A Three-year Study of General and Specific Combining Ability in Tomatoes[1]

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Extensive literature has been written on the extent of hybrid vigor and combining ability in the tomato. The problems relating to general and specific combining ability over locations or years present difficulties and data in this area are lacking. If general combining effects are large, then it may be possible to predict the best hybrid from these effects. If there is a one-to-one correspondence between the parents and general combining values, then it will be possible to predict the best hybrid from the parents' values, assuming sufficient replication. The effect of both general combining ability (the average performance of a line in hybrid combinations) and specific combining ability (the unique effect of a particular combination) assumes importance from the standpoint of recommendations to the seedsmen and growers.

The purpose of this study was to determine the effects of general and specific combining ability in tomato crosses over a three-year period, 1948–1950, utilizing six parental varieties and all possible hybrid combinations (15 hybrids) for yield and fruit size.

Literature Review

According to Sprague and Tatum (4), variance (σ_g^2) of general ..ning ability is largely additive genetic variance, while specific ..bining variance (σ_s^2) is largely dominance variance. Recent work by Matzinger[2] indicates that both general and specific combining variances contain epistatic variance with the latter containing con- iderably more than the former. Sprague and Tatum (4) found with untested corn lines that σ_g^2 was larger than σ_s^2, indicating that the additive effects were much greater than the epistatic and dominance effects. In previously tested lines σ_s^2 was greater than σ_g^2 because of selection and elimination of variation with respect to average performance in hybrids.

Another study by Rojas and Sprague (3), utilizing a number of highly selected inbred lines in two tests over a period of four years, found that σ_s^2 was consistently larger than σ_g^2 in the individual experiments. The interaction of *general* x *years* was relatively smaller than the interaction of *specific* x *years.* Hence, information on general combining ability variation over years is more useful than information on specific combining variation over years.

In a study conducted at two widely separated locations—St. Paul, Minnesota, and Kingston, Rhode Island—by Currence *et al* (2) on

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[2]Matzinger, Dale F., Agronomy Department, Iowa State College. Personal communication.

six parent tomato varieties and their 15 possible F_1 crosses, the authors concluded, "In both localities there appears to be a close agreement between the yield of a variety and its general combining ability. This suggests that the better yielding varieties for a locality will probably produce the better yielding hybrids." The authors added that it seemed feasible that strains with good general combining ability might be used to test the value of numerous varieties as parents of hybrid combinations, and that it appeared evident that the same tested varieties could not be used in widely separated regions.

Materials and Methods

All possible combinations of hybrids derived from six homozygous tomato varieties were grown in 1948, 1949, and 1950 along with the parental varieties. The parent varieties utilized were the canner types Rutgers, Indiana Baltimore, and Pritchard, all of midseason maturity; Earliana, an early home garden variety of relatively low quality; Jubilee, a late maturing large fruited tangerine-colored variety; and Pan America, a midseason maturing wilt-resistant USDA release.

A randomized block design with 21 treatments (15 hybrids and six parents) was utilized in all experiments. Four replications were grown in each year and the plot size consisted of five plants in a row. All tests were grown at the Horticulture Farm, Ames, Iowa, on a fertile Clarion-Webster soil.

All crosses were made in the greenhouse during the winter, utilizing the same parent stocks over the three-year period. The seed of all varieties and hybrids were planted in flats in the greenhouse, the small seedlings transplanted to 3-inch pots, and later transplanted into the field when there was no longer any danger from frost. The following table presents the date of seeding and dates of transplanting for the period of study.

Table 1.—Seeding and transplanting dates for the six parents and 15 hybrids for 1948–1950.

Year	Seeding date	Seedlings transplanted	Field transplants
1948	April 15	April 26–28	May 24–25
1949	April 21	May 1–3	May 20
1950	April 13–15	April 20–23	May 25–26

The tomatoes were harvested once a week. The yield data were divided into early yield and total yield. The early yield period was determined largely by a break in the price level caused by an overabundance of fruit on the market. Table 2 presents the total num-

Table 2.—Total number of harvests, number of early and late harvests and date of harvest for the six parents and 15 hybrids for 1948–50.

Year	Number of harvests	Early harvest		Late harvest	
		Number	Period	Number	Period
1948	9	3	August 11–23	6	August 28–September 25
1949	8	3	August 4–18	5	August 22–September 22
1950	8	3	August 7–21	5	August 28–September 27

ber of harvests, number of early and late harvests, and the date of harvest.

