synthesis, as pointed out by Banga et al. (3). No particular color advantage accrues for early vigor in the spring because temperatures warm up rapidly to an unfavorable range (Table 1) before much root sizing occurs (6, 8, 9).

These data suggest that selection for good color may be facilitated by high temperatures. Lines with good color in warm conditions also did well in cool weather, but many lines that did well in cool weather did not develop good color under hotter conditions. A breeder would presumably select lines with good color under a wide range of conditions if all other factors were equal. However, selection of lines with good color in cool weather, but not in warmer weather might also be feasible if higher yield is also related, since most carrots are grown in relatively cool areas or in cool seasons in other areas. Most of the active carrot breeding programs are conducted in northern areas. Cooperative screening under warm conditions such as has been done by this station in cooperation with the Idaho, Michigan, and Wisconsin Stations would seem to offer some promise that varieties giving satisfactory color and other quality factors for warmer conditions may be selected. When color values of F_1 hybrids tested are compared with many of the standard varieties, it is very evident that the breeders have made significant progress in incorporating higher color in their material (Table 4). It is axiomatic that a successful variety must also be satisfactory in numerous other quality factors besides color, as well as yield.

LITERATURE CITED

1. Association of Official Agricultural Chemists. 1960. Official methods of analysis. 9th Ed. Washington, D. C.
2. Banga, O. and J. W. De Bruyn. 1954. Selection of carrots for carotene content. *Euphytica* 3:203–211.
3. ————, ————, and Smeets, L. 1955. Selection of carrots for carotene content : Sub-normal content at low temperatures. *Euphytica* 4:183–189.
4. Barnes, W. C. 1936. Effects of some environmental factors on growth and color of carrots. *Cornell Agr. Exp. Sta. Mem.* 186.
5. Booth, V. H., and S. O. S. Dark. 1949. The influence of environment and maturity on total carotenoids in carrots. *J. Agr. Sci.* 39:226–236.
6. Bradley, G., and D. Smittle. 1965. Carrot quality as affected by variety, planting, and harvest dates. *Proc. Amer. Soc. Hort. Sci.* 86:397–405.
7. ————, and H. Vose. 1966. Obtaining good stands of carrots. *Ark. Farm Res.* 15(2):10.
8. ————, D. Smittle, A. A. Kattan, and W. A. Sistrunk. 1967. Planting date, irrigation, harvest sequence, and varietal effects on carrot yields and quality. *Proc. Amer. Soc. Hort. Sci.* 90:223–234.
9. ————, and R. L. Dyck. 1968. Carrot color and carotenoids as affected by variety and growing conditions. *Proc. Amer. Soc. Hort. Sci.* 93:402–407.
10. Davis, B. H. 1965. Analysis of carotenoid pigments. Chapter 18 of Chemistry and biochemistry of plant pigments. T. W. Goodwin, Ed. Academic Press, New York.
11. Lafarriere, L. 1965. Inheritance of color total carotenoids, alpha-carotene and beta-carotene in carrots. Ph.D. Thesis. Univ. of Wisconsin.

The Influence of Population Density and Competition on Phenotypic Stability of Tomato Plants[1]

B. F. George and L. C. Peirce,
University of New Hampshire, Durham

Abstract. Three varieties, 'Red Top', 'Fireball' and 'Valiant,' and their hybrids were grown in a split-plot design of mixed and pure populations at high and low population densities. The frequencies with which varieties or hybrids were selected for earliness and fruit size within high density (1 ft in-row spacing) and low density (3 ft in-row spacing) plots when genotypes were mixed did not differ significantly. Selections for concentrated ripening within the 2 densities were significantly different. The mean response of hybrids to density change was not significant. The mean response of inbreds to density change was significantly different for earliness and fruit size. Fruit size of the inbreds was also affected by competition when grown in mixed stands.

