CAROTENOIDS OF CORN AND SORGHUM
III. Variation in Xanthophylls and Carotenes in Hybrid, Inbred, and Exotic Corn Lines[1]

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ABSTRACT

Common hybrids of commercially grown yellow corns supply only part of the xanthophyll pigments desired in poultry rations. Xanthophylls of typical double-cross hybrid yellow dent corns varied from 10 to 30 p.p.m. and carotenes from 1 to 4 p.p.m. The feasibility of breeding high-xanthophyll corn was investigated by a preliminary screening of selected inbred and exotic corn lines of known genetic background. Several inbred samples look promising as sources of the high-xanthophyll character at the 50-p.p.m. level. Some exotic strains from South America, particularly Argentina, contained approximately 60 p.p.m. xanthophylls, which is the highest level found to date. The degree of yellow pigmentation in a cross-section of the endosperm was used for preliminary visual estimation, since outward appearance of the intact seed was not correlated with xanthophyll content. Analyses of several samples indicates that xanthophylls and carotenes may be independently inherited.

The color of yellow corn results primarily from the presence of two general classes of carotenoid pigments, the xanthophylls and the carotenes. Xanthophylls are important in feed grains because they impart desirable yellow color to egg yolks and to the skin and shanks of broilers and fryers. Carotenes serve as vitamin A precursors and as a source of yellow color for milk and body fat of cattle.

Ratcliff *et al.* (6) reported that xanthophylls in yellow corn are more efficiently utilized as broiler pigments than xanthophylls in corn gluten or alfalfa meals. However, as the sole source of these pigments, yellow corn is inadequate, assuming 60% corn in the ration. Corn gluten products often are used as pigment supplements to increase the level of xanthophylls. The amount of gluten meal in mixed feeds is limited by cost and maintenance of proper amino acid balance. Variability of the xanthophylls in these wet-milled fractions concerns the mixed feed manufacturer who desires a dependable low-fiber source

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of these pigments. The variation may reflect differences in the xanthophyll level of the corn used for wet-milling. This possibility is being investigated.

In the present work, variation in the carotenoid level was determined in corn hybrids comparable to the ones processed by wet-millers. Selected samples of exotic strains and inbred lines of known genetic background were analyzed to determine the possibility of breeding high-xanthophyll corn.

Materials and Methods

Double-cross hybrid corns used were typical of those grown commercially in various areas of the United States. Several waxy types were included in this group. Thirty-nine inbred lines of known genetic background were selected phenotypically for variation in xanthophylls, and 17 exotic strains were selected by the same method. Seed of hybrids were taken from test plots of different breeding programs in the eastern half of the United States, whereas the seed of the inbred lines and exotic strains were taken from self-pollinated ears in the Mississippi corn-breeding nursery.

The method for determining xanthophylls and carotenes as well as the distribution of individual carotenoids in the two fractions has been described (1).

Results

Samples of commercial hybrid corns (Table I) showed a three- to fourfold variation in xanthophylls (10–30 p.p.m.) and carotenes (1–4 p.p.m.). The samples grown in Mississippi had average xanthophyll levels lower than those from other geographical areas. However, since a relatively small number of samples were analyzed, the low values may be due to arbitrary selection rather than to true geographical influence. The variation in xanthophylls and carotenes actually might have been greater if the seed had been from selfed or sib-pollinated rather than open-pollinated ears. However, the range for the hybrids should not be as great as for a large number of unselected lines, since differences are masked through crossing.

Inbred lines of yellow corn (Table II) had an even greater range of xanthophylls (5–50 p.p.m.) and of carotenes (0–7 p.p.m.). This variation may be expected, since characteristics are fixed through inbreeding. Several samples looked particularly good as sources of the high-xanthophyll character.