The fruits were graded according to the standards of the U. S. Dept. of Agriculture. The No. 1 grade included all fruits of high canning quality which had at least 90 per cent good red color, free from mold and decay, and not over 10 per cent loss by weight caused by defects. Total yield included the No. 1's and the remainder. Data are presented on the following characters:

Fruit size, early yield Fruit size, total yield	ounces per fruit
U.S. #1 yield, early U.S. #1 yield, total Yield all grades, early Yield all grades, total	pounds per plot

The mathematical model chosen for the portion of the combined experiment over years involving the hybrids only was $y_{ii'tq} = \mu + r_{tq} + g_i + g_{i'} + s_{ii'} + h_t + (gh)_{it} + (gh)_{i't} + (sh)_{ii't} + e_{ii'tq}$ where $y_{ii'tq}$ is the yield in the qth replication of the tth year of the cross of the ith and i'th parent lines. The contribution due to the general combining effects of the ith and i'th genotypes combined in any cross is $g_i + g_{i'}$ and the specific combining effect is $s_{ii'}$. The effect of the tth year is h_t; the replication effect, r_{tq}; and the error, $e_{ii'tq}$. The interactions are represented by the terms in parentheses. All of the terms of the model with the exception of μ and r_{tq} are random variables with expectation zero, zero correlations and variances σ_g^2, σ_s^2, σ_h^2, σ_{gh}^2, σ_{sh}^2 and σ^2. σ_g^2 and σ_s^2 represent the general and specific combining variances. σ_{gh}^2 and σ_{sh}^2 are variances due to the failure of general and specific combining effects to be the same from year to year. Years were assumed to be random although in fact the years were a sequence of three. However, the years involved in the study did not appear atypical of the years which might appear in any sequence of three.

The model for the value of a parent was

$$z_{itq} = \mu + r_{tq} + p_i + h_t + (ph)_{it} + e_{itq}$$

where p_i, the effect of the ith parent, is assumed to be a random variable with zero mean and variance σ_p^2.

The analysis of variance used in estimating the components of genotypic variance are shown in Table 3 along with the expected mean squares. The components of genotypic variance were estimated in the usual fashion. For example σ_g^2 was estimated by $(G' - S' - G'_h + S'_h)/rh(n-2)$. Under the assumption of no correlation between the environmental errors of parent values and general combining effects, the sample phenotypic covariance of parent values and general combining effects is an estimate of the genotypic covariance of parent values and general combining effects. The estimate was

$$\hat{Cov}(p,g) = \frac{1}{r^2h^2(n-2)(n-1)}\left\{\Sigma_i Z_{i..} Y_{i...} - \left(\frac{1}{n}\right)\left(\Sigma_i Z_{i..}\right)\left(\Sigma_i Y_{i...}\right)\right\}$$

where $Z_{i...} = \Sigma_t \Sigma_q z_{itq}$ and $Y_{i...} = \sum_{i' > i} \Sigma_t \Sigma_q y_{ii'tq} + \sum_{i' < i} \Sigma_t \Sigma_q Y_{iitq}$

The estimate of the phenotypic correlation of parent values and general combining effects was

$$\frac{\hat{Cov}\,(p,g)}{\sqrt{\frac{L'}{rh}\;\frac{G'}{rh(n-2)}}}$$

and the estimate of the genotypic correlation was

$$\frac{\hat{Cov}\,(p,g)}{\sqrt{\hat{\sigma}_p^2 \cdot \hat{\sigma}_g^2}}$$

Experimental Results

The estimates of general and specific combining variances and other quantities of interest are shown in Table 4 for each of the individual years and for the combined experiment over years.

Table 3.—Analysis of variance and mean square expectations for the combined experiment over years.