INTRODUCTION

THE high population density used for mechanical harvesting of tomatoes reportedly alters the expression of certain genetic characters (4, 5, 9, 10). Thus the tomato breeder may question whether to continue the current practice of selecting from a low density population or to select instead from a high population density system when the objective is machine harvestable varieties.

The purpose of this study was to determine whether selection pressure would be equally effective if applied to high density and low density plots having a mixture of genotypes. A related objective was to determine whether naturally pollinated tomato lines and hybrids would maintain equal phenotypic stability between the different densities.

MATERIALS AND METHODS

Three standard varieties, 'Fireball', 'Red Top' and 'Valiant', and their F_1 hybrids were used in this study. Four treatments combining population density and population type comprised the main plots of this split-plot trial. The 2 densities consisted of 3 ft in-row spacing and 1 ft in-row spacing. All rows were spaced 6 ft apart. The population types were mixed, consisting of the 6 varieties and hybrids planted at random, or pure, consisting of a single entry in a plot. Of these 4 treatments, the combination 1 ft pure was used to approach a machine harvestable environment. The 3 ft mixed and 1 ft mixed simulated to some degree a segregating population under low and high population density conditions. The 3 ft pure treatment represented the wider spacings normal in hand-picked tomato plantings.

Each pure plot at a given density contained 6 randomized subplots, 30 ft in length, of each entry. The mixed plots were 180 ft long consisting of randomized genotypes, an equal number drawn from each variety and F_1 entry. Qualitative gene markers, a field map and individual plant labels provided genotype identification. Subplot values could thus be summated from individual plant data within the mixed plots. Four replicates were planted.

Each plant was evaluated for earliness, fruit size, and concentrated ripening. Earliness was recorded as the date when the first fruit reached the breaker stage. Fruit size was calculated as the average weight of the first 10 ripe fruit. Concentrated ripening was expressed as the number of days from first fruit at breaker stage to 10 ripe fruit.

After accumulating single plant data, selections of the superior 5% were made for each character from each mixed treatment. The plants

---

[1] Received for publication July 11, 1968. Published with the approval of the Director of the New Hampshire Agricultural Experiment Station as Scientific Contribution No. 442.

J. Amer. Soc. Hort. Sci. 94:65–67. 1969.

selected were later identified as to their genotype by fruit marker genes, and selection effectiveness was then determined by comparing the frequencies with which each variety or hybrid was selected in high and low densities. The number of plants selected in the low density treatment was equated to the number in high density plots by multiplying by 3. A chi-square analysis could then be used to test differences in frequencies.

The ratio of performance in one environment to performance in another environment was calculated to provide an index of phenotypic stability (1, 3). Maximum stability with this index is equal to 1.

The response of inbreds and hybrids to population type and population density was determined by analysis of variance.

RESULTS AND DISCUSSION

Differences found between mixed and pure populations of genotypes were considered to be due to competition. The term, competition, is used in the genetic sense as proposed by Sakai (6, 7, 8). In this sense competition is plant response to differential stress which may occur in a mixed genotype environment, in contrast to the equilateral stress occurring in a pure genotype stand.

Differences found between population densities of pure stands are considered to be due to equilateral stress, or interference (2) of closely spaced plants. The degree of interference will be referred to in this study as density response.

Response to selection. It was assumed for purposes of chi-square analysis that density would not affect relative performance of entries. Selection, therefore, should yield similar results regardless of the density. Differences in density in this trial did not significantly influence selection effectiveness for earliness and fruit size. However, the selections made for concentrated ripening were substantially different (Table 1). In 3 ft mixed plots, 'Fireball' and the hybrid, 'Fireball' × 'Red Top', were selected with approximately equal frequency for concentrated ripening. In 1 ft mixed plots, however, the hybrid was selected 3.5 times more frequently than 'Fireball'. The decrease in selection frequency of 'Fireball' was attributed both to decreases in mean performance (1.87 days) and in standard error of the mean (.63 days) when in high density plots (Table 2).

Table 1. Chi-square analysis of frequency of entries selected from 3 ft and 1 ft mixed plots for earliness, fruit size and concentrated ripening.

