

Genetic Variation in Color of Sweetpotato Flour Related to Its Use in Wheat-Based Composite Flour Products

LILIA S. COLLADO,¹ LINDA B. MABESA,² and HAROLD CORKE^{1,3}

ABSTRACT

Cereal Chem. 74(5):681-686

Sweetpotato flours vary widely in color depending on genotype, and when used in wheat-based composite flours, they will impart characteristic colors which may be favorable or unfavorable for particular food products. Sweetpotato flour (SPF) was prepared from 44 genotypes and analyzed for proximate composition and biochemical properties. The Hunter Color L^* , a^* , b^* values of the dry SPF and their modified Pekar slicks (PS) with water and with alkali were measured. Polyphenol oxidase activity, α -amylase activity, and total sugar were significantly correlated to L^* values of dry SPF and of their PS tests with water and with alkali. The yellow pigment level was significantly correlated to the yellowness (b^*) of the dry flour and of the PS test with water, but less cor-

related to b^* of the PS test with alkaline. The results indicated a complex biochemical basis to SPF color, and no single biochemical factor examined was adequate to predict the color of a food product made from SPF. However, the PS color parameters were highly correlated with the color of dough sheets for white-salted and yellow-alkaline noodles made from wheat and sweetpotato composite flour (75:25). Thus, the simple modified PS test could be used in screening of genotypes for color stability and suitability for a specific end-use. SPF genotypes conferred a wide range of colors on composite flour dough preparations. Some colors, particularly the range of greens and bright orange, may be useful in specialty product development.

The utilization of particular types of sweetpotato (*Ipomea batatas*) for food depends mostly on local or regional food preferences. In most temperate countries, the sweet dessert types are preferred and have been used successfully as canned tubers, baby food, and patties. Processing the perishable sweetpotato tuber into intermediate products such as flour and starch, which are more stable and less bulky, widens the potential opportunities for its utilization. There have been several attempts to use sweetpotato flour (SPF) in different food products such as butter cookies, pretzels, cakes, hotcake mixes, and instant porridges, and as a composite with wheat in the production of noodles and bread (Angue and Inocencio 1992, Truong 1992, Amante 1993, Collado and Corke 1996). These products have specific quality requirements, and quality standards for the SPF should be devised for each end-use. Color is a critical sensory attribute that affects consumer acceptance, that is, color is a dominant factor in assessing the commercial value of Japanese noodles (Yasunaga and Uemura 1962). The significance of color in product development from SPF, particularly in the Asian context, should not be underestimated. SPF is being tried in products such as steamed bread and cakes which are common staple foods in Asia. In these products, the addition of lye is common for acid neutralization and development of appropriate flavor and texture (Ding and Zheng 1991), so pH-dependent color effects should be considered. The alkaline Pekar slick (PS) test was used to evaluate wheat flour components that affect the color of Cantonese noodles (Miskelly 1984). Previously, we showed that white-salted and yellow-alkaline noodles could be made from a wheat and sweetpotato composite flour (75:25) with texture similar to an all-wheat control (Collado and Corke 1996).

Polyphenol oxidase (PPO) occurs widely in plants and plays the major role in enzymatic browning reactions in food. In wheat-based products, PPO activity was involved in the discoloration that affects the acceptability of certain products like noodles (Miskelly 1984; Kruger et al 1992, 1994; Baik et al 1995), Chinese steamed bread (Dexter et al 1984), Middle Eastern flat breads (Faridi 1988), and chapattis (Edwards et al 1989). PPO

variants purified from wheat bran differed in their stability and were very substrate specific (Singh and Sheoran 1972, Tikoo et al 1973), so the major phenolic compound present as a potential substrate is not necessarily the major cause of browning (Lea 1992). Conflicting reports have been published on the pH optimum of the PPO enzyme even from the same source. Edwards et al (1989) reported a pH optimum for catechol oxidases (phenolase, PPO, tyrosinase, catecholase) to be between pH 5 and 7. There were reports on differences in pH optimum depending on the phenolic substrate being oxidized (Mayer and Harel 1979). PPO purified from sweetpotato had a pH optimum ranging from 4.5 to 6.5, depending on the substrate (Lourenco et al 1992).

