Tomato Fruit Size and Quality Interrelationships[1]

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Abstract. The interrelationships between tomato fruit weight, Brix, pH and titratable acidity were studied in 2 constant parent groups of F_1's, their 11 parental lines and 2 sets of P-F_1's. Estimates of genetic and phenotypic correlations between high Brix and high titratable acidity and between low pH and high titratable acidity suggested considerable pleiotropic role of genes. The desirable assocation of high Brix with low pH was phenotypically unstable and appeared to have little detectable genetical basis. Fruit weight was poorly correlated with quality traits. Implications of these findings in a breeding program are discussed.

There exists a paucity of genetic studies relating fruit weight, Brix, pH and titratable acidity in the tomato. This may be due to the fact that only recently has interest been given to the quantitative inheritance of tomato fruit quality traits. In recent studies, Thompson and co-workers (9, 11) reported data on phenotypic correlations between various fruit characteristics.

The genetic basis of a likely interrelationship between fruit traits would be especially valuable to the plant breeder. The possible pleiotropic action of genes between the fruit traits suggests further study. Griffing (4), in a study of the genetic interrelations between tomato yield components in constant parent groups of F_1's and parental lines, found that the genotypes of F_1's having a common parent were correlated and suggested that the manifold effects of one set of pleiotropic genes were primarily responsible for the expression of the yield attributes.

It was the purpose of this study to investigate the genetic and phenotypic interrelationships between the tomato fruit attributes and to discuss their implications in a breeding program.

Materials and Methods

Experimental procedures. Two constant parent groups (Cpg) of 11 F_1's each, their 11 parental lines and 2 common parents were used in this study. One Cpg consisted of the F_1's resulting from crossing each of the 11 inbred lines to the common parent Mo. Accession 223 (P.I. 272689) and the other Cpg was comprised of F_1's resulting from crossing each of the same 11 lines to Mo. Accession I-417-1. The common parent lines 223 and I-417-1 were chosen for a companion study of combining ability (7) and, unfortunately, were lower in acidity and Brix than lines previously reported (9). The field design consisted of a randomized complete block, with each entry being replicated 7 times. Each replication consisted of 3 plants spaced 2 ft apart within rows spaced 3 ft apart.

Seeding and culture. All seeds were produced in the greenhouse during the fall and winter of 1967. These were planted in flats containing vermiculite on April 18, 1968. When the seedlings reached a height of 4-5 in., they were transplanted in peat pots containing a standard soil mixture. On May 25, the seedlings were transplanted to the field at the Horticulture Research Facility at New Franklin, Missouri. Conventional cultural practices in commercial tomato growing were used; however it is likely that high N-K fertilization under irrigation contributed to the atypically high pH and low Brix values which were observed.

Harvesting procedure. Firm ripe fruits were harvested from individual plants on August 15 and immediately frozen in plastic bags at -4° to 0°F. The average fruit weight (ft wt) for each plant sample was determined separately, each sample consisting of one to ten fruits, depending on fruit size and availability. The Brix, pH and titratable acidity (TA) determinations were essentially those previously outlined by Lambeth, et al (8), using a Bausch and Lomb Abbe' refractometer for Brix and a Fisher automatic titrimeter for pH and TA determinations. Ten-ml aliquots of centrifuged juice were diluted to 100 ml with demineralized water. A 0.0675N NaOH solution was used for titration and the TA was expressed as citric acid equivalent (CAE). Brix readings were corrected for temperature.

Statistical analysis. Individual plant data on fruit weight were transformed to logarithms ($\log_e$) before computing the analysis of variances. Variances and covariances were obtained by employing standard variance analysis procedures. The total variance was partitioned into appropriate components. Correlations between traits within Cpg's and between inbred parental groups (Ipg) were obtained by employing standard product-moment methods. Genetic correlations (r_G) from parent-offspring were computed after Bogart's formula (1) modified into:

$$r_{G_1G_2} = \frac{\text{Cpg}_{\text{Cov. }x_1x_2} + \text{IPG}_{\text{Cov. }x_1x_2}}{\sqrt{(\text{Cpg}V_{x_1} + \text{Ipg}V_{x_1})\ \ (\text{Cpg}V_{x_2} + \text{Ipg}V_{x_2})}}$$

where Cpg is the constant parent group; Ipg, the inbred parent group; V_{x_1} and V_{x_2}, the variances of traits 1 and 2, respectively. A significance test of genetic correlations was not made since a reliable interpretation has not been developed.