Source	d. f.	S. S.	M. S.	Expected mean squares
Years	$h-1$			
Reps in years	$h(r-1)$			
Lines in years				
Among parents in years				
Among parents	$n-1$	L	L′	$\sigma^2 + r\,\sigma_{ph}^2 + rh\,\sigma_p^2$
Parents x years	$(n-1)(h-1)$	L_h	L_h	$\sigma^2 + r\,\sigma_{ph}^2$
Among crosses in years				
Among crosses	$\left(\frac{1}{2}\right)n(n-1)-1$	V	V′	
gi′s	$n-1$	G	G′	$\sigma^2 + r\,\sigma_{sh}^2 + rh\sigma_s^2 + (n-2)\,r\sigma_{gh}^2 + rh(n-2)\sigma_g^2$
sii′s	$\frac{1}{2}n(n-3)$	$S = V - G$	S′	$\sigma^2 + r\,\sigma_{sh}^2 + rh\,\sigma_s^2$
Crosses x years		V_h	V_h'	
(gh)it′s	$(n-1)(h-1)$	G_h	G_h'	$\sigma^2 + r\,\sigma_{sh}^2 + (n-2)\,r\,\sigma_{gh}^2$
(sh)ii′t′s	$\frac{1}{2}(h-1)n(n-3)$	$S_h = V_h - G_h$	S_h'	$\sigma^2 + r\,\sigma_{sh}^2$
Parents vs. crosses in years				
Parents vs. crosses	1			
Parents x crosses x years	$h-1$			
Error	$\left(\frac{1}{2}n(n+1)-1\right)(r-1)(h-1)$	E	E′	σ^2

Fruit Size:—Early yield is similar to total yield, except that the average fruit size tends to be smaller in the case of total yield. Over the three-year period Jubilee was the largest fruited variety and Earliana the smallest. In crosses with the large fruited variety, Jubilee, the means of all hybrids were substantially larger than combinations with the other parents. No hybrid, however, exceeded the parent variety, Jubilee, in size. The mean fruit size of the hybrids involving Earliana as a common parent were smaller in size than hybrid combinations with other parents. All the hybrids with Earliana as a common parent exceeded Earliana in fruit size.

Table 4.—Means and components of variance for six tomato characters.[a]

	Early yield				Total yield			
	1948	1949	1950	Combined	1948	1949	1950	Combined
Fruit size ***(ounces per fruit)***								
Mean	4.8895	6.3368	5.5645	5.5969	4.3604	5.6288	5.7892	5.2594
$\hat{\sigma}_g^2$	0.4175**	0.9305**	0.6709**	0.6036**	0.3648**	0.5904**	0.6769**	0.4494**
$\hat{\sigma}_{gh}^2$	—	—	—	0.0694*	—	—	—	0.0946**
$\hat{\sigma}_s^2$	0.0364	0.1074*	0.0903*	0.0121	0.0142	0.0484	-.0369	0.0471**
$\hat{\sigma}_{sh}^2$	—	—	—	0.0660*	—	—	—	-0.0385
Côv(p,g)	0.5203	1.4716	0.6972	0.8923	0.3149	1.1381	0.5168	0.6341
$\hat{\sigma}_p^2$	0.8294**	3.0835**	1.4813**	1.1677**	0.3084**	2.2035**	1.6118**	0.9183**
$\hat{\sigma}_{ph}^2$	—	—	—	0.6304**	—	—	—	0.4563**
$\hat{\sigma}^2$	0.3610	0.3357	0.3557	0.3508	0.1341	0.3288	0.5438	0.3356
C.V.	12.3	9.1	10.7	10.6	8.4	10.2	12.7	11.0
U.S. No. 1 yield ***(pounds per plot)***								
Mean	14.18	24.73	7.45	15.45	62.82	90.98	49.91	67.91
$\hat{\sigma}_g^2$	36.16*	98.33**	4.38**	30.03*	-3.27	33.62	101.30**	9.34
$\hat{\sigma}_{gh}^2$	—	—	—	16.25**	—	—	—	34.54**
$\hat{\sigma}_s^2$	30.39**	14.08**	-1.48	3.41	27.55	103.73**	-20.61	20.35
$\hat{\sigma}_{sh}^2$	—	—	—	10.92**	—	—	—	16.55
Côv(p,g)	16.33	77.43	3.16	23.29	-12.64	41.39	37.53	31.54
$\hat{\sigma}_p^2$	39.88**	81.09**	1.69	21.78*	73.37*	190.15**	193.55**	6.89
$\hat{\sigma}_{ph}^2$	—	—	—	19.10**	—	—	—	145.47**
$\hat{\sigma}^2$	25.94	19.00	10.23	18.39	133.50	102.92	138.08	124.83
C.V.	35.9	17.6	42.9	27.8	18.4	11.2	23.5	16.4
Yield of all grades ***(pounds per plot)***								
Mean	17.59	26.57	10.71	18.29	83.94	116.06	80.30	93.43
$\hat{\sigma}_g^2$	58.16**	134.61**	18.73**	55.86**	2.71	72.38	12.62	21.42
$\hat{\sigma}_{gh}^2$	—	—	—	14.64**	—	—	—	7.82
$\hat{\sigma}_s^2$	33.08**	20.28**	1.25	9.08*	70.29*	104.22**	-14.47	6.55
$\hat{\sigma}_{sh}^2$	—	—	—	9.12**	—	—	—	46.80**
Côv(p,g)	39.04	91.05	30.12	51.78	24.78	165.09	1.39	32.25
$\hat{\sigma}_p^2$	57.61**	80.36**	48.62**	54.75**	163.66**	363.22**	14.52	-1.91
$\hat{\sigma}_{ph}^2$	—	—	—	7.44*	—	—	—	182.38**
$\hat{\sigma}^2$	38.52	24.62	12.24	25.13	194.66	132.30	268.03	198.33
C.V.	35.3	18.7	32.7	27.4	16.6	9.9	20.4	15.1

