Acre

Number	Cross	Parents		F_1
		♀	♂	
1	3-38 x Valiant	20.53	23.39	32.67
2	3-38 x Earliana	20.53	28.04	29.57
3	3-38 x 11-38	20.53	27.35	23.47
4	3-38 x Allred	20.53	19.17	23.03
5	3-38 x 6-38	20.53	20.75	23.17
6	11-38 x Valiant	27.35	23.39	28.80
7	11-38 x Allred	27.35	19.17	21.26
8	11-38 x Earliana	27.35	28.04	27.32
9	Valiant x 10-38	23.39	19.49	24.44
10	Valiant x Allred	23.39	19.17	26.63
11	Valiant x Earliana	23.39	28.04	25.47
12	Earliana x Scarlet Dawn	28.04	25.22	27.61
13	Earliana x 10-38	28.04	19.49	24.26
14	10-38 x Allred	19.49	19.17	19.98
15	10-38 x 6-38	19.49	20.75	26.90
16	Scarlet Dawn x 6-38	25.22	20.75	33.21
17	6-38 x 11-38	20.75	27.35	27.87
18	6-38 x Valiant	20.75	23.39	24.24
19	Redcap x Allred	21.88	19.17	26.05

Significant difference—5.41 tons.
Highly significant difference—7.36 tons.

ent. They were 3-38 x Valiant, 3-38 x Earliana, 3-38 x 6-38, 11-38 x Valiant, Valiant x Earliana, Earliana x 10-38, 10-38 x Allred, 6-38 x 11-38, and Redcap x Allred. It seems possible that the genes for high yield are at least partially dominant and that the cumulative effect of dominant high-yielding genes from both parents resulted in productive F_1 progenies.

In considering the ability of different parents to transmit yield, it is noted that in the combinations which significantly exceeded the yield of either parent, strain 6-38 was a common parent in four, and strains 3-38, Valiant, Earliana, and 10-38 were present in three combinations each. It seems that none of the strains were consistently superior parents although certain strains appeared to have better combining ability than others. Few of the parents of the high-yielding F_1 lines were high in productivity, and it is apparent that testing of combinations must be emphasized rather than making predictions from the yield records of the parental strains. This is illustrated by strain 3-38 which was low in yield but appeared to have good combining ability, and 11-38 which was high in yield but was present in the parentage of two low-yielding crosses.

Total Yields of F_1 and F_2 Generations

The combined analysis of variance for total yield gave highly significant F values of 16.76, 42.70, and 3.49 for hybrids, generations, and the interaction hybrids by generations, respectively. Here as for early yield the interaction suggests a differential response of different hybrids in the different generations.

Six of the crosses in the F_2 significantly exceeded the average of their respective parents; but only one, 3-38 x 6-38, table 9, significantly exceeded the yield of either parent. No F_2 was significantly below its poorer-yielding parent and the majority were approximately midway between the parental average and the F_1. Although certain F_2 lines produced yields equal to their F_1 generations, none definitely exceeded them. Numerous F_2's were significantly below their F_1's, depending upon the extent of increase of the F_1 over its parental average. In other words, for the F_1 to be significantly higher yielding than the F_2 it must exceed the F_2 by 2.88 tons or more. Hence, since the degree of reduction from F_1 to F_2 is expected to be 50 per cent, the F_1 of that cross must have exceeded the parental average by 2 x 2.88 or 5.76 tons. However, two F_2 hybrids, 3-38 x 11-38 and Earliana x 10-38, produced total yields considerably less than their parental average.

Table 9. Total Yield in Tons per Acre of the Parental, F_1, and F_2 Generations of 14 Tomato Crosses Grown in 1941

Number	Cross	♀ Parent	♂ Parent	Mean of parents	F_1	F_2
1	3-38 x Valiant	11.82	20.93	16.41	24.93	18.89
2	3-38 x Earliana	11.82	18.31	15.09	26.35	20.68
3	3-38 x 11-38	11.82	16.82	14.34	18.21	11.61
4	3-38 x Allred	11.82	10.68	12.14	14.66	13.64
5	3-38 x 6-38	11.82	17.60	14.72	22.59	20.99
6	11-38 x Valiant	16.82	20.93	18.92	26.81	21.44
7	Valiant x 10-38	20.93	12.64	16.82	20.42	20.79
8	Valiant x Allred	20.93	10.68	15.85	21.12	19.50
9	Valiant x Earliana	20.93	18.31	19.66	24.79	21.78
10	Earliana x 10-38	18.31	12.64	15.49	22.03	12.76
11	10-38 x Allred	12.64	10.68	11.68	15.25	14.19
12	10-38 x 6-38	12.64	17.60	14.58	19.52	15.84
13	6-38 x 11-38	17.60	16.82	15.80	22.34	20.27
14	Redcap x Allred	17.91	10.68	14.30	22.71	20.16
Mean of generations				15.47	21.56	18.04
Significant diff. within generations		3.21	3.21	1.67	3.43	2.81

Interaction of strains x generations: significant difference = 2.88 tons.

This suggests that the parents of these crosses contained fewer dominant high-yielding genes and the F_2's were segregating numerous low-yielding plants.