Results and Discussion

The mean values for fruit attributes of the parental strains and common parents are presented in Table 1 and the variances and covariances appear in Table 2. Means for fruit weight are from untransformed data.

Table 1. Means for fruit weight and quality attributes of 11 parental strains and 2 common parents.

	Means			
Lines	Ft wt (g)	Brix (%)	pH	CAE(%)
Mo. 90 (P.I. 127810)	37.7	5.52	4.59	.262
Mo. 31 (P.I. 118785)	38.1	4.79	4.31	.494
Mo. 98 (P.I. 128223)	40.8	5.60	4.28	.502
Mo. 2 (P.I. 91458)	48.9	5.84	4.61	.299
Mo. 117 (P.I. 128886)	68.3	4.67	4.50	.284
Mo. 235 (P.I. 272709)	69.3	5.55	4.24	.523
H 1370	107.4	4.08	4.53	.335
Mo. 197 (P.I. 270246)	134.1	4.98	4.53	.320
Orange Jubilee	167.5	5.55	4.48	.421
Tomboy	191.0	5.26	4.41	.457
Imp. Garden State	265.1	4.70	4.40	.348
Mo. 223 (P.I. 272689)[a]	19.5	6.78	4.40	.467
I-417-1[a]	174.1	5.92	4.46	.374
L.S.D. (5%)	19.9	0.34	0.40	.041

[a] Common parent.

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Table 2. Genotypic variances and covariances involving variables log fruit weight (X_1). Brix (X_2), pH (X_3), and titratable acidity (X_4) within parental strains (P) and constant parent groups. $F_1{}^1$ and $F_1{}^2$.

Traits	Group	Log ft wt (X_1)	Brix (X_2)	pH (X_3)	CAE (X_4)
Log ft wt (X_1)	P	0.5074	-0.1046	0.0063	-0.0678
	$F_1{}^1$	0.1320	-0.0778	0.0033	0.0999
	$F_1{}^2$	0.1371	-0.0302	0.0125	-0.1845
Brix (X_2)	P	---	0.0356	-0.0042	0.2719
	$F_1{}^1$	---	0.0735	-0.0073	0.1804
	$F_1{}^2$	---	0.0960	-0.0097	0 2796
pH (X_3)	P	---	---	0.0141	-0.2655
	$F_1{}^1$	---	---	0.0003	-0.0165
	$F_1{}^2$	---	---	0.0009	-0.0360
CAE (X_4(	P	---	---	---	0.7246
	$F_1{}^1$	---	---	---	0.7069
	$F_1{}^2$	---	---	---	1.3354

Variance and covariance of traits. The variances of the 2 Cpg's ($F_1{}^1$ and $F_1{}^2$) were essentially the same for log fruit weight (X_1X_1), Brix (X_2 X_2), and likely for pH (X_3 X_3), but not for titratable acidity (X_4 X_4). Variances of the 3 groups of populations for log ft wt (X_1 X_1) were considerably greater than those for Brix (X_2 X_2) and pH (X_3 X_3), but were less than those for titratable acidity (X_4 X_4).

The covariances of Cpg's for log ft wt vs Brix (X_1 X_2) and pH vs TA (X_3 X_4) were lower than those for Ipg, but higher for log ft wt vs TA (X_1 X_4) and Brix vs pH (X_2 X_3). Except in the single instance of log ft wt vs Brix (X_1 X_3), the magnitude of the covariances of the $F_1{}^2$ group was appreciably greater than those of Cpg $F_1{}^1$ for (X_1 X_3), (X_1 X_4), (X_2 X_3), (X_2 X_4), and (X_3 X_4). The difference in magnitudes of variances and covariances between the 2 groups may be explained in part by differences in the inherent genotypic properties of the 2 common parents, the I-417-1 line being of complex genetic history.