Character	Entry	Number of plants		Chi square
		Selected from 3′ spacing	Selected from 1′ spacing	
Earliness....	Fireball	24	27	
	Fbl × Red	3	2	
	Fbl × Val	6	7	
	Val × Red	3	1	4.97
Fruit size....	Valiant	3	5	
	Fbl × Red	3	3	
	Fbl × Val	30	27	
	Val × Red	0	1	2.13
Concentrated ripening...	Fireball	15	6	
	Red Top	3	2	
	Valiant	0	3	
	Fbl × Red	18	21	
	Fbl × Val	0	2	
	Val × Red	0	3	17.10*

*Values exceeding a chi-square of 7.82 are significant at P = .05.

Table 2. Concentrated ripening means in days for 2 population densities grown in mixed populations.

Entry	Density	
	3 ft	1 ft
Fireball.........	11.07 ± 1.93	12.94 ± 1.30
Red Top........	13.35 ± 2.82	15.23 ± 0.16
Valiant..........	16.26 ± 1.01	15.71 ± 0.89
Fbl × Red......	11.08 ± 1.01	12.27 ± 1.10
Fbl × Val.......	14.28 ± 1.15	15.15 ± 0.74
Val × Red......	14.21 ± 1.10	14.56 ± 0.83

The mean performance of 'Fireball × 'Red Top' also decreased (by 1.19 days) in high density plots, but the standard error increased slightly. Thus, increased selection of 'Fireball' × 'Red Top' appeared to be largely due to its lack of stability for concentrated ripening within 1 ft mixed plots. The plants showing greater concentration were selected.

The relative merit of 1 ft and 3 ft mixed plots as selection environments was also assessed by calculating a stability index using the 1 ft pure treatment means as a common numerator. The ratio of 1 ft pure/3 ft mixed may be compared to that of 1 ft pure/1 ft mixed to determine genotypic stability between the different selection treatments relative to the machine harvestable environment. These data are presented in Table 3. The results suggest that selections from mixed plots of 1 ft spaced plants would maintain stable expression of earliness and fruit size if grown in 1 ft pure stands. Selections from 3 ft mixed plots would be much less likely to show comparable performance in 1 ft pure stands. This tendency reflects primarily the effect of density. Competition did not appear to influence phenotypic expression of most of the genotypes tested.

Table 3. Stability indices of selection environments: ratios of 1 pure treatment means to those of 1 ft or 3 ft mixed treatments for earliness, fruit size, and concentrated ripening.

Entry	Earliness		Fruit size		Concentrated ripening	
	1P/ 3M[a]	1P/ 1M	1P/ 3M	1P/ 1M	1P/ 3M	1P/ 1M
Fireball.....	1.27	0.93	1.00	1.10	1.15	0.99
Red Top....	1.07	1.07	0.96	0.93	1.00	0.88
Valiant......	1.33	0.95	0.91	1.06	0.92	0.95
Inbred avg..	1.22	0.98	0.96	1.01	1.02	0.94
Fbl × Red..	1.16	1.06	0.85	0.94	0.96	0.87
Fbl × Val...	1.09	0.95	0.85	0.95	1.08	1.02
Val × Red..	1.24	1.03	0.82	0.93	1.02	1.00
Hybrid avg.	1.18	1.01	0.84	0.94	1.02	0.96
Total avg...	1.20	1.00	0.90	0.98	1.02	0.95

[a] 1P = mean of 1 ft pure treatment; 3M = mean of 3 ft mixed treatment; 1M = mean of 1 ft mixed treatment.

Level of heterozygosity and stability. The mean earliness of varieties, as a group, was significantly affected by density (Table 4). Hybrid response to density was not significant, and both varieties and hybrids showed little response to competition as reflected

Table 4. Analysis of variance for earliness, fruit size and concentrated ripening.