Under the discussion of fruit size, page 20, it will be noted that strains 10-38 and 11-38 appear to contain numerous partially dominant genes for small fruit size, and certain combinations containing one or the other strain segregate numerous small-fruited plants in the F_2 generation. This is of interest since it seems that these two selections contain few dominant genes for high yield. It is possible that the combination of these two characters in hybrids 3-38 x 11-38 and Earliana x 10-38 resulted in a high proportion of segregates that were low in both yield and fruit size.

The average increase of the F_1 over the mean of the two parents was 39 per cent. Assuming that the yield of the homozygous segregates will be the average of the parents, an increase of 19.5 per cent of the F_2 over the parental average would be expected. The actual increase was 23 per cent. The difference of 3.5 per cent is within limits of experimental error and conforms to the expected progressive reduction in yield as homozygosity increases from 0 to 50 per cent. From these data it may be suggested that average total yields in later generations may be predicted from yields of F_1's which have been adequately tested.

Individual high-yielding plants were noted in the F_2 generation of various crosses. There were 11 plants yielding in excess of 50 pounds, nine of them from high-yielding F_1 lines. Two were from 3-38 x 6-38, two from Redcap x Allred, two from Valiant x

10-38, and one each from 3-38 x Earliana, 11-38 x Valiant, 3-38 x Valiant, 6-38 x 11-38, and Valiant x Earliana. The F_1 of Valiant x 10-38, although not outstanding in yield as an F_1, was equal to the highest-yielding variety in the test. In testing the relationship between the yield of the highest-yielding F_2 plant in each cross with the yield of the respective F_1 line, a highly significant correlation coefficient of 0.739 was obtained. From this it would appear that suggestions might be obtained from F_1 comparisons as to which crosses are likely to produce high-yielding selections in a relatively small F_2 population.

Fruit Size of the F_1 Generation

Size of fruit was determined by counting and weighing all fruits of the first six harvests during 1939 and 1940, and counting and weighing all fruits during 1941.

Individual analyses of variance were calculated for the 1939, 1940, and 1941 data. Highly significant F values for each analysis indicating definite differences between means were obtained.

The 1939 data presented in table 10 suggest that 12 of the 19 F_1 generation lines did not differ significantly from their respective parental average, and 8 of the 12 did not differ significantly from the smaller parent. Five hybrids were significantly smaller in fruit size than the mean of the parents, four of the five were not

Table 10. The 1939 Means of 19 F_1 Tomato Lines and Their Parents for Size of Fruit in Ounces

Number	Cross	Parents		F_1
		♀	♂	
1	3-38 x Valiant	3.73	6.77	4.99
2	3-38 x Earliana	3.73	4.54	3.84
3	3-38 x 11-38	3.73	4.37	4.10
4	3-38 x Allred	3.73	5.01	3.80
5	3-38 x 6-38	3.73	3.57	4.13
6	11-38 x Valiant	4.37	6.77	6.59
7	11-38 x Allred	4.37	5.01	4.94
8	11-38 x Earliana	4.37	4.54	4.88
9	Valiant x 10-38	6.77	2.29	4.19
10	Valiant x Allred	6.77	5.01	5.22
11	Valiant x Earliana	6.77	4.54	5.20
12	Earliana x Scarlet Dawn	4.54	6.82	5.12
13	Earliana x 10-38	4.54	2.29	3.15
14	10-38 x Allred	2.29	5.01	2.67
15	10-38 x 6-38	2.29	3.57	2.55
16	Scarlet Dawn x 6-38	6.82	3.57	4.45
17	6-38 x 11-38	3.57	4.37	4.80
18	6-38 x Valiant	3.57	6.77	3.57
19	Redcap x Allred	6.21	5.01	4.83

Significant difference—0.65 ounces.
Highly significant difference—0.88 ounces.

different from the smaller parent, while one was significantly smaller. Two hybrids averaged more than 0.65 ounce increase over the mean of their respective parents but neither exceeded the larger parent by a significant amount.

Hybrids 4 and 10, as shown in table 3, of the 1940 data did not differ significantly from the parental average or from the smaller parent. Both were significantly smaller than the larger parent. Of the 14 F_1 lines tested in 1941 (table 13) 10 were approximately the size of the parental average. The remaining four were significantly smaller than the average of their parents. As indicated by F_1 data the inheritance of fruit size is intermediate, with a tendency toward the smaller-fruited parent. This is in agreement with findings of other workers *(7, 8, 16, 23)*. Correlation coefficients were calculated for size of fruit in progenies and parents. The fruit size of the F_1 in relation to those of the smaller parent, the larger parent, and the average of the parents gave correlation coefficients of 0.779, 0.545, and 0.768, respectively, in 1939 and 0.878, 0.572, and 0.915 in 1941. The correlations between the larger parent and F_1 are significant to the 5 per cent level, whereas the others are highly significant.