[a]The components which were significantly different from zero at the 5 per cent and 1 per cent level are indicated respectively by * and **. No test was made of whether the Côv(p,g) were significantly different from zero.

The effects of specific combining ability were not stable from season to season. Although the Jubilee crosses ranked high, no particular specific combination was consistently a top performer for fruit size. Pritchard crossed with Jubilee ranked second in size for two years and first once, while Earliana x Jubilee ranked last in size twice and next-to-last once. These were the most consistent crosses. The parental and general combining variances were significantly different from zero in all cases. The variances due to interactions with years of general combining effects and parental values were significant though from one half to four times smaller than σ_p^2 and σ_g^2. In the few instances of significance of specific combining effects the variance due to specific combining effects was small relative to the general combining variance. It can be shown that the specific combining variance is zero under the assumptions of no dominance or epistasis.

U.S. No. 1 Yield and Yield of All Grades:—Earliana and Jubilee were respectively the earliest and latest in fruit ripening. Parental and cross early yields were greatest for Earliana and least for Jubilee in all three seasons. The remaining parental combinations were intermediate in early yield and no definite rankings were observed. Specific combining ability for early yield was not consistent since the individual hybrids did not show any uniform rankings from one season to the next.

In the case of total yield the average total hybrid yield of the varieties were approximately the same by the end of the season. This suggested that Earliana combinations produced a larger proportion of their yields in the early yield period while Jubilee combinations produced the larger proportion of their yields during the late harvest period. In individual years the estimates of the parental variances were significant with the exception of early U. S. No. 1 yield in 1950 and total yield of all grades in 1950. The components due to interactions with years were all significant except σ_{sh}^2 for total U.S. No. 1 and σ_{gh}^2 for total yields of all grades. Early yield presented an entirely different picture from total yield in that (A) the coefficient of variation was about twice as large for early yield, (B) the estimates of general combining variances were all significant in the case of early yield but were non-significant in the case of total yield except for total U.S. No. 1 yield in 1950, and (C) the combined over-years estimates of σ_g^2 and σ_p^2 were significant for early yield but not for total yield.

Although many of the variance component estimates of Table 4 were significantly different from zero, the estimates were subject to a large sampling variance. For example, the estimate of σ_{gh}^2 for early U.S. No. 1 yield was 16.25 while the confidence interval was 7.6 to 38.4, using the method of Bross (1). Since moderate differences in the magnitudes of the variance components may cause considerable changes in genetic interpretations and in eventual recommendations, the subsequent interpretation must be regarded more as suggestive than final.

Discussion

Comparisons of $\hat{\sigma}_g^2$, Côv (p,g) and $\hat{\sigma}_p^2$:—Comparisons among these quantities are of interest because the ratio of σ_g^2 to Cov (p,g) to σ_p^2 is 1: 2: 4 under the assumption of two alleles per locus, no dominance or epistasis, and assuming no correlation of the environmental errors of the parents and general combining effects.