In the present study, the aims were to: 1) characterize SPF from a wide range of genotypes, including highly colored varieties, for compositional and biochemical properties related to color development; 2) test a simple method of color evaluation, the Pekar slick test, for its suitability for prediction of color in products made with SPF; and 3) identify sweetpotato genotypes with unusual and attractive colors with potential for new product development.

MATERIALS AND METHODS

Preparation of SPF

A set of 44 sweetpotato genotypes representative of varieties and advanced breeding lines adapted to Philippine conditions were supplied by the Asian Sweetpotato and Potato Research and Development program, Philippines. They were grown in uniform field conditions for yield trials, and harvested after three months cultivation in Tarlac, Philippines. The roots were processed into flour at the Institute of Food Science and Technology, University of the Philippines, Los Baños. The roots were washed, peeled, sliced thinly, soaked in 0.1% sodium metabisulfite, dried in a convection dryer at 50°C and then ground in a cyclone sample mill (Udy Corp., Fort Collins, CO) into a flour that could pass through a 60–80 mesh screen (212 μ m aperture). The flours were sealed in polyethylene bags and shipped to Hong Kong. All experiments were conducted in Hong Kong.

Analytical Methods

SPF were analyzed by AACC (1995) methods for crude protein (Method 46-13), moisture (Method 44-15A), total ash (Method 08-01), total starch (Method 76-13), reducing sugar content (Method 80-60), diastatic activity (Method 22-15), and yellow pigment content (Method 14-50). Also analyzed were crude fat

¹Cereal Science Laboratory, Department of Botany, University of Hong Kong, Pokfulam Road, Hong Kong.

²Institute of Food Science and Technology, University of the Philippines, Los Baños, Philippines.

³Corresponding author. Fax: +852 28583477. E-mail: harold@hkusua.hku.hk

(Soxtec system HT6, Tecator AB, Höganäs, Sweden), total free sugar using the phenol sulfuric method (Dubois 1956), and TCA soluble nitrogen content (Adler-Nissen 1986). The dietary fiber content (percent) was approximated by subtraction of starch, sugar, protein, lipid, and ash from 100. PPO activity was measured by monitoring O₂ uptake using a biological oxygen monitor (model 5300, Yellow Springs Instrument Co., Inc., Yellow Springs, OH) following Marsh and Galliard (1986) with slight modifications. The temperature used for determination of PPO activity was 37°C, a phosphate buffer at pH 7.0 was used (Edwards 1989), and the values were corrected for autoxidation of substrate.

Modified Pekar Slick Test

The modified Pekar Slick (PS) test (see Method 14-10 of AACC 1995, Miskelly 1984) involved pressing the flour to a smooth surface, immersing in water for 2 min, and allowing the sample to stand under a cover glass for 2 hr before measurements were taken. We used a combination of the features of the method of Miskelly (1984) and the dough-ball method of Kruger et al (1992), which involved the stirring of an alkaline solution into 25 g of flour in a beaker over a 1-min period, forming a ball. The dough ball was flattened, and measurements of color (Hunter *L**, *a**, *b**) were taken on the flattened ball using a Minolta CR-300 chromameter (Minolta Camera Co., Ltd., Tokyo, Japan).

For the PS test with water, the SPF sample (5.0 g, db) was weighed into a 100-mL beaker to which distilled water was added to make a final moisture content of 40%. This was mixed with a spatula for 2 min until a homogeneous mixture of uniform color was achieved. The mixture was placed in a transparent plastic container (4.5 cm diameter, 2 cm in height), smoothed to a flat surface, and covered with a tight-fitting lid to prevent drying. The color was read after 2 hr using the chromameter.

For the PS test with alkaline using lye water, the SPF sample (5.0 g, db) was weighed into a 100-mL beaker to which solution was added to make a final moisture content of 40%. The solution contained lye water, made from Na₂CO₃ and K₂CO₃ (9:1) adjusted to achieve a 1% concentration (w/w) in the flour. The mixture was then treated as for the PS test with water.