As stated earlier, other workers have reported fruit size as intermediate in the F_1 with a tendency toward the smaller-fruited parent. In 1941 MacArthur *(16)* reported the size of the F_1 closely approached the geometric mean of the two parents. His results showed an average deviation of 4.7 per cent of the calculated geometric mean from the observed. The average deviation of the calculated arithmetic mean from the observed was 178.5 per cent. Powers *(18)* presented evidence showing a reasonably good agreement between the observed and calculated geometric mean. However, his data showed the observed fruit size to be slightly but consistently smaller than the calculated geometric mean. He does not conclude that the effects of genes differentiating weight of fruit were strictly geometrically cumulative, but postulates an unknown quantity as also being effective in differentiating fruit size.

The geometric means for fruit size of the 19 hybrids tested in 1939 are presented in table 11. They averaged 6.0 per cent larger than the observed. Data of the 1941 test, as shown in table 11, also showed the geometric mean to be slightly but consistently greater than the observed. In 1941 the means averaged 9.2 per cent greater than the observed.

If size is geometrically cumulative, it is expected that large differences between the arithmetic averages of the parents and

Table 11. A Comparison of Observed Fruit Size in Ounces of the Various F_1 Tomato Lines with the Calculated Geometric Average of Their Respective Parents

Number	Cross	1939 Observed F_1	1939 Calculated geometric mean	1939 Deviation	Number	Cross	1941 Observed F_1	1941 Calculated geometric mean	1941 Deviation
				Per cent					Per cent
1	3-38 x Valiant	4.99	5.02	0.6	1	3-38 x Valiant	2.88	3.09	7.3
2	3-38 x Earliana	3.84	4.11	7.0	2	3-38 x Earliana	2.56	3.09	20.7
3	3-38 x 11-38	4.10	4.04	— 1.5	3	3-38 x 11-38	3.36	3.16	— 6.0
4	3-38 x Allred	3.80	4.32	13.7	4	3-38 x Allred	3.04	3.16	3.9
5	3-38 x 6-38	4.13	3.65	—11.6	5	3-38 x 6-38	2.56	2.87	12.1
6	11-38 x Valiant	6.59	5.44	—17.4	6	11-38 x Valiant	3.36	3.60	7.1
7	11-38 x Allred	4.94	4.68	— 5.3	7	Valiant x 10-38	2.56	2.60	1.6
8	11-38 x Earliana	4.88	4.45	— 8.8	8	Valiant x Allred	3.52	3.60	2.3
9	Valiant x 10-38	4.19	3.94	— 6.0	9	Valiant x Earliana	3.20	3.52	10.0
10	Valiant x Allred	5.22	5.82	11.5	10	Earliana x 10-38	2.08	2.60	25.0
11	Valiant x Earliana	5.20	5.50	5.8	11	10-38 x Allred	2.24	2.66	18.7
12	Earliana x Scarlet Dawn	5.12	5.56	8.6	12	10-38 x 6-38	1.92	2.42	26.0
13	Earliana x 10-38	3.15	3.22	2.2	13	6-38 x 11-38	3.52	3.35	— 4.8
14	10-38 x Allred	2.67	3.39	27.0	14	Redcap x Allred	3.52	3.68	4.5
15	10-38 x 6-38	2.55	2.86	12.1					
16	Scarlet Dawn x 6-38	4.45	4.93	10.8					
17	6-38 x 11-38	4.80	3.95	—17.7					
18	6-38 x Valiant	3.57	4.92	37.8					
19	Redcap x Allred	4.83	5.58	15.5					

the F_1 would result from crosses of parents with extreme differences in fruit size. An F_1 of a cross between 3- and 4-ounce parents would, according to the geometrically cumulative hypothesis, average 3.40 ounces, which is not greatly different from the arithmetical mean of 3.50 ounces, but a cross between parents averaging one ounce and 8 ounces, respectively, would geometrically average 2.83 ounces, as compared to the arithmetic average of 4.50 ounces. Earliana x 10-38, 10-38 x Allred, and 10-38 x 6-38 (table 13) were between parents that differed widely in fruit size. Although the F_1's of the first and second crosses are significantly smaller than both the arithmetic and geometric averages of their respective parents, the differences between the F_1 and the arithmetic average are greater than the differences between the F_1 and the geometric average. The F_1 of 10-38 x 6-38 is significantly smaller than the arithmetic average, but it does not differ significantly from the geometric average of its parents.

The evident relation between parental fruit size and that of the F_1 makes possible the calculation of regression coefficients and the computation of a prediction equation by which F_1 fruit size may be predicted with relative accuracy. Table 12 shows the actual F_1 size of fruits grown in 1939 and the estimated sizes as calculated from the following prediction equation: Estimate = 0.22885 x + 0.73859 y — 0.3596 where x equals the average size in ounces of the larger parent and y equals the average size in ounces of the smaller parent.