TABLE I

LEVEL OF XANTHOPHYLLS AND CAROTENES IN DOUBLE-CROSS CORN HYBRIDS

Hybrid	Where Grown	Xanthophylls[a]	Carotenes[a]
		p.p.m.	*p.p.m.*
Ga. 7007	Miss.	10.1	1.4
T 7004	Miss.	14.4	3.2
NC 8010	Miss.	17.3	2.4
NC 8008	Miss.	15.6	2.6
Dixie 22	Miss.	16.4	2.7
Ala. 5201	Miss.	24.9	2.7
Miss. 8046	Miss.	15.6	3.0
Miss. 8024	Miss.	13.6	2.6
Miss. 8220	Miss.	15.1	2.2
Miss. 8062	Miss.	17.1	2.3
Miss. 8228	Miss.	16.6	2.6
Miss. 8048	Miss.	17.4	2.5
Minn. 508	Minn.	27.8	2.5
Minn. 509	Minn.	27.9	2.6
Minn. 512	Minn.	25.6	2.7
Minn. 507	Minn.	33.0	3.5
Minn. 611	Minn.	25.5	2.1
Minn. 612	Minn.	27.3	2.2
Ill. 3070	Ill.	19.7	1.8
Ill. 1951	Ill.	21.7	2.0
Ill. 1945	Ill.	21.3	2.1
Ill. 1656-2	Ill.	25.6	2.1
Ill. 1889	Ill.	29.1	2.7
Ill. 1927	Ill.	24.1	2.2
Mo. 804	Mo.	21.0	3.1
Mo. 801	Mo.	24.0	2.7
Mo. 880	Mo.	26.0	3.1
Mo. 924	Mo.	31.9	4.2
ARS 801	Mo.	24.6	2.4
Mo. 860	Mo.	20.6	1.5
V.P.I. 653	Va.	20.9	2.5
U.S. 262A	Va.	21.0	2.1
V.P.I. 648	Va.	23.0	2.4
Va. 556	Va.	22.7	2.1
V.P.I. 426	Va.	28.3	3.1
Va. 126t	Va.	30.8	3.3
Commercial Seed			
Light-yellow dent	Ill.	26.0	1.9
Light-yellow waxy	Ill.	27.6	2.0
Dark-yellow dent	Ill.	31.5	2.6
Dark-yellow waxy	Ill.	30.5	2.6
Yellow dent	Ill.	24.3	1.9
Yellow dent	Ill.	29.3	2.1
Yellow dent	Ill.	19.1	1.8
Yellow dent	Ill.	17.5	1.4
Yellow waxy	Ill.	25.2	2.1
Yellow dent	Ill.	30.9	3.2

Regression line:
Xanthophylls, p.p.m. = 3.82 (carotenes, p.p.m.) + 13.67
95% confidence limits for b = 0.98 to 6.66
$r^2 = 14.3\%$

[a] Values calculated on 10% m. b.

TABLE II

LEVEL OF XANTHOPHYLLS AND CAROTENES IN INBRED LINES OF CORN

INBRED LINE	XANTHOPHYLLS[a]	CAROTENES[a]
	p.p.m.	*p.p.m.*
MP 1	48.0	4.1
MP 414	19.3	5.9
MP 420	46.2	5.1
MP 424	12.8	5.1
MP 426 cms RfRf	42.7	4.6
MP 428	16.9	1.2
MP 440	32.8	3.5
MP 442	19.6	2.3
MP 444	27.7	5.7
MP 446	3.7	0.2
MP 448	18.6	2.2
MP 460	14.5	1.3
MP 464	36.1	4.9
MP 468[3] cms RfRf	33.0	3.1
MP 480	18.3	1.0
F44	24.0	3.1
CI 82C	17.6	3.6
CI 88	23.0	3.4
T204	13.4	1.3
SC 149	12.1	4.2
Y. Jel. 54	19.1	3.1
Y. Jel. 88	44.0	7.2
Kls 143D	31.2	3.4
Miss. 1100.3-4	18.7	4.6
Y. Pay. 92[3] cms RfRf	29.0	3.3
AB 18	14.7	0.6
Tx 4601	27.8	5.8
MP1 X T61	39.9	3.3
Kls 143D X MP 424, F_8	29.0	1.9
NC 224 X MP 414, F_4	15.6	0.7
NC 224 X MP 428, F_4	17.1	1.1
NC 224 X MP 482, F_4	19.8	1.3
NC 88 X MP 414, F_4	19.8	1.2
NC 88 X B 41, F_3	18.6	0.9

Regression line:
Xanthophylls, p.p.m. = 3.41 (carotenes, p.p.m.) + 13.87
95% confidence limits for b = 1.66 to 5.16
$r^2 = 33.0\%$

[a] Values calculated on 10% m. b.