Under these assumptions but assuming dominance

$$\sigma_g^2 = E\,\Sigma_j\,\Sigma_{j'}\,u_j u_{j'}\left[\hat{Cov}\,(\lambda_{j},\lambda_{j'})\right]\left[1+\frac{na_j(1-2\lambda_{.j})}{n-2}\right]\left[1+\frac{na_j(1-2\,\lambda_{.j'})}{n-2}\right]$$

$$Cov(p,g) = 2E\,\Sigma_j\,\Sigma_{j'}\,u_j u_{j'}\left[\hat{Cov}(\lambda_{j},\ \lambda_{j'})\right]\left[1+\frac{na_{j'}}{n-2}(1-2\lambda_{,j'})\right]$$

$$\sigma_p^2 = 4E\,\Sigma_j\,\Sigma_{j'}\,u_j u_{j'}\,[Cov\,(\lambda_{j},\lambda_{j'})]$$

where the model for the jth locus was u_j, $a_j u_j$, and $-u_j$ for the (+ +), (+ −) and (− −) phases respectively, Thus u was a measure of the half distance between the two homozygotes and a was a measure of degree of dominance. λ_{ij} equals one when the jth locus of the ith line is (+ +) and zero. Otherwise $\lambda_{.j} = \frac{1}{n}\Sigma_i\,\lambda_{ij}$ and $Cov\,(\lambda_{j},\lambda_{j'}) = \frac{1}{n-1}\Sigma_i\,(\lambda_{ij}-\lambda_{.j})\,(\lambda_{ij'}-\lambda_{.j'})$.

The expectation is taken over the joint distribution of the λ_{ij}'s.

The ratios [Côv (p,g)] /$\hat{\sigma}_g^2$ and $\hat{\sigma}_p^2/\hat{\sigma}_g^2$ are shown in Table 5, omitting those ratios for which $\hat{\sigma}_g^2$ or $\hat{\sigma}_p^2$ are non-significant. For fruit size the first ratio varies between 1 and 1½ while the second ratio is about 2. The ratios for U. S. No. 1 yield and yield of all grades depart erratically from the pattern of 1: 2: 4. Thus the data suggest either that a completely additive model with two alleles per locus does not provide an adequate explanation of the characters under consideration, or that the parent lines cannot be regarded as a random sample of lines.

Table 5.—Ratios [Côv (p,g)]/$\hat{\sigma}_g^2$ and $\hat{\sigma}_p^2/\hat{\sigma}_g^2$ for fruit size and yield data.

Fruit size	Early yield 1948	1949	1950	Combined	Total yield 1948	1949	1950	Combined
[Côv (p,g)]/$\hat{\sigma}_g^2$..	1.2	1.6	1.0	1.5	0.9	1.9	0.8	1.4
$\hat{\sigma}_p^2/\hat{\sigma}_g^2$........	2.0	3.3	2.2	1.9	0.8	3.7	2.4	2.0
U.S. No. 1 yield								
[Côv (p,g)]/$\hat{\sigma}_g^2$..	0.5	0.8	0.7	0.8	—	—	0.4	—
$\hat{\sigma}_p^2/\hat{\sigma}_g^2$........	1.1	0.8	—	0.7	—	—	1.9	—
Yield of all grades								
[Côv (p,g)]/$\hat{\sigma}_g^2$..	0.7	0.7	1.6	0.9	—	—	—	—
$\hat{\sigma}_p^2/\hat{\sigma}_g^2$........	1.0	0.6	2.6	1.0	—	—	—	—

Genotypic Correlations:—Under the assumptions necessary for equality of $4\sigma_g^2$, 2Cov (p,g), and σ_p^2 mentioned earlier, the genotypic correlation of parent values with their general combining effects is one. The correlation is also one in the case of a single locus even though dominance is present. With more than one locus and the presence of dominance, the correlation may or may not deviate from one, depending on the joint distribution of the λ_{ij}'s. Sample phenotypic correlations for individual years and averaged over-years of parent values and general combining effects are shown in Table 6. The α % points of r for 4 degrees of freedom are .61, .73, .81 and .92 for α = .2, .1, .05 and .01 respectively.

Table 6.—Phenotypic correlations among and between parent values and general combining values for six tomato characters.