Table 12. Comparison of Observed Fruit Size in Ounces of 19 F_1 Tomato Lines with Fruit Size Computed from the Equation: 0.22885 (larger parent) + 0.73859 (smaller parent) — 0.3596

Number	Cross	Observed	Estimated	Deviation
1	3-38 x Valiant	4.99	4.66	—0.33
2	3-38 x Earliana	3.84	4.15	0.31
3	3-38 x 11-38	4.10	4.11	0.01
4	3-38 x Allred	3.80	4.26	0.46
5	3-38 x 6-38	4.13	3.85	—0.28
6	11-38 x Valiant	6.59	5.14	—1.45
7	11-38 x Allred	4.94	4.73	—0.21
8	11-38 x Earliana	4.88	4.63	—0.25
9	Valiant x 10-38	4.19	3.60	—0.59
10	Valiant x Allred	5.22	5.61	0.39
11	Valiant x Earliana	5.20	5.26	0.06
12	Earliana x Scarlet Dawn	5.12	5.27	0.15
13	Earliana x 10-38	3.15	3.09	—0.06
14	10-38 x Allred	2.67	3.20	0.53
15	10-38 x 6-38	2.55	2.87	0.32
16	Scarlet Dawn x 6-38	4.45	4.56	0.11
17	6-38 x 11-38	4.80	4.00	—0.80
18	6-38 x Valiant	3.57	4.54	0.97
19	Redcap x Allred	4.83	5.48	0.65

Fruit Size of F_1 and F_2 Generations

From the material grown in 1941 the combined analysis of variance for fruit size gave a highly significant F value for hybrids, but for generations it was slightly below the 5 per cent level. A highly significant F value for hybrids by generations was obtained, indicating that different hybrids differed significantly in the two generations.

The F_2 of 3-38 x 6-38, as shown in table 13, was significantly larger in fruit size than its parental average and its comparable F_1. It appears that numerous large segregates were obtained from this cross. In this cross it is probable that transgressive segregation occurred since the F_2 exceeded its larger-fruited parent. It may be of some interest to note that the F_2 populations of 3-38 x 11-38, 10-38 x 6-38, and 6-38 x 11-38 were significantly smaller than their corresponding parental and F_1 averages. This is unusual since the two strains 3-38 and 6-38 were the parents of the large-fruited F_2 previously mentioned. From this it may be considered that selections 10-38 and 11-38 contain partially dominant genes for small fruit size which result in a large percentage of small-fruited segregates in the F_2 generation.

Hybrids of 11-38 x Valiant, Valiant x Allred, Valiant x Earliana, 6-38 x 11-38, and Redcap x Allred, recorded in table 13, average for the two generations 3.3 ounces or greater per fruit. These are all crosses involving parents that averaged 3.0 ounces or more per fruit and consistently produced large fruits in their progenies.

Table 13. Average Fruit Size in Ounces of the Parental, F_1, and F_2 Generations of 14 Tomato Crosses Grown in 1941

Number	Cross	Parents ♀	Parents ♂	Mean of parents	F_1	F_2
1	3-38 x Valiant	2.72	3.52	3.12	2.94	3.04
2	3-38 x Earliana	2.72	3.52	3.12	2.50	3.04
3	3-38 x 11-38	2.72	3.68	3.20	3.38	2.72
4	3-38 x Allred	2.72	3.76	3.24	2.98	3.36
5	3-38 x 6-38	2.72	3.04	2.88	2.56	3.52
6	11-38 x Valiant	3.68	3.52	3.60	3.42	3.84
7	Valiant x 10-38	3.52	1.92	2.72	2.56	2.88
8	Valiant x Allred	3.52	3.76	3.64	3.52	3.52
9	Valiant x Earliana	3.52	3.52	3.52	3.26	3.20
10	Earliana x 10-38	3.52	1.92	2.72	2.13	2.08
11	10-38 x Allred	1.92	3.76	2.84	2.30	2.40
12	10-38 x 6-38	1.92	3.04	2.48	2.14	1.92
13	6-38 x 11-38	3.04	3.68	3.36	3.52	3.04
14	Redcap x Allred	3.68	3.76	3.72	3.52	3.52
Mean of generations		.....	.....	3.15	2.91	3.00
Significant difference within generations		0.30	0.30	0.21	0.24	0.38

Interaction of strains x generations, significant difference = 0.36 ounces.

Interrelation of Early Yield, Total Yield, and Fruit Size in the F_1 Generation

Three important factors in evaluating commercial tomato strains are earliness, high yield, and ability to produce large enough fruit to meet requirements. Since these characters are definitely important, analysis of covariance was used to indicate the extent of their association for each of the three years' data.

In determining the relationship between early yield and total yield for F_1 lines, respective correlation coefficients of —0.144, 0.369, and —0.576 were obtained for the years 1939, 1940, and 1941. These are given in table 14. The 1941 negative value is significant at the 5 per cent level and suggests hereditary association between high early yield and low total yield for that season. There was no significant relationship between the two characters in the 1939 and 1940 material. The above correlations are of some interest inasmuch as they suggest the possibility that an F_1 hybrid could be obtained having both high early yield and high total yield. The r values for error are 0.120, 0.444, and 0.203 for the years 1939, 1940, and 1941, respectively. Although the second correlation is significant at the 5 per cent point, there seems to be little association between early yield and total yield resulting from environmental effects.