Noodle Dough Sheet Preparation

A commercial Hard Red Winter wheat flour blend (Red Bicycle brand) widely used in Hong Kong for noodle production was purchased from Hong Kong Flour Mills, Kowloon, Hong Kong, and used in the wheat-sweetpotato composite flours that were used for preparation of dough sheets for color evaluation. Yellow-alkaline noodle (YAN) and white-salted noodle (WSN) dough sheets were prepared according to Moss et al (1986), using Red Bicycle wheat flour in the ratio 75:25 (w/w) for wheat and sweetpotato flour. For the composite flour, the amount of water used was increased from

32 to 40%. The dough sheet was kept in polythene bags at room temperature (20–25°C) for 24 hr before color readings in three areas were made using the chromameter.

Statistical Analysis

All analyses were replicated twice. The genotype means, standard deviation of genotype means (SD), and least significant difference (LSD) for comparison of genotype means for each parameter were determined. Pearson correlation coefficients of the flour properties with the modified PS test color readings were calculated. A multiple regression analysis of the PS test color values with the flour properties was performed using a forward stepwise procedure, in which only significant factors were included to minimize the error mean square (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Proximate Composition and Biochemical Properties of SPF

On a dry weight basis, carbohydrates were the major constituents of the SPF samples (Table I), with a mean starch content of 71.7%, ranging from 57.5% in 88ws623 to 79.6% in 30-Inubi. The total free sugar content ranged from 6.7% in 89-2-10 and VSP-6 to 22.7% in 88ws623 with a mean of 11.3%. These results were comparable to the ranges reported by Bradbury and Holloway (1988) of 44.3–73.7% for starch and 3.4–19.8% for sugars. Total sugar as high as 23.6% for uncooked sweetpotato has been reported (Martin and Deshpande 1985). The starch content mean in our study is slightly higher than the mean of 68.1% for sweetpotato grown under post-rice rain-fed conditions (Amante et al 1992) and grown in upland rain-fed open field conditions with 69.6% for starch and 9.7% for total free sugar (Rasco et al 1992) in the Philippines. Lower free sugar content was, as expected, associated with higher starch content. Starch content was significantly negatively correlated with fiber content ($r = -0.78$, $P < 0.001$), total free sugar ($r = -0.55$, $P < 0.001$), and ash content ($r = -0.39$, $P < 0.01$).

The protein contents were generally low, ranging from 1.0% in No.-65-CIP to 5.3% in CN94625, with a mean of 3.9%. The reported protein content in sweetpotato ranged from 1.5 to 11.1% (Bradbury and Holloway 1988). Fat content ranged from 0.1% in Inagahapon to 1.9% in 30-Inubi with a mean of 0.6%. Previously reported crude fat contents ranged from 0.1 to 0.8%, while ash content ranged from 2.5 to 2.9% (Bradbury and Holloway 1988). The ash contents ranged from 1.3% in 12-Tres-Colores to 2.5% in Binoras-23 with a mean of 1.9%. The fiber content ranged from 2.3% in Adams-3 to 19.3% in VSP-6, with a mean of 10.3%. These values are generally higher than those reported previously, which ranged from 4.1 to 9.5% (Bradbury and Holloway 1988, Amante et al 1992, Rasco et al 1992).

The total PPO activity (nmol O₂/min/g of SPF) from the different genotypes ranged from 7 in OPS44 to 336 in V37-151 with a mean of 132 (Table II). α -Amylase activity (Ceralpha units/g of SPF) ranged from 0.26 in VSP-6 to 11.1 in 46-12A with a mean of 2.0. The reducing sugar (%) ranged from 1.2 in BPISP2 to 12.0 in CN94132 with a mean of 4.9 (Table I). The α -amylase activity was not correlated with reducing sugar content or total sugar content of the SPF, although the total and reducing sugar contents were significantly correlated ($r = 0.64$, $P < 0.001$). Collins (1982) also observed an apparent wide diversity in these characteristics among sweetpotato genotypes. Sweetpotato can be classified into four groups based on initial sugar concentration and its change during cooking: 1) low sugar/low starch hydrolysis, 2) low sugar/high starch hydrolysis, 3) high sugar/low starch hydrolysis, and 4) high sugar/high starch hydrolysis (Morrison et al 1993). These differences may be attributed to several factors, such as the rate of inactivation of α - and β -amylases, differences in starch gelatinization temperature, presence of enzyme inhibitors, and starch structural resistance to hydrolysis (Martin and Deshpande 1985, Morrison et al 1993, Takahata et al 1994).