Source of variation	df	Mean squares		
		Earliness	Fruit size	Concentrated ripening
Replicates..................................	3	20.59*	12.54	3.76
Treatments..................................	3	21.48*	214.57*	6.92
Population type...........................	(1)	.84	1.36	6.31
Population density........................	(1)	63.39*	625.21*	13.65*
Type × density............................	(1)	.22	17.16	.79
Error (a).....................................	9	5.06	22.33	2.08
Main plot total............................	15			
Genotypes....................................	5	220.55*	1,727.59*	48.94*
Inbreds.......................................	(2)	501.38*	2,638.76*	54.08*
Hybrids.......................................	(2)	19.57*	1,275.22*	65.84*
I × H...	(1)	60.94*	809.97*	4.84
Gen. × treatment...........................	15	2.37	21.20*	1.44
Gen × type...................................	(5)	1.15	25.23*	1.18
Inbred × type..............................	(2)	1.82	28.31*	.78
Hybrid × type..............................	(2)	1.01	6.58	2.12
Residual.....................................	(1)	.08	56.40	.11
Gen × density................................	(5)	5.49*	35.27*	2.41
Inbred × density...........................	(2)	12.09*	61.71*	5.88
Hybrid × density...........................	(2)	.82	8.98	.15
Residual.....................................	(1)	1.62	34.98	.00
Gen × type × density......................	(5)	.47	3.10	.73
Error (b)......................................	60	1.90	7.90	10.26
Subplot total.................................	80			
Total..	95			

*significant at .05 level.

by population type. Earliness indices reflecting separate density effects are presented in Table 5. The average stability indices for varieties and hybrids show that the hybrids tended to be more stable and uniform in response to density (Table 5). However, the most stable single entry for earliness was the variety 'Red Top'.

Table 5. Stability indices computed as ratios of density means for earliness and fruit size, and population type means for fruit size.

Entry	Earliness 1/3[a]	Fruit size 1/3	Fruit size P/M
Fireball.....	1.25	1.11	1.11
Red Top....	1.03	1.00	.96
Valiant......	1.40	1.07	1.06
Inbred avg..	1.23	1.09	1.04
Fbl × Red..	1.10	1.18	1.00
Fbl × Val...	1.13	1.16	.98
Val × Red..	1.20	1.13	.93
Hybrid avg.	1.14	1.16	.97

[a] 1 = Mean of 1 ft treatments; 3 = Mean of 3 ft treatments; P = Mean of pure genotype treatments; M = Mean of mixed genotype treatments.

The fruit size of varieties responded to both density and population type (Table 4). Hybrid response was not significant for either treatment. Although average stability over the 2 densities was slightly less for hybrids than for varieties, the indices for individual hybrid phenotypes showed greater uniformity than did those of varieties (Table 5). 'Red Top', however, was again the most stable single entry in density response. 'Red Top' also contributed to the significant competition response of inbreds. As shown by the ratios of pure stand means to mixed stand means in Table 5, its performance paralleled that of the hybrids with slightly larger fruit in the mixed plots than in the pure plots (Table 5). This variety appeared to show aggressiveness, as reflected in fruit size, in mixed populations that was not shown in pure stands.

The mean concentrated ripening for hybrid and non-hybrid groups did not differ significantly. Each entry within both groups was quite variable in performance and the results of the analysis of variance (Table 4) reflect this variability. There is no apparent relationship to level of heterozygosity. It is recognized that little experimentation has been done to assess the criterion for concentrated ripening which was used in this investigation.

The competition observed among the genotypes and the similar response of the hybrids to density change suggest that high density testing and selection be delayed in a breeding program beyond the initial 1 or 2 segregating generations. In this manner the confounding factor of competition might be greatly reduced, since the material would be more homozygous. Also the greater homozygosity, perhaps in F_4 or F_5, could be expected to reveal differences in stability for varying population densities more consistently. If a conscious effort were made to try to assess stability in a selection program, particularly with reference to high density environment, comparative tests of spacing would seem to be required. The earliest generation at which this would be done remains to be determined.