Phenotypic correlations. Generally, the correlation of 2 characters in the 2 Cpg's were equal to or much more enhanced than those of Ipg (Table 3). Except in the case of $F_1{}^1$ for (X_1 X_4), the positive or negative nature of the relationship in the 2 Cpg's was that characteristic of the Ipg. The perfect correlation estimates of 1.0 (Table 3 & 4) are possible in theory but exceedingly rare in actual situations. These estimates may have been high in themselves and were probably biased upward by environmental and non-additive genetic causes. No estimates of environmental correlations were made in this study.

Large fruit weight was significantly associated with low Brix values among the parental strains and among the $F_1{}^1$ group where the common parent was small fruited. The association of higher pH (toward basicity) with larger fruit weight was also significant in the Cpg's, particularly so in the $F_1{}^2$ where the common parent was a large-fruited, low-acid line. Although the Cpg's showed consistently higher correlation than the Ipg between fruit weight and TA (X_1 X_4), the direction was not consistent. The negative correlation for the $F_1{}^2$ group was apparently due to the common parent being a large-fruited, low-acid line. These findings on ft wt - pH and ft wt - TA relationships are in agreement with those previously reported (9).

Brix and pH (X_2 X_3) were consistently negatively correlated but the correlation was significant only in the $F_1{}^2$ group.

The 2 Cpg's were strikingly similar in showing a high correlation between Brix and TA, the r values being .792 and .781, respectively, as compared to an estimated .608 for Ipg. The consistently high and significant correlation between Brix and TA, as compared to that for Brix and pH, indicates that TA has more phenotypic stability in relation to Brix than does pH and suggests that selection for fruit quality should be based on TA rather than pH.

The strong negative correlation between pH and TA was expected since their numerical values are inverse. Thompson. et al.(11) reported similar findings in certain high acid backcross selections but they also observed a correlation between high pH and high TA in high acid parents. In the current study, all 3 groups of populations were observed to have significantly high negative correlations between pH and titratable acidity.

Table 3. Phenotypic correlation between fruit weight and quality traits among inbred and constant parent groups.

		Trait		
Trait	Group	Brix (X_2)	pH (X_3)	CAE (X_4)
Log ft wt (X_1)	P	-0.779**	0.074	-0.112
	$F_1{}^1$	-0.790**	0.508*	0.327
	$F_1{}^2$	-0.264	1.000**	-0.431*
Brix (X_2)	P	---	-0.067	0.608**
	$F_1{}^1$	---	-0.149	0.792**
	$F_1{}^2$	---	-1.000**	0.781**
pH (X_3)	P	---	---	-1.000**
	$F_1{}^1$	---	---	-1.000**
	$F_1{}^2$	---	---	-1.000**

*Significant at P = .05
**Significant at P = .01

Table 4. Genetic correlations between log fruit weight (X_1), Brix (X_2), pH (X_3) and titratable acidity (X_4).

		Trait		
Trait	Set	Brix (X_2)	pH (X_3)	CAE (X_4)
Log ft wt (X_1)	P - $F_1{}^1$	-0.691	0.100	0.033
	P - $F_1{}^2$	-0.463	0.191	-0.219
Brix (X_2)	P - $F_1{}^1$	---	-0.290	1.000
	P - $F_1{}^2$	---	-0.312	1.000
pH (X_3)	P - $F_1{}^1$	---	---	-1.000
	P - $F_1{}^2$	---	---	-1.000

Genetic correlations. The genetic independence between fruit weight and Brix, as indicated in Table 4, was much more marked in the P - $F_1{}^1$ set where the common parent was small-fruited with high Brix. This relationship was indicated by the phenotypic correlations (Table 3). The r_G's between ft wt vs pH and ft wt vs TA (Table 4) indicated some difficulty would be encountered in selecting for large fruit-high acid combinations. However, selections in which large fruit-high solids and large fruit-high acidity were combined have been reported in other germ-plasm sources (10, 11).

The degree of genetic association between high Brix and low pH was consistent in both Cpg's but not of sufficient magnitude to suggest that genotypes for these 2 traits were similar or had many genes in common. On the other hand, r_G estimates for Brix-TA (X_2 X_4) and high TA-low pH (X_3 X_4) were quite high, suggesting that considerable genetic variation for TA was associated with variability of Brix and pH.