TABLE I

Mean and Range Values for Compositional Parameters (% dry basis) and Color of Sweetpotato Flour from 44 Genotypes

	Minimum	Maximum	Mean	SD ^a
Starch	57.5	79.6	71.7	5.46
Sugar	6.8	22.7	11.3	3.33
Protein	1.0	5.3	3.9	0.79
Fat	0.06	1.90	0.60	0.38
Ash	1.28	2.53	1.89	0.28
Fiber	2.3	19.3	10.3	4.49
Soluble nitrogen	0.04	0.24	0.12	0.04
Reducing sugar	1.18	12.0	4.94	2.45
Color ^b				
<i>L</i> *	86.6	99.2	95.5	2.69
<i>a</i> *	-0.58	2.62	0.11	0.52
<i>b</i> *	-0.88	13.9	2.97	2.67

^a Standard deviation for variation in genotype means ($\alpha = 0.05$).

^b *L** = brightness (measures total light reflected), *a** = redness, *b** = yellowness.

Yellow pigment as carotenoids ($\mu\text{g/g}$ of SPF) ranged from 2.9 in G-139-21 to 150.6 in P16 with a mean of 13.8. In sweetpotato, selected deep yellow varieties are a rich source of pro-vitamin A in the form of the pigment β -carotene (Oke 1990). The soluble N (%) ranged from 0.04 in VSP-6 to 0.2 in CN1425170 with a mean of 0.12.

Color of SPF

The mean L^* value of the dry flour was 95.5 with the lowest value of 86.7 in Inubi Zambales, a purple variety, and the highest value of 99.2 in G88, a white variety (Table I). The mean a^* value was 0.11 with the highest value of 2.62 (the most red), observed in Inubi Zambales and lowest value of -0.58 (slightly yellow) in VSP-7. The mean b^* value was 3.9, the highest in P16 with 13.9 and the lowest in G-139-21 with -0.05 . These colors changed drastically in the two types of modified PS test.

Modified PS Test

The highest L^* values, 74.0 and 70.1 in the modified PS test with water and alkali respectively, were from UPLSP2, a white variety. The lowest L^* values, 37.3 and 28.4 for the PS test with water and alkali respectively, were observed in PNG-L6, a purple variety (Table II). A marked decrease in brightness was observed in all genotypes as the flour was moistened with water or alkali. The lowest L^* was observed for all genotypes in the modified PS test with alkali. The correlation coefficients of the color of the dry flour and of the PS test with water and with alkali, with some flour properties (Table III) indicated higher correlations between the PS test color values and the dry flour color values than with the biochemical properties of the SPF.

The total PPO activity was very significantly correlated to the L^* value of the dry flour color ($r = -0.54$, $P < 0.001$), and even

TABLE II
Biochemical Properties and Pekar Slick (PS) Color^a of Sweetpotato Flour from 44 Genotypes

