Carotenes, Xanthophylls, and Color in Carrot Varieties and Lines as Affected by Growing Temperatures[1]

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Abstract. Eleven of 39 varieties and lines resulted in good canned slice color in both unusually warm and unusually cool growing seasons for carrots. A number of lines showed seasonal interaction in color, with better color in the cool season, while others resulted in consistently fair or poor color in both growing seasons. No single pigment was highly correlated with color across the range of environmental and genetic diversity encountered in the study. Beta-carotene was the only single component showing a significant positive correlation with color. The highest multiple relationship with color considered beta-carotene, other carotenes except alpha-carotene, and xanthophylls. Within a season this multiple correlation accounted for 47 to 50% of the color variance (R of .710 for spring and .686 for fall grown carrots).

Introduction

EXTENSIVE studies on carrot production have been made at this station since 1962 (6, 7, 8, 9). A major problem has been obtaining satisfactory color of processed products when the carrots are planted in late winter or early spring because of high temperatures during root sizing (6, 8, 9). Good color has been consistently obtained with fall harvest, but the required summer planting dates result in problems of seedling maintenance (7). In addition Arkansas processors are already heavily scheduled with other early fall harvested crops. Plantings made quite late in the summer avoid the high temperatures which cause seedling mortality, and also mature late enough to avoid the fall rush of other crops. Sometimes, however, unusually cool falls have resulted in color that is not as good as desired, using the presently available varieties (9). Varieties that would develop good color in either warm or unusually cool temperatures would be valuable for this region.

Banga et al. (2, 3) and Booth (5) pointed out that culture and environment greatly affect color and carotenoids within a line or variety, making it difficult to separate genetic and environmental effects. Studies at this station have shown total carotenoids to be unsatisfactory as a measure of color when carrots are produced over a wide range of environmental conditions (8, 9). Beta-carotene has been the pigment best correlated with color, but this also has serious limitations when a wider range of genetic material is utilized. Established varieties were used in much of the earlier work at this station (6, 8, 9), and in most of these color was well correlated with beta-carotene or with beta- and alpha-carotene in a multiple relationship.

The objectives were (1) to discover lines that might be uniquely adapted and, if found, to determine if particular pigment relationships were involved and (2) to relate carotenes and xanthophylls to color over a wide range of genetic diversity and two extremes of temperature during root sizing.

Materials and Methods

Named varieties representing 'Danvers', 'Chantenay', 'Imperator' and 'Nantes' types were obtained from seedsmen[2]. Advanced experimental lines, mostly F_1 hybrids, were also obtained from seedsmen and from the Idaho Agricultural Experiment Station.[3]

Thirty-nine entries were planted in duplicate plots March 14 (spring planting) and August 10, 1967, (fall planting) with respective harvest on June 28 and December 4. These were grown on beds 30 ft long, spaced on 40 inch centers with 2 rows one foot apart per bed. A plant stand of 6 to 8 per foot was achieved by thinning. Irrigation was provided throughout the season, and growth and uniformity of all plots were good. Average weekly temperatures and extremes are shown in Table 1 for the 8 weeks preceding harvest.

Table 1. Temperatures by weeks in the 8 week period preceding harvest in spring and fall carrots. Van Buren, 1967.

Week preceding harvest	Average air temp (F)	Maximum reached	Minimum reached
	Spring		
1	78.8	93	68
2	81.8	95	69
3	79.2	91	68
4	72.9	88	54
5	73.1	89	58
6	66.2	87	49
7	68.3	92	45
8	66.7	87	50
	Fall		
1	41.7	58	25
2	48.7	72	30
3	53.4	73	29
4	54.1	81	26
5	44.7	64	27
6	57.1	78	34
7	60.4	84	34
8	62.0	87	42

Representative samples of 25 to 30 roots were canned as slices immediately after harvest, using standard processing methods, and a known amount of fresh carrots at canning. Cans were opened at random from spring and fall plantings for determination of Hunter a/b color of canned slice blend, total carotenoids, beta- and alpha-carotene by methods previously described (6, 8). Xanthophylls were estimated by methanol extraction (1). Carotenes other than beta- and alpha were estimated by subtracting from the total carotenoids, the xanthophylls and beta- and alpha-carotenes, and this estimate was confirmed by semi-quantitative examination of the pigments by means of circular chromatography on filter paper inpregnated with aluminum oxide or with infusorial earth[4] (10). This technique was especially valuable in confirming unusual

[4]Schleicher and Schuell Nos. 287 and 288.

Table 2. Correlation between Hunter a/b color of canned slice blend and various carotenoid components.