Analyses of exotic yellow strains (Table III) showed a range in xanthophylls of 5 to 60 p.p.m. and in carotenes of 1 to 5 p.p.m. The high and low samples are indicated for each introduction. The strains from South America, particularly Argentina, contained about 60 p.p.m. of xanthophylls, which is the highest value found to date. Samples from Turkey were the lowest as a whole, but there were a few selections containing approximately 35 p.p.m. The Turkish strains were a bright light-orange color compared with the dark orange of the Argentine strains. Both were flint-type corns with endosperm composed mainly of horny starch.

TABLE III
LEVEL OF XANTHOPHYLLS AND CAROTENES IN EXOTIC STRAINS OF CORN

EXOTIC STRAIN	XANTHOPHYLLS [a]	CAROTENES [a]
	p.p.m.	*p.p.m.*
Lombardo 20	45.7	5.1
Sprague exotic selection	49.5	3.4
Italian high xanthophyll	34.2	2.2
PI 162574 – High	54.9	3.9
– Low	38.0	4.2
PI 162700 – High	57.7	5.5
– Low	33.8	3.1
PI 162702 – High	50.6	4.1
– Low	41.7	2.4
PI 186217 – High	58.3	3.0
– Low	51.1	3.3
PI 198892 – High	51.9	5.2
– Low	36.4	4.4
PI 226685 – High	39.6	4.4
– Low	34.9	3.6
PI 175984 – High	9.0	2.2
– Low	6.8	1.1
PI 185074 – High	18.6	1.0
– Low	13.4	0.7
PI 239573 – High	36.4	3.6
– Low	23.8	2.4
PI 221853 – High	38.8	3.0
– Low	27.9	2.8
PI 186191 – One sample	47.3	5.1
PI 183737 – One sample	15.0	1.3
PI 204829 – One sample	11.5	1.8
PI 204830 – One sample	12.5	1.1

Regression line:
Xanthophylls, p.p.m. = 9.19 (carotenes, p.p.m.) + 6.22
95% confidence limits for b = 6.41 to 11.97
$r^2 = 64.7\%$

[a] Values calculated on 10% m. b.

Discussion and Conclusions

The variation in carotenoid content of corn with known genetic background indicates that the breeding of high-xanthophyll corn is distinctly possible. The goal would be a commercially acceptable corn that would supply the total xanthophylls desired in the feed. Assuming a poultry ration with 60% corn and that approximately 25 p.p.m. of xanthophylls in the whole ration are necessary for adequate pigmentation (3,4,5), a xanthophylls level of 40 to 45 p.p.m. in the corn grain would be required. The content of some of the pure lines available for hybrid combinations is within this range. At present, these high-xanthophyll corn lines are mostly of the flint type rather than the preferred dent type. However, screening of additional samples may reveal dent or semi-dent types with a comparable xanthophyll content. In addition, further research will be directed toward introducing the high-xanthophyll character into standard yellow dent lines.

Production of high-xanthophyll dent corn could be of considerable value in the United States export market. Japanese millers, for example, reputedly purchase quantities of Argentine corn because of its high level of xanthophylls.

Lack of a strong relationship between xanthophylls and carotenes indicated that these two types of carotenoids may be independently inherited. At best, the index of determination (r^2) was only 64.7%, which was shown by the exotic strains (Table III). Therefore calculation of xanthophyll level from data on carotenes (5) may give erroneous results. Lower ratios of xanthophylls to carotenes in the samples grown in Mississippi contributed to the low index of determination (14.3%) in the double-cross corn hybrids (Table I). The index becomes 45.5% when these values are not included in the calculations.

Brunson and Quackenbush (2) reported positive and highly significant correlations between provitamin A content and most of the inactive polyenes in corn. However, zeaxanthin showed no significant correlation. Analyses of individual carotenoids in a limited number of our corn samples, particularly of the flint type, indicated that zeaxanthin was the major xanthophyll. Therefore, variation of zeaxanthin content may be a major factor contributing to the lack of strong correlation between xanthophylls and carotenes.

Outward appearance of the whole corn was not a reliable guide for predicting carotenoid content, but preliminary estimates can be made by observing the proportion and degree of yellow pigmentation in the horny endosperm. A cross-section of the seed at the apex of the coleoptile must be inspected, since in a longisection the horny endosperm area located near the pericarp in some strains cannot be observed. In addition, very thin regions containing horny starch were more apparent in a cross-section. Since pigmentation was more apparent in the horny endosperm than in the floury, the amount and types of carotenoids in these two fractions are currently being investigated.

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