Genotype	PPO ^b	α -Amylase ^c	Pigment ^d	PS (with water)			PS (with alkali)		
				L^*	a^*	b^*	L^*	a^*	b^*
CN94625	27	1.01	6.49	62.4	2.96	18.7	55.0	0.44	18.9
CN94132	43	0.29	4.69	60.2	3.73	18.9	53.4	-0.56	23.2
CN148989	322	1.74	7.55	57.1	3.64	18.8	45.8	-2.45	17.6
CN1425170	55	1.22	89.8	57.4	8.35	29.5	54.9	5.36	29.9
BPISP2	94	0.57	11.6	68.1	1.57	18.9	62.8	-2.35	21.5
Miracle	70	0.50	10.5	61.1	3.40	19.1	53.8	1.86	21.1
26-Pariados	17	0.65	12.9	65.7	2.42	19.3	60.1	1.04	23.1
13b-Tres-Colores	28	0.32	8.03	66.0	3.30	18.1	58.1	-0.07	19.5
Binicol	72	0.61	9.23	61.4	3.59	19.4	56.4	1.33	22.7
30-Inubi	111	0.34	10.4	58.8	5.15	18.3	52.5	-2.23	16.1
Adams-3	110	0.77	7.03	66.9	2.02	16.5	60.2	-2.51	19.7
P5	132	2.46	11.5	56.6	3.06	19.3	51.0	-2.04	18.3
P16	295	2.07	150	50.6	9.57	28.2	44.8	2.14	23.6
No.-46-CIP	199	2.05	9.14	52.3	4.87	17.9	46.1	0.23	16.6
NTA1023	238	0.88	12.0	67.7	2.30	18.7	61.7	1.03	23.4
12-Tres-Colores	114	0.51	8.21	64.6	3.67	18.9	58.2	-2.36	22.9
Binoras-23	165	0.63	11.8	48.9	6.64	17.2	40.2	1.04	17.3
Inubi-Zambales	132	0.96	4.93	39.7	6.78	13.6	28.7	-3.19	4.5
Catanduanes	130	1.05	15.3	62.0	2.74	20.2	56.6	0.65	21.8
Taiwan	253	2.44	11.6	45.1	6.49	18.6	36.8	-1.93	12.6
Bureau	135	2.12	10.1	58.7	4.28	20.2	51.7	-1.40	22.1
No.-65-CIP	160	2.03	5.41	40.5	6.27	15.1	30.5	-3.12	7.9
L002	149	1.10	11.7	55.1	3.55	20.0	47.3	0.52	20.1
NPSP	138	0.74	5.41	68.3	1.20	17.1	59.8	-2.99	21.6
PNG-L6	263	9.11	7.43	37.3	5.54	14.3	28.4	-2.30	6.4
UPLSP2	34	0.66	8.15	74.0	0.86	18.2	70.1	-0.26	24.1
UPLSP5	36	0.91	3.97	60.1	3.89	18.1	50.6	0.11	20.6
46-12A	220	11.1	5.35	58.1	3.79	19.0	50.2	-0.12	17.7
89-2-10	97	0.72	8.75	70.4	0.18	16.1	64.3	-1.20	20.7
88ws623	279	3.08	13.1	51.6	6.12	20.3	45.4	-0.71	19.3
G88	54	0.61	8.18	72.3	1.17	17.5	68.4	-0.34	23.0
25-11A	113	0.83	6.28	68.9	1.66	16.5	63.4	-1.83	19.4
G-139-21	100	0.53	2.92	66.6	2.03	16.4	60.1	2.08	22.3
93-006	16	0.99	10.9	68.9	2.86	18.9	66.6	-2.40	20.9
VSP-6	126	0.97	3.64	60.0	3.68	18.3	53.6	0.65	18.5
VSP-6	34	0.26	15.7	67.7	3.35	20.0	60.4	-0.07	23.4
V37-151	336	6.01	6.25	48.8	5.86	16.2	40.7	-0.69	16.3
OPS44	7	5.00	4.15	67.2	2.66	15.4	62.2	-4.65	20.2
VSP-7	64	1.95	15.7	54.8	5.23	21.6	51.6	-0.09	22.1
V30-595	21	1.93	6.67	65.3	3.29	18.2	58.1	-3.05	21.9
OP101-R89	31	2.54	4.66	61.0	3.65	17.6	54.3	-0.80	20.6
OPS101	328	4.10	6.46	44.9	5.44	16.6	36.7	-3.20	11.9
Inagahapon	137	8.35	4.03	64.6	2.59	15.8	54.4	-0.87	21.2
UPLSP4	311	2.24	17.7	53.0	5.17	18.2	44.3	-1.01	18.7
Mean	131.7	2.02	13.8	59.3	3.88	18.5	52.6	-0.73	19.4
SD _(0.05) ^e	97.2	2.41	24.7	9.02	1.98	2.84	10.2	1.88	4.76
LSD _(0.05) ^f	7.2	0.12	0.60	0.65	0.78	0.73	0.73	4.22	0.87

^a L^* = brightness (measures total light reflected), a^* = redness, b^* = yellowness.

^b Polyphenol oxidase activity, nmol O_2 /min/g.