It may be that some degree of inherited relationship exists between early yield and fruit size. Analyses of covariance calculated to determine the relationship gave r values of —0.750, —0.520, and —0.683 for hybrids and r values of 0.104, —0.361, and 0.139 for error during the 1939, 1940, and 1941 seasons, respectively. The values are given in table 14. The first and last of the correlations for hybrids are highly significant. The second is slightly below the 5 per cent level of significance. These relatively high negative correlations suggest difficulty in combining large fruit size and early maturity in the F_1.

Table 14. Correlation Coefficients Obtained from Analyses of Covariance to Determine the Interrelation between Early Yields, Total Yields, and Fruit Sizes of F_1 Tomato Lines

Year	Correlated characters					
	Early yield and total yield		Early yield and fruit size		Total yield and fruit size	
	F_1 Lines	Error	F_1 Lines	Error	F_1 Lines	Error
1939	—0.144	0.120	—0.750**	0.104	0.407*	0.118
1940	0.369	0.444	—0.520	—0.361	0.191	—0.257
1941	—0.576*	0.203	—0.683**	0.139	0.229	0.080

* Significant.

** Highly significant.

None of the hybrids tested combined these two characters although 3-38 x Valiant seems most nearly to approach the desired combination. This F_1 was relatively early, smooth fruited, and had a fair fruit size. Early maturing, large-fruited lines can be obtained if fruit roughness is not eliminated. Numerous early maturing, smooth, small-fruited strains are known. There was an apparent close association of these characters in the materials tested. Whether or not a self-pollinated strain exists that equals the above F_1 line in the combination of desired characters cannot be definitely stated. However, it appears reasonably sure that a homozygous strain with the yield and earliness of Earliana and the fruit type and quality of Rutgers or Marglobe has not occurred and therefore may be a physiological impossibility in a self-pollinated line. This might also apply to first generation crosses but their possibilities in this respect are somewhat promising and may justify thorough investigation.

The correlations obtained between size of fruit and total yield are 0.407, 0.191, and 0.229 for the 1939, 1940, and 1941 seasons, respectively. Only the first equals the 5 per cent point and the absence of definite association suggests the existence of all ranges in the various hybrids. For example, 3-38 x 11-38 (tables 9 and 13) produced fruits averaging 3.38 ounces and produced a total yield of 18.21 tons per acre which is 2.72 tons per acre less than the highest-yielding variety, whereas the F_1 of 11-38 x Valiant (tables 9 and 13) averaged 3.42 ounces but produced a total yield exceeding the highest-yielding variety by 5.88 tons per acre.

Reaction of Hybrids to Different Spacings

This test was made to determine the interactive effect of spacings and hybrids on early yield, total yield, and fruit size to reveal whether or not high-yielding crosses were the result of increased plant size and therefore need wider spacings to produce maximum yields. The spacings were 2, 3, 4, and 6 feet between plants in rows that were 4 feet apart.

A split plot planting design was used in which the four spacings were randomized in long rows across each block. The four hybrids and one self-pollinated variety were planted at random across the four spacing rows. Three replicates of each of the combinations were grown. The first harvest was made on July 30 and last on September 18. Early yields are based on harvests made between July 30 and August 8.

Early Yield—Early yields in tons per acre are presented in

table 15. The analysis of variance gave significant F values for spacings, strains, and the interaction of strains by spacings.

Decreasing the spacing from 6 feet to 2 feet progressively increased the early yield. The average yield of 3.26 tons per acre for the 2-foot spacing was greater by 1.31, 1.47, and 2.34 tons per acre than the 3-, 4-, and 6-foot spacings, respectively. All crosses significantly exceeded the early yield of Pritchard, but did not differ significantly from each other.

The interaction being significant, it is assumed that all strains did not respond the same to all spacings. The difference in early yield of hybrids Earliana x 3-38 and Red River x Pritchard at 2- and 6-foot spacings was 4.43 — 2.99 = 1.44 tons, and 1.26 — 1.45 = —0.19 tons or 1.44 + 0.19 = 1.63 tons. The standard error of the cross difference is 0.677 tons and twice this is 1.35 tons. Therefore, significant difference in early yield exists between the two hybrids with Earliana x 3-38 producing a larger early yield at a 2-foot spacing and hybrid Red River x Pritchard producing more at a 6-foot spacing. Similar differential responses may be noted among the other strains at the different spacings. A possible explanation may be the differences in plant size of the various hybrids. Since strains Earliana and 3-38 are of small decumbent plant type, the F_1 is also small and decumbent. However, strains Red River and Pritchard develop relatively large plants and a cross between these two strains produces a large plant type. It seems logical that a 2-foot spacing retarded the development of Red River x Pritchard but was sufficient to allow a greater development of the smaller-sized Earliana x 3-38 plants. If this is the case, a proportionate reduction in yield may be expected from Earliana x 3-38 as the spacing is increased from 2 to 6 feet. Red River x Pritchard, however, should vary only slightly up to the spacing treatment that allows full development of the plants.

Table 15. Early Yields in Tons per Acre of the F_1 of Four Tomato Crosses and One Variety at Four Different Spacings

Hybrids	Spacings				Mean*
	2 feet	3 feet	4 feet	6 feet	
Redcap x 3-38	3.60	1.81	1.48	0.98	1.97
Earliana x 3-38	4.43	2.80	2.22	1.26	2.68
Red River x Pritchard	2.99	2.36	2.73	1.45	2.38
Hybrid 46	3.80	1.77	2.24	0.50	2.08
Pritchard	1.48	1.00	0.30	0.41	0.80
Mean**	3.26	1.95	1.79	0.92	.....