Fruit size	Early yield							Total yield						
	p_{49}	p_{50}	g_{48}	g_{49}	g_{50}	$\bar{p}$	$\bar{g}$	p_{49}	p_{50}	g_{48}	g_{49}	g_{50}	$\bar{p}$	$\bar{g}$
p_{48}	.81	.38	.81	.83	.83	.81	.86	.96	.58	.87	.94	.85	.89	.94
p_{49}	—	.74	.90	.84	.84	.98	.89	—	.73	.87	.95	.84	.96	.94
p_{50}	—	—	.81	.72	.66	.82	.75	—	—	.53	.56	.47	.88	.55
g_{48}	—	—	—	.83	.78	.95	.90	—	—	—	.84	.68	.80	.87
g_{49}	—	—	—	—	.99	.89	.99	—	—	—	—	.95	.87	.99
g_{50}	—	—	—	—	—	.87	.98	—	—	—	—	—	.76	.95
$\bar{p}$	—	—	—	—	—	—	.94	—	—	—	—	—	—	.86
U.S. No. 1 yield														
p_{48}	.66	.61	.36	.36	.33	.87	.37	−.60	−.33	−.35	−.78	−.38	−.64	−.70
p_{49}	—	.80	.77	.82	.79	.94	.83	—	−.12	−.22	.34	.69	.60	.55
p_{50}	—	—	.51	.60	.71	.84	.60	—	—	−.25	.65	.25	.61	.43
g_{48}	—	—	—	.87	.84	.65	.94	—	—	—	.23	−.28	−.33	.15
g_{49}	—	—	—	—	.97	.69	.98	—	—	—	—	.56	.79	.89
g_{50}	—	—	—	—	—	.67	.96	—	—	—	—	—	.62	.84
$\bar{p}$	—	—	—	—	—	—	.70	—	—	—	—	—	—	.71
Yield of all grades														
p_{48}	.81	.72	.57	.58	.52	.91	.58	.25	−.68	.30	.11	.00	−.00	.16
p_{49}	—	.90	.80	.82	.80	.97	.83	—	−.46	.62	.80	.39	.84	.80
p_{50}	—	—	.87	.98	.94	.93	.96	—	—	−.86	−.68	.03	−.20	−.67
g_{48}	—	—	—	.89	.94	.80	.96	—	—	—	.85	.15	.32	.87
g_{49}	—	—	—	—	.98	.85	.98	—	—	—	—	.28	.74	.95
g_{50}	—	—	—	—	—	.80	.99	—	—	—	—	—	.34	.51
$\bar{p}$	—	—	—	—	—	—	.84	—	—	—	—	—	—	.64

Sample genotypic correlations are shown in Table 7, where dashes indicate cases in which the correlations were not computed because of negative estimates of σ_p^2 and σ_g^2. No tests of significance of these correlations were made. However, if the corresponding phenotypic correlation was significant, one would expect the genotypic correlation to be real, since the latter correlation is expected to be larger than the former.

Fruit Size, Early U. S. No. 1 Yield and Yield of All Grades:— Many of the phenotypic correlations were significant at the 5 per cent level and most of the genotypic correlations were above .85. In view of the sampling error, the evidence of the departure of the genotypic correlations from one is not marked and the inference drawn from $[\hat{Cov}(p,g)]/\hat{\sigma}_g^2$ and $\hat{\sigma}_p^2/\hat{\sigma}_g^2$ regarding failure of assumptions for early U. S. No. 1 yield and yield of all grades cannot be drawn here. The ability to predict, assuming sufficient replication, the best general combiners from the parent values, appears to be quite high for these characters.

Total U. S. No. 1 Yield and Total Yield of All Grades. Phenotypic and genotypic correlations were highly erratic. In view of the sampling

Table 7.—Estimates of genotypic correlations among and between parent values and general combining values for six tomato characters.