Literature Cited

1. Andrew, R. H. 1967. Influence of environment on stability of corn during vegetative growth. *Crop Sci.* 7:253–256.
2. Harper, J. L. 1965. The nature and consequence of interference amongst plants. *Genetics Today, Int. Congr. of Genet. Proc.* 11:465–482.
3. Lewis, D. 1954. Gene-environment interaction: A relationship between dominance, heterosis, phenotypic stability and variability. *Heredity* 8:333–356.
4. Moore, J. N., A. A. Kattan, and J. W. Fleming. 1958. Effect of supplemental irrigation, spacing and fertility on yield and quality of processing tomatoes. *Proc. Amer. Soc. Hort. Sci.* 71: 356–368.
5. Reeve, E., and W. A. Schmidt. 1952. Influence of plant spacing on canning tomato yields. *Proc. Amer. Soc. Hort. Sci.* 59:384–388.
6. Sakai, K. 1955. Competition in plants and its relation to selection. *Cold Springs Harbor Symp. Quant. Biol.* 20:137–157.
7. ————, and K. Gotoh. 1955. Studies on competition in plants. IV. Competitive ability of F_1 hybrids in barley. *J. Hered.* 46:139–143.
8. ————. 1961. Competitive ability in plants: its inheritance and some related problems. *Soc. Exptl. Biol.* 15:245–263.
9. Vittum, M. T., and W. T. Tapley. 1953. Spacing and fertility level studies with a determinate type tomato. *Proc. Amer. Soc. Hort. Sci.* 61:339–342.
10. ————, and ————. 1957. Spacing and fertility level studies with a paste type tomato. *Proc. Amer. Soc. Hort. Sci.* 69:323–326.

The Effect of Cultural Practices on the Suitability of Cabbage for Once-Over Harvest[1]

C. H. Miller, W. E. Splinter, and F. S. Wright,[2]
North Carolina State University, Raleigh

Abstract. The effects of cultural practices on the yield and uniformity of 2 cabbage varieties were studied during a 3-year period. There was no advantage of using more than 60 lb. of N per acre. Most uniform plants, as measured by variance of head weights, were produced on plots transplanted at a shallow or medium depth although greater yields were usually produced on the deeply transplanted plots. Largest yields of cabbage were produced by plants designated as large at transplanting. There were no important uniformity differences between plant sizes. Spacing of plants 9 inches apart in the row instead of 12 or 15 inches resulted in larger yields. In all experiments, the hybrid variety 'Emerald Cross' was equal to or superior to the non-hybrid 'Round Dutch'. These experiments suggest that the best combination of conditions for once-over harvest is use of large plants of a hybrid variety fertilized with 60 lb. of N per acre and transplanted 9 inches apart in the row at a medium depth.

Introduction

MECHANICAL cabbage harvesters under development in North Carolina (11), New York (6), and Michigan (8) are all based on once-over harvesting. This requires a high degree of uniformity of size of heads in order to obtain commercially feasible yields of marketable cabbage. The trend in varieties has been toward hybrids, many of which are genetically quite uniform. In addition, manipulations of cultural practices markedly influence yields of cabbage and related crops.

Davey (2) reported reduced head size from 3 to 2 lb. each by reducing in-row spacing of plants from 16 to 9 inches. The yields per acre, however, were slightly greater at the 9-inch spacing. Halsey et al. (3) and others (1, 7, 10) have also reported reduced head size at closer spacing but with a nonsignificant increase in yields.

Zink and Arkana (12) reported highest yields of broccoli from 8-inch spacing in 13-inch rows. Spacings were

---

[1] Received for publication August 27, 1968. Published with the approval of Director of Research as paper No. 2697 of the Journal Series.

[2] Departments of Horticultural Science, and Biological and Agricultural Engineering. Dr. Wright is presently Agricultural Engineer, Agricultural Engineering Research Division, U. S. Department of Agriculture, Holland, Virginia.

J. Amer. Soc. Hort. Sci. 94:67–69. 1969.