* Significant difference—1.10 tons.

** Significant difference—0.73 tons; highly significant difference—1.11 tons.

Interaction of hybrids x spacings: significant difference—0.99 tons.

In this instance, a 4-foot spacing appears to be ample. This possibility is supported by the results of the early yields shown in table 15.

Total Yield—Total yields in tons per acre are presented in table 16. The analysis of variance for total yield gave F values of 5.31 for hybrids and 9.55 for spacings. Both were significant to the 5 per cent point. The interaction of hybrids by spacings was not significant.

Like the early yields the total yields were progressively increased by a decrease in the spacing distance. However, the differences in total yield among the three closer spacings are not significant. The total yield at the 6-foot spacing was significantly less than any other spacing treatment.

The data here suggest that competition between plants at spacings of 3 feet or less has limited the amount of production per plant but the increase in number of plants offsets this loss. It appears that relative yields of the strains did not change at different spacings and indicates that plant size is not the only factor involved in hybrid vigor as measured by total yield.

Pritchard was significantly lower yielding than the other four strains which did not differ significantly among themselves.

Fruit Size—As the competition between plants was reduced, the average fruit size became progressively larger. The average fruit sizes for the 2-, 3-, 4-, and 6-foot spacings were 3.47, 3.70, 4.15, and 4.25 ounces, respectively. Although the fruit size of the wider-spaced plants was greatest, the difference between it and the size of fruits from plants spaced at 4-foot intervals was extremely small. It is not likely that a spacing wider than 6 by 6 feet would further increase the size of fruit.

The majority of tested hybrids that exhibit heterosis have averaged 5 ounces or less in fruit size. The hybrids that have

Table 16. Total Yields in Tons per Acre of the F_1 of Four Tomato Crosses and One Variety at Four Different Spacings

Hybrids	Spacings				Mean*
	2 feet	3 feet	4 feet	6 feet	
Redcap x 3-38	31.6	26.4	22.1	18.6	24.7
Earliana x 3-38	26.3	26.3	23.1	20.7	24.1
Red River x Pritchard	22.9	25.4	24.9	19.0	23.0
Hybrid 46	27.8	26.6	26.6	16.4	24.3
Pritchard	18.6	18.5	14.4	12.6	16.0
Mean**	25.4	24.6	22.2	17.5	.....

* Significant difference—5.17 tons.
** Significant difference—4.01 tons.

Table 17. Average Fruit Size in Ounces of the F_1 of Four Tomato Lines and One Variety at Four Different Spacings

Hybrids	Spacings				Mean*
	2 feet	3 feet	4 feet	6 feet	
Redcap x 3-38	3.30	3.23	3.76	3.71	3.50
Earliana x 3-38	2.51	2.77	2.99	2.96	2.81
Red River x Pritchard	3.97	4.05	4.19	4.42	4.16
Hybrid 46	3.14	3.63	3.92	4.99	3.92
Pritchard	4.45	4.83	5.90	5.17	5.09
Mean**	3.47	3.70	4.15	4.25	.....

* Significant difference—0.54 ounces; highly significant difference—0.79 ounces.
** Significant difference—0.37 ounces; highly significant difference—0.56 ounces.

averaged greater than 5 ounces per fruit have been crosses of two large-fruited strains and have not produced superior yields. Certain combinations of large-fruited strains may exhibit heterosis in yield, but such combinations appear to be relatively scarce.

In this test the variety Pritchard averaged 5.09 ounces per fruit and was significantly greater in size than the large-fruited hybrid, Red River x Pritchard, which averaged 4.16 ounces per fruit. The hybrid Earliana x 3-38 was the smallest, its average being 2.81 ounces per fruit.

The interaction of spacings with hybrids was not significant, the F value being 1.90 while the 5 per cent level of significance was 2.12. With the interaction approaching significance it might be possible that all strains did not respond equally to the different spacings.

Previously it was suggested that Earliana x 3-38 produced a greater early yield at the 2-foot spacing than did Red River x Pritchard because the former hybrid was of smaller plant size and thus was not retarded in development as much as the latter hybrid. In conjunction with this it is interesting to note that in fruit size Earliana x 3-38 closely approximated its maximum size at a spacing of 3 feet between plants, whereas the fruit size of Red River x Pritchard gradually increased as the spacings were increased from 2 to 6 feet between plants. This suggests that maximum development of plant size for the former hybrid was attained at a 3-foot spacing, whereas the latter hybrid attained its probable maximum development at the 6-foot spacing. The average fruit sizes of the crosses Earliana x 3-38 and Red River x Pritchard at the 6-foot spacing were 2.96 and 4.42 ounces, respectively. Their respective total yields at the same spacing were 24.1 and 23.0 tons per acre. It is evident that the former strain produced over one third again as many fruits as the latter. The

fact that the yields of these two crosses were approximately the same might be considered as adding further emphasis to the possibility that plant size is not the only major factor in heterosis of this crop.