Variables	r		
	Spring & Fall	Spring only	Fall only
Hunter a/b color—total carotenoids	.015	.253**	.372**
Hunter a/b color—beta-carotene	.207**	.350**	.462**
Hunter a/b color—alpha-carotene	.006	.385**	.361**
Hunter a/b color—beta/alpha-carotene ratio	.097	−.353**	−.247*
Hunter a/b color—xanthophylls	−.261**	−.384**	−.177
Hunter a/b color—other carotenes[a]	−.214**	−.300*	−.021
	R		
	Spring & Fall	Spring only	Fall only
a/b—total, beta- and alpha-carotene	.452**	.661**	.522**
a/b—beta-carotene, other carotenes and xanthophylls	.519**	.710**	.686**

[a]Other carotenes are carotenes other than beta- and alpha-carotenes.
*—significant at 5% level.
**—significant at 1% level.

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[2]Asgrow Seed Company, Jos. Harris Seed Company, and Northrup-King Seed Company supplied varieties and lines.

[3]We are especially indebted to Prof. De Lance Franklin of the Idaho Station who has generously shared his breeding material with us.

Table 3. Carrot color, carotenoid components and yield by color response to warm and cool growing seasons. Van Buren, Arkansas. 1967.

Color response grouping	No. of lines	Hunter[a] a/b	Total caro-tenoids	Beta-caro-tene	Alpha-caro-tene	Xantho-phylls	Other caro-tenes	Beta/ Alpha caro-tene ratio	Average yield T./Acre
			Mg per 100 g fresh weight						
Spring[b]									
Good both seasons	11	.70±.04	15.5±1.5	6.0±.05	7.9±1.0	0.9±0.2	0.8±0.1	0.8±0.1	15.9
Poor to fair spring, good fall	6	.52±.07	15.0±2.0	5.1±0.7	7.6±1.4	1.4±0.2	0.7±0.1	0.7±0.1	15.6
Poor spring, fair to good fall	6	.48±.03	12.6±1.3	3.8±0.6	5.6±1.0	1.9±0.3	0.7±0.1	0.7±0.1	17.4
Fair both seasons	7	.59±.03	14.1±1.7	5.4±1.0	6.1±1.3	0.5±0.2	0.9±0.1	0.9±0.1	14.9
Poor both seasons	9	.48±.03	14.3±2.3	5.2±1.3	6.6±1.2	0.8±0.2	0.8±0.1	0.8±0.1	15.1
Fall[c]									
Good both seasons	11	.70±.05	9.1±1.0	4.7±0.5	1.7±0.3	0.8±0.2	0.9±0.2	1.8±0.3	17.6
Poor to fair spring, good fall	6	.76±.04	10.9±0.9	5.6±0.3	3.6±0.3	0.9±0.3	0.8±0.2	1.6±0.2	21.3
Poor spring, fair to good fall	6	.62±.02	7.8±1.0	3.5±0.4	2.1±0.2	1.0±0.2	1.2±0.3	1.6±0.2	20.0
Fair both seasons	7	.60±.03	8.0±1.1	4.3±0.5	2.0±0.3	0.7±0.2	1.0±0.2	2.1±0.2	15.9
Poor both seasons	9	.49±.03	8.3±1.3	4.2±0.6	2.1±0.2	1.3±0.3	0.8±0.2	2.0±0.2	17.5
Spring average	39	.57	14.4**	5.2**	6.9**	1.6**	0.8	0.8	
Fall average	39	.63**	8.8	4.5	2.5	0.9	0.9	1.8 **	

[a]Hunter a/b of canned carrot slices blended with 1 part of water, based on fresh weight of carrots at time of processing.
[b]Planted March 14, harvested June 28.
[c]Planted August 10, harvested December 4.
**Indicates significantly higher value for respective summer or fall mean value by F test.

concentrations of xanthophylls or other carotenes and permitted a look at the particular carotene components involved. All determinations were duplicated at a later time period.

Hunter color of the slice blend was correlated with all pigments in simple and multiple relationships. Lines were classified into 5 groups based on color response to the 2 growing conditions, and means and standard errors were computed. Means were compared on the basis of standard errors to determine if any pigment patterns could be detected relative to the color groups.

Results and Discussion

No single pigment or combination of pigments was highly correlated with color across the range of environmental and genetic diversity encountered (Table 2). Beta-carotene was the only single component positively correlated with color. Xanthophylls and other carotenes were negatively correlated with color. The best multiple correlation obtained was between color and beta-carotene, other carotenes, and xanthophylls, but only 27% of the color variation over both seasons is accounted for by the R of .519. Within the warm and cool seasons, this multiple relationship accounted for 47 to 50% of the color variance, (R's of .686 and .710) indicating that utilizing these factors in selection for color may have some value. Such a selection technique would have to be proven better than selecting for color alone in order to justify the added expense of pigment determinations. Banga et al. (2, 3), Barnes (4), Bradley et al. (8, 9) and others have shown that many variables other than genotype affect the expression of carotenoids in carrots. To account for 50% of the color variation on the basis of pigment relationships may therefore be considered quite good in this study.