The relative magnitudes of r_G estimates compared to the phenotypic correlation estimates (Table 3) were strikingly similar. Furthermore, of the 6 sets of variables compared, 5 had algebraic signs pointing to correlation in the direction of the parental combinations, an evidence that pleiotropy, or genetic linkage, or both (3) may be involved. It is believed that pleiotropy may play a large role in the correlated responses of characters which are end-products of common or similar growth processes. This may explain the highly significant Brix-TA and low pH-high TA correlations.

The r_G's of ft wt vs the quality traits, excepting Brix, were generally low. These low values may be due to weak or incomplete, multifactorial linkage as suggested by Grant (3) in explaining low or partial correlations, especially between developmentally unrelated characters. Because more genes may be involved in ft wt inheritance (6) than in quality traits (5, 9) the possibility for various degrees of linkage cannot be ignored. However, it was observed that the genetic variance of pH was the lowest (Table 2), thus genetic sampling for this trait may have been a source of error (2) contributing to a downward bias of correlation estimates for pH-Brix and pH-ft wt comparisons.

The data on the relationships of fruit weight to quality traits suggest that genetic improvement in this trait would be accompanied by little, if any, genetic improvement in fruit soluble solids and acidity. However, where fruit size can be subordinated somewhat to fruit quality considerations, as in the development of processing cultivars, breeding to combine high soluble solids and high acidity should be a relatively easy objective to achieve.

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Influence of Atmospheric Moisture, Ion Balance, and Ion Concentration on Growth, Transpiration and Blackheart of Celery (*Apium graveolens* L.)[1]

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Abstract. Intermittent misting of celery plants grown in nutrient solutions resulted in higher top and sucker fresh weights and a lower percentage of dry matter. Misting reduced transpiration up to 27% but did not affect ion uptake nor the incidence of blackheart.

Total top and sucker fresh weights generally decreased with increasing Ca/K ratio in the nutrient solutions while percentage dry matter increased. The 50ppm Ca/235 ppm K ratio resulted in a high water-use efficiency while the 200/59 ratio resulted in a low efficiency. Blackheart symptoms decreased with increasing Ca/K ratio.

Osmotic concentrations of 0.3 and 4.8 atm. in the nutrient solutions decreased both the fresh and dry weights of tops but increased the percent dry matter as compared to the 1.2 atm. nutrient solution. Water-use efficiency was lower at the 0.3 than at the 1.2 and 4.8 atm. concentrations. Blackheart was most severe in the 1.2 atm. solutions.

Plant water balance is critical to many plant processes. Numerous methods may be used to prevent or reduce the development of water stress in plants. These include misting by overhead irrigation (4), manipulation of the soil moisture level (5), the ion concentration (6, 11), or the ion balance (2).

Blackheart of celery, a physiological disorder characterized by the deterioration of heart tissue, has been closely associated with unbalanced water relations and heavy fertilizer applications (1, 3, 12, 14). A low Ca content in the celery heart tissue is characteristic of plants with blackheart symptoms (1, 8, 12). In the case of celery, Ca may affect water balance in the plant (2) or conversely - water balance may affect Ca uptake and metabolism (7).

The purpose of this study was to investigate the effects of ion concentration, ion balance, and atmospheric treatments on growth, water balance and the incidence of blackheart in celery.

Materials and Methods

Experiment 1. Celery plants, cv. Utah 52-70, were established in aerated half-strength Hoaglands No. 2 nutrient solution (9) in 2-gallon crocks on greenhouse benches. On May 13, 1966 the following treatments were imposed in a split-plot design with 4 replications: main plots - 1) mist, 2) control, 3) heat lamps; sub-plots) - a) 50 ppm Ca/235 ppm K, b) 100 ppm Ca/176 ppm K, c) 150 ppm Ca/117 ppm K, d) 200 ppm Ca/59 ppm K.

Treatments of the main plots were applied every day between 9:00 a.m. and 4:00 p.m. Deionized water mist was applied from fine nozzles for 2 seconds every 3 or 6 minutes depending on the atmospheric conditions. This insured that the leaves were moist but not dripping. Normal greenhouse conditions (21°C night temperature) constituted the control. In treatment 3, 250 watt infrared heat lamps were placed 14 inches above the foliage with one lamp supplying heat radiation to 2 plants.

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