Utilization of the Hybrid Vigor Exhibited by Tomato Crosses

Wellington and other workers have suggested the probable value of tomato hybrids in commercial production. Such use depends on several factors. The hybrid should be superior in at least one respect to the best self-pollinated varieties. It should also possess all the favorable characteristics of size, shape, yield, earliness, etc., equal to the standard varieties. The cost of producing seed must not be prohibitive in relation to the value of the product. Hybrid 3-38 x Valiant over a three-year period produced a total yield which was 22.3 per cent greater than the highest-yielding variety, Earliana (table 18). The fruit of this cross was slightly later maturing than Earliana but in fruit size it was equal to Earliana and the fruit shape was more nearly globular.

A difficulty in producing F_1 tomato seed is the expense encountered in making pollinations. The problem is such that data for estimating the cost under all conditions cannot be obtained. However, certain observations have been made and may be of interest. A workman thought to have average skill in pollinating work was able to emasculate, pollinate, and tag approximately 150 flowers in eight hours. Thirty per cent of the flowers developed into fruits producing approximately an ounce of seed. Postulating the cost of labor at 70 cents per hour places a cost of $5.60 per ounce of seed; allowing $1.40 for other expense, the total cost becomes $7.00 per ounce. An ounce of tomato seed varies in number, but weighing and counting several samples has established a general average of approximately 8,000 seeds. With good germination this would be expected to provide plants for about two acres at planting distances normally used for unstaked plants.

Table 18. A Comparison between the Three-Year Averages of an Outstanding F_1 Tomato Line with Two of the Better Parental Varieties

Variety or hybrid	Early yield per acre	Total yield per acre	Fruit size
	Tons	Tons	Ounces
Earliana	0.77*	23.47**	3.97
3-38 x Valiant	0.59	28.72	4.14
Valiant	0.23	22.36	5.14***

* Earliest maturing of parents tested.
** Highest yielding of parents tested.
*** Largest fruited of parents tested.

The 1940 average price for market tomatoes as given by Agricultural Statistics *(20)* was $1.24 per bushel and the average yield for the United States was given as 116 bushels per acre. With these values a 22 per cent increase in yield would provide an additional income of approximately $31.65 per acre to the grower to more than balance the $3.50 estimated cost of seed.

As subjects for further study, several alternative methods of seed production might be suggested, such as the use of the F_2 generation, and the possible use of a male sterile strain to eliminate the necessity of emasculating flowers. Lesley and Lesley *(14)* have reported on such strains; consequently they are known to exist. From studies of the F_2 population of crosses between male steriles by male fertiles they obtained close approximates of 15 male fertiles to one male sterile. In backcross tests of male sterile x (male sterile x male fertile), ratios of three fertile to one sterile were obtained. These results led the authors to suggest that male sterility probably depends on two recessive genes which are either independent or not closely linked.

The elimination of several hand processes in the production of hybrid tomato seed and the assurance that only hybrid seed was being produced would be of considerable economic importance. With this in mind a possible procedure in breeding a male sterile line having good combining ability is suggested.

Making use of a backcrossing plan and assuming that the recurrent parent having good combining ability was homozygous dominant for fertility, an initial cross could be made between the male sterile x male fertile. Second generation seed obtained from selfing of the genotypically heterozygous F_1 would produce plants segregating at a ratio of 15 fertiles to one sterile. The steriles could be selected and backcrossed to the recurrent parent late in the summer. The seed of this cross, which again would produce plants heterozygous for male sterility, could be planted in the greenhouse and allowed to self. A large progeny from this selfed seed should be grown in the field. Repeating the operations, selections for male steriles should be made when they can be easily noted, and again backcrossed to the recurrent parent. Possibly this process should be repeated for four years. In this manner male steriles could be obtained which each year had added more of the better characters of the recurrent parent. The male sterile selections should be carried on by asexual propagation methods while a proper field test is made to determine the combining ability of the most promising male sterile lines in combination with a few homozygous strains. Those sterile strains found to have

the desired combining ability might be increased asexually and distributed through proper organizations or individuals.

Another possibility in taking advantage of heterosis in the tomato without prohibitive seed cost is the use of second generation seed. No F_2 was definitely superior to the better varieties in this limited test, but it seems there are some which approach this goal and suggest that the method be more adequately studied. One F_2 as shown by table 6 was significantly earlier than any of the self-pollinated strains in the test. In the F_2 of seven hybrids the yields were significantly greater than the average of their parents, table 9, and the F_2 populations of 11-38 x Valiant and Valiant x Earliana, if thoroughly tested, may prove to be higher yielding than the highest-yielding variety. Since a good percentage of the hybrid vigor remains in the F_2, it should be possible to demonstrate their superiority in yield. Maximum segregation occurs in the second generation, and Curtis *(5)* has pointed out that most hybrids showing heterosis have been derived by crossing extremely different types. Working with summer squash *(Cucurbita pepo),* he suggests that if hybrids could be produced by crossing inbreds or varieties which were similar in plant and fruit characteristics but were sufficiently different in growth factors to produce heterosis, then the extreme variations which normally appear in the second generation might be reduced. In tomatoes it may not be essential to have uniform plants, but uniformity of fruit type would seem quite desirable for most purposes.