Eleven entries developed roots which had canned slice color considered good enough for grade A pack in both seasons, based on previous comparisons of Hunter a/b and ratings of canned slices (6, 8). 'Waltham Hi-Color', 'Hi-Color 9', and 'Carousel' are commercially available of these 11, while the other 8 are F_1 hybrids from the Idaho Station. A camparison of the mean pigment values of these 11 lines with the lines that resulted in fair or poor color in both seasons indicates that the groups with good color tended to have higher total carotenoids, beta- and alpha-carotenes in both growing periods, although none of these differences exceeded the combined standard errors. The group with good color averaged lower xanthophylls in the fall than the poor group. 'Waltham Hi-Color' showed low total carotenoids, and beta-carotene and a low beta/alpha ratio for this group, as had been reported previously (9). This variety also showed a higher amount of other carotenes in relation to xanthophylls (Table 4). Examination of the carotene complex on alumina impregnated paper showed that gamma and delta-carotenes were quite prominent and that zeta-carotene was less prominent than in most varieties. The importance of these findings in relation to color remain to be determined.

Twelve lines showed significantly better color in the fall than in the spring (Table 3). These lines tended to show relatively higher total carotenoids, beta- and alpha-carotene in the fall than spring. These groups had the highest xanthophylls in the spring, but in the fall they did not differ in xanthophylls from the other groups. The lines in the interacting color groups showed good vigor in both plantings, but especially so in the fall, as shown by yields (Table 3). Since much of the fall crop growth was made under quite cool temperatures, a line with early vigor may have made more of its root growth under more favorable temperatures for carotenoid

Table 4. Color and carotenoid pigments of some lines showing different response to warm and cool seasons.

Line		Hunter a/b	Total carotenoids	Beta-carotene	Alpha-carotene	Beta/ alpha	Xantho-phylls	Other carotenes
			mg 100 g fresh weight			ratio		
Good both seasons in color								
Id. 4 (F_1)	S[ab]	.81	13.8	5.6	6.2	0.9	0.9	1.1
	F[a]	.80	9.1	5.4	2.3	2.3	0.7	0.7
Hi-Color 9	S	.74	15.6	5.4	9.0	0.6	0.3	0.9
	F	.70	8.2	4.6	3.0	1.6	0.2	0.4
Waltham	S	.77	12.6	4.9	6.6	0.7	0.4	0.7
Hi-Color	F	.66	7.6	3.1	2.4	1.3	0.7	1.4
Id. 22 (F_1)	S[b]	.68	15.0	6.1	7.0	0.9	1.0	0.9
	F	.65	11.0	6.3	3.7	1.7	0.4	0.6
Carousel (F_1)	S	.68	16.3	5.1	7.8	0.7	1.6	0.8
	F	.65	7.6	3.4	2.0	1.7	1.0	1.2
Interacting with season in color								
Id. 1 (F_1)	S[b]	.49	13.8	4.0	8.4	0.5	1.1	0.3
	F	.85	9.8	5.9	2.7	2.2	0.5	0.4
Id. 48 (F_1)	S[b]	.58	16.6	7.0	9.0	0.8	0.5	0.1
	F	.78	12.0	5.6	3.7	1.5	1.6	1.1
Pioneer (F_1)	S	.50	13.0	4.6	6.4	0.7	1.0	1.0
	F	.66	6.9	3.1	2.1	1.5	0.6	1.1
Royal Chantenay	S	.42	10.9	3.0	3.4	0.7	2.0	1.6
	F	.58	9.3	4.7	2.7	1.7	0.8	1.1
Fair in color both seasons								
Danvers 126	S	.59	13.0	5.8	6.4	0.9	0.5	0.3
	F	.61	8.3	4.6	2.3	2.0	0.7	0.7
Long Imp. 11	S	.56	16.0	7.4	7.9	0.9	0.5	0.2
	F	.56	9.4	4.8	2.3	2.1	1.0	1.3
Id. 36 (F_1)	S[b]	.59	13.4	5.5	6.2	0.9	0.6	1.1
	F	.64	9.3	4.9	2.0	2.4	1.0	1.4
Poor color both seasons								
Long Imp. 58	S	.40	14.8	6.4	6.9	0.9	0.9	0.6
	F	.45	7.7	4.0	2.0	2.0	0.9	0.8
Id. 32 (F_1)	S[b]	.45	12.0	4.3	6.2	0.7	0.8	0.7
	F	.47	7.3	3.2	1.6	2.0	1.4	1.1

[a]S—spring, F—fall.
[b]These are our designations of the Idaho lines. The parentage is available.

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.

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

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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

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