	Early yield							Total yield						
Fruit size	p_{49}	p_{50}	g_{48}	g_{49}	g_{50}	$\bar{p}$	$\bar{g}$	p_{49}	p_{50}	g_{48}	g_{49}	g_{50}	$\bar{p}$	$\bar{g}$
p_{48}	.87	.42	.88	.89	.91	.94	.93	1.03	.76	.94	1.03	.92	1.04	1.05
p_{49}	—	.78	.94	.87	.88	1.09	.93	—	.90	.90	1.00	.87	1.07	1.01
p_{50}	—	—	.87	.76	.70	.94	.80	—	—	.66	.70	.58	1.18	.70
g_{48}	—	—	—	.88	.84	1.08	.96	—	—	—	.87	.70	.89	.93
g_{49}	—	—	—	—	1.04	1.00	1.04	—	—	—	—	1.00	.98	1.07
g_{50}	—	—	—	—	—	.99	1.03	—	—	—	—	—	.85	1.02
$\bar{p}$	—	—	—	—	—	—	1.06	—	—	—	—	—	—	.99
U.S. No. 1 yield														
p_{48}	.73	1.05	.43	.40	.37	1.09	.44	-.80	-.43	—	-1.32	-.46	-2.38	-1.51
p_{49}	—	1.31	.88	.87	.84	1.13	.95	—	-.14	—	.52	.78	2.03	1.09
p_{50}	—	—	.90	.97	1.16	1.54	1.06	—	—	—	.97	.27	2.00	.80
g_{48}	—	—	—	1.00	.97	.85	1.18	—	—	—	—	—	—	—
g_{49}	—	—	—	—	1.02	.83	1.13	—	—	—	—	.80	3.41	2.24
g_{50}	—	—	—	—	—	.81	1.10	—	—	—	—	—	2.00	1.54
$\bar{p}$	—	—	—	—	—	—	.91	—	—	—	—	—	—	3.93
Yield of all grades														
p_{48}	.90	.81	.67	.64	.58	1.02	.67	.30	-1.85	1.18	.16	.00	—	.23
p_{49}	—	.96	.90	.88	.85	1.05	.93	—	-1.14	2.26	1.02	.59	—	1.04
p_{50}	—	—	.98	1.03	1.00	1.00	1.06	—	—	-7.06	-1.96	.10	—	-2.01
g_{48}	—	—	—	.99	1.04	.90	1.12	—	—	—	3.57	.73	—	3.79
g_{49}	—	—	—	—	1.03	.90	1.08	—	—	—	—	.49	—	1.45
g_{50}	—	—	—	—	—	.85	1.09	—	—	—	—	—	—	.91
$\bar{p}$	—	—	—	—	—	—	.94	—	—	—	—	—	—	—

errors, it is difficult to determine whether lack of a clear-cut relationship was due to a failure of the genetic assumptions or due to sampling errors.

Genotype x Year Interactions:—The components $\hat{\sigma}_{gh}^2$, $\hat{\sigma}_{sh}^2$ and $\hat{\sigma}_{ph}^2$ were significant in almost all cases. One of the ways in which such interactions may arise is a result of a random uniform scale change from year to year. Suppose the average value of the jth genotype in the ith year is a_i y_j where a is a constant for a particular year but varies from year to year, then genotype x year interaction variance would exist. The magnitude of genotypic variance would vary from year to year, although genotypic correlations would be unaffected. Interactions of this type could be removed by scaling, but if a completely additive model (no dominance or epistasis) was adequate for single years, then it may be no longer adequate under a log transformation.

A suggestion of genotype x year interaction due to a uniform scale change was contained in the following comparison for early U.S. No. 1 yield. σ_g^2 was 98.33 and 4.38 in 1949 and 1950, respectively, both values being highly significant, yet the estimated phenotype correlation of general combining effects for 1949 and 1950 was .97 and the estimated genotypic correlation was 1.02. Again σ_p^2 was 81.09 in 1949 (highly significant) and 1.69 in 1950 (non-significant), yet the phenotypic correlation was .9. Similar comparisons can be made for early yield of all grades. The data were not adequate to establish clearly that the bulk of genotype x environmental interaction of the data was due to a random uniform scale change from one year to another.

Summary

Estimates of variance components due to parents, general and specific combining effects and their interactions with years were summarized for six tomato characters for a three-year tomato experiment involving six parent lines and their fifteen crosses. These estimates were interpreted under a set of genetic assumptions in the light of (A) the ratios of general combining variance to covariance of parents and their general combining effects to variance of general combining effects, (B) phenotypic and genotypic correlations of parent values and their general combining effects, and (C) genotype x year interaction.

It was found that (A) the simple genetic model of two alleles per locus and no dominance or epistasis did not provide an altogether adequate explanation of early and total yield for the characters: fruit size, U. S. No. 1 yield, and yield of all grades and (B) genotype x year interactions may be due to a uniform scale change from one year to another.

Literature Cited

1. Bross, I. 1950. Fiducial intervals for variance components. *Biometrics,* 6:136–144.
2. Currence, T. M., R. E. Larson, and A. A. Virta. 1944. A comparison of six tomato varieties as parents of F_1 lines resulting from fifteen possible crosses. *Proc. Amer. Soc. Hort. Sci.* 45:349–352.
3. Rojas, Basilio, A., and G. F. Sprague. 1952. A comparison of variance components in corn yield trials; III. General and specific combining ability and their interaction with locations and years. *Agron. Jour.* 44:462–466.
4. Sprague, G. F., and L. A. Tatum. 1942. General vs. specific combining ability in single crosses in corn. *Jour. Amer. Soc. Agron.* 34:923–932.