SUMMARY AND CONCLUSIONS

During the three-year period 1939 to 1941, field studies were made to determine some of the effects of crossing on earliness, total yield, and fruit size of the F_1 generation of tomato hybrids. In 1941 similar studies were made on the F_2 generation. Covariance analyses have been used to determine the interrelation of early yield, total yield, and fruit size.

A test was conducted in 1940 to determine the effect of different spacings on earliness, size, and yielding ability of certain hybrids.

The results of these studies indicate that early yield is intermediately inherited in the F_1 with a tendency toward the larger early-yielding parent. The average increase in early yield of the F_1 over the parental average was 47 per cent; the F_2 increase over the parental average was 8 per cent.

The interaction of strains by generations for early yield was

significant, indicating that certain hybrids may mature early in one generation and later in another. A possible explanation was offered on the basis of the cumulative effect of genes for yield and earliness producing certain superior F_1 lines and the segregation of a majority of early- or late-maturing plants in the F_2 depending upon the genotype of the hybrid.

The cumulative effect of genes for yield occasionally gives rise to a superior yielding F_1 line. The average yield increase of the F_1 over the parental average was 39 per cent. The F_2 increase over the parental average was 23 per cent. A high positive correlation of 0.739 was obtained between the average yield of F_1 lines and the yield of the highest-yielding selection within each respective F_2. The suggestion was made that better selections might be obtained in the F_2 from high-yielding rather than low-yielding F_1's.

It was noted that certain hybrids responded differently in the different generations. Most F_1's were superior to the average of their parents, several significantly so. Certain F_2's were significantly lower yielding than their F_1 lines. This was assumed to be due in part to reduction incurred as homozygosity was approached. However, two F_2 lines were significantly lower yielding than their parental average and it was suggested that the strains present in these crosses combined characteristics of low yield and small fruit size and thereby caused production of numerous low-yielding small-fruited segregates.

The inheritance of fruit size is intermediate in the F_1 with a tendency toward the smaller-fruited parent. A comparison of F_1 fruit size with the geometrical average of their parents indicated a close relationship. However, inasmuch as the calculated geometric mean was somewhat larger than the observed fruit size it was comparable to the results obtained by Powers *(18)* who suggested that some unknown quantity was involved.

A significant interaction, indicating that certain hybrids were larger in one generation than in another, was obtained. Differences in size between the parental average and the F_1 lines were explained on the assumption that the size of the F_1 is the geometric mean of the two parents. Thus the geometric average of two parents that varied considerably in size was likely to be significantly less than the arithmetic average of the two parents. It appeared that large differences between the F_1 lines and their related F_2's might be explained on the basis of the number of partially dominant genes for small fruit size that were present in the hybrid.

No important relationship exists between early yield and total yield or fruit size and total yield. However, a definite negative association exists between fruit size and early yield. It is probable that certain F_1 lines can be obtained having both large fruit size and large early yield, but the high negative association suggests difficulty in attaining these results.

The interrelation of spacings with hybrids as measured in early yields indicated that a spacing of 2 feet between plants resulted in significantly greater early yields as compared with the results obtained from the 3-, 4-, and 6-foot spacings. The significant interaction, however, indicated variations among hybrids in their response to different spacings.

The differential responses occurring between two hybrids at two different spacings may be due to differences in plant size. Smaller plants develop to a greater extent at a narrow spacing than do the larger plants and therefore mature earlier. Where the spacing is ample for the large plant hybrids, they may mature as early or earlier than the hybrids having small plants, providing that the genetic factors for maturity are similar.

The total yields were progressively increased as the spacing decreased from 6 to 2 feet between plants. The differences among the three closest spacings, however, are not statistically significant. High-yielding hybrids appear to be high at any spacing, indicating that the quantity of total yield may not be totally dependent on plant size.

Average fruit size increased as planting distances were increased from 2 to 6 feet. The fruit sizes of the 4- and 6-foot spacings were not significantly different, and it seems that a wider spacing than 6 feet would not cause a further increase.

Although the interaction of strains with spacings, as measured by fruit size, was not significant, it was noted that certain strains did not respond equally to the different spacings. Here again it appeared that large plant hybrids failed to develop their maximum fruit size under narrow spacing limitations. Small plant hybrids, however, exhibited a maximum fruit size at a relatively narrow spacing and did not increase as the spacing between plants was increased.

In a practical respect it appears that distinct advantages are to be gained in the utilization of the F_1 of tomato hybrids. Numerous F_1 lines were significantly earlier than either parent. Many matured as much early fruit as the variety Earliana which is commonly grown for early market purposes. The advantage to be gained here is in the better shape and smoothness of the F_1

fruit as compared to Earliana. Total yields of several F_1 lines exceeded those of the highest-yielding varieties in the respective test. Hybrid 3-38 x Valiant over a three-year period averaged 22 per cent more than the highest-yielding variety. Such hybrids, regardless of maturity, should warrant trial in production of tomatoes for industry.

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