^c Ceralpha unit/g

^d Yellow pigments as carotenoids, $\mu\text{g/g}$.

^e Standard deviation for variation in genotype means ($P < 0.05$).

^f Least significant difference for comparison of treatment means ($\alpha = 0.05$).

more highly correlated to the L^* values of the PS with water ($r = -0.62, P < 0.001$), and with alkali ($r = -0.64, P < 0.001$). PPO had the highest correlation to the L^* values of the two PS tests among all the biochemical properties determined.

The α -amylase activity was significantly negatively correlated to the L^* value of dry flour ($r = -0.34, P < 0.05$), PS with water ($r = -0.37, P < 0.05$), and PS in alkali ($r = -0.38, P < 0.05$), but much less correlated than PPO activity. The yellow pigment content was highly significantly correlated to the b^* value of the dry flour color ($r = 0.79, P < 0.001$) and of the PS with water ($r = 0.81, P < 0.001$), but much less correlated to that of PS in alkali ($r = 0.32, P < 0.05$). In wheat flour, carotenoids, principally xanthophylls, together with flavone compounds are responsible for the yellow color of the flour. Colorless flavones present in flour undergo a chromophoric shift to yellow color under alkaline conditions. Advantage is taken of this in the production of yellow noodles where an alkaline solution is used to develop the desired color (Miskelly 1984). In SPF however, the yellow pigments may be present with other pigments, possibly anthocyanins, which form colors that affect the red-green chromaticity, as seen in increased correlation of the yellow pigment content to the a^* value of the PS with water ($r = 0.58, P < 0.001$) and of the PS with alkali ($r = 0.48, P < 0.001$), compared with that to the a^* value of dry SPF ($r = 0.35, P < 0.05$). Although not analyzed in

this study, anthocyanins are the major pigment in red, purple, and blue colors of fruits and vegetables (Penfield and Campbell 1990).

The total sugar content was significantly negatively correlated with the L^* value of the dry flour ($r = -0.35, P < 0.05$), and the correlations increased in the PS with water ($r = -0.54, P < 0.001$) and the PS with alkali ($r = -0.51, P < 0.001$). However, the reducing sugar content, although significantly correlated with the total free sugar content ($r = 0.64, P < 0.001$), did not correlate significantly with any color attribute of the dry flour and the PS tests. Carbonyl-amine (Maillard) browning or nonenzymatic browning is affected by pH, temperature, moisture content, and water activity, as well as the sugars and amino acids available. The specific sugars and amino acids involved and other reaction conditions affect the flavor development, as well as the rate and extent of browning (Penfield and Campbell 1990). Pentoses are more reactive than hexoses, and sucrose being a nonreducing sugar, does not participate in Maillard browning. The major free sugar found in raw sweetpotato is sucrose followed by glucose, fructose, and traces of verbascose (Truong 1986). Nonenzymatic browning increases with increasing pH especially in the 7.8–9.2 range (Whistler and Daniel 1985), which is close to the pH of the PS test in alkali.

Ash content, although not significantly correlated to the L^* value of dry SPF, was significantly correlated to the L^* values of

TABLE III
Correlation Coefficients of Dry Flour Color^a and the Modified Pekar Slick (PS) Color with Some Biochemical Properties of Sweetpotato Flour^b

	Dry Flour Color			PS (with water)			PS (with Alkali)		
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
L^* (flour)	...	...	...	0.87***	-0.72***	0.17	0.88***	0.21	0.81***
a^* (flour)	...	...	...	-0.25	0.39**	0.00	-0.25	-0.07	-0.32*
b^* (flour)	...	...	...	-0.57***	0.84***	0.66***	-0.51***	0.39**	0.06
PPO ^c	-0.54***	-0.07	0.43**	-0.62***	0.47**	-0.02	-0.64***	-0.10	-0.44**
α -Amylase	-0.34*	-0.06	0.14	-0.37*	0.19	-0.20	-0.38*	-0.19	-0.35*
Pigment	-0.11	0.35*	0.79***	-0.15	0.58***	0.81***	-0.08	0.48**	0.32*
Soluble nitrogen	0.07	-0.07	0.17	-0.10	0.17	0.17	-0.15	0.12	0.11
Reducing sugar	-0.13	0.18	0.06	-0.20	0.02	-0.08	-0.20	-0.07	-0.19
Total sugar	-0.38*	-0.13	0.41**	-0.54***	0.47**	0.11	-0.51***	-0.01	-0.25
Ash	-0.15	-0.04	0.30	-0.39*	0.40**	0.23	-0.38*	0.52**	-0.03
Protein	0.21	-0.08	0.06	0.04	0.03	0.30*	0.04	0.45**	0.25

^a L^* = brightness (measures total light reflected), a^* = redness, b^* = yellowness.

^b $n = 44$. *, **, *** in the data refer to significance level at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

^c Polyphenol oxidase activity, nmol O_2 /min/g.

TABLE IV
Multiple Regression Analysis of the Color^a of the Modified Pekar Slick (PS) Test with Some Biochemical Properties of Sweetpotato Flour (SPF)^b

	PS (with water)			PS (with alkali)		
	L^*	a^*	b^*	L^*	a^*	b^*
Intercept	-224.9	24.4	-46.0	-264.6	-9.29	-167.8
Coefficients						
SPF L^*	0.91***	-0.35**	0.61**	0.90***	...	1.10***
SPF a^*	0.21*	...	...	0.20*	...	0.09*
SPF b^*	...	0.51***	0.92***	...	...	0.06***
PPO ^c	-0.19*	...	-0.16*	-0.22*	-0.29	-0.18
α -Amylase	...	...	...	...	...	...
Yellow pigment	...	...	0.17*	...	...	...
Soluble nitrogen	-0.22**	...	...	0.12*	...	-0.08*
Reducing sugar	...	-0.25**	...	...	...	...
Total sugar	...	0.24**	...	...	...	...
Ash	...	0.19*	...	...	0.50***	...
Protein	...	...	...	...	0.32*	...
Multiple correlation, R	0.95***	0.93**	0.93***	0.95***	0.82***	0.95**

^a L^* = brightness (measures total light reflected), a^* = redness, b^* = yellowness.

^a $n = 44$. *, **, *** in the data refer to significance level at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

^b Polyphenol oxidase activity, nmol O_2 /min/g.

both the PS test with water and of the PS test with alkali, and more significantly to the a^* values of the PS tests than to that of the dry SPF. A high correlation between mineral content and Agron color reading for hard red spring wheat was found, enabling development of an ash predictive method for color (Shuey and Skarsaune 1973). Mineral content, and to a lesser extent starch damage, were the most important factors related to wheat flour paste color (Miskelly 1984). Copper is required at the active site of the PPO molecule and its functionality has been extensively reviewed (Mayer and Harel 1979).

Correlations of PS color values L^* and a^* with individual biochemical factors ranged from nonsignificant, to highly significant but moderate (up to 0.64). Yellow pigment content was largely a direct measure of b^* and was highly correlated to it in dry flour ($r = 0.79, P < 0.001$) and PS with water ($r = 0.81, P < 0.001$), but not for PS with alkali ($r = 0.32, P < 0.05$). Obviously many factors contribute to final color. Multiple regression of individual color components with other flour attributes yielded improvement in the correlation coefficients (Table IV). The equations presented were derived by a forward stepwise procedure where only significant variables were included to minimize the standard error. The factors that influenced the L^* values of the PS test with water and with alkali were the L^* and a^* values, PPO activity, and soluble nitrogen content of the flour. In the TCA extraction conditions for nitrogen solubility measurement, all large proteins are precipitated. The TCA-soluble fraction of albumin hydrolysate consists mainly of peptides with a chain length of not more than four amino acids (Adler-Nissen 1986). Free amino acids have a complicated role in browning reactions. Foods differ in relative availability of more reactive amino acids for nonenzymatic browning (Penfield and Campbell 1990). Many types of polypeptides and amino acids appear to be involved in the inhibition of PPO. The inhibitory action of short polypeptides in reacting with the copper in several types of PPO has been reported, for example a short polypeptide isolated from *Agaricus hotensis* which competitively inhibited PPO consisted of equivalent amount of phenylalanine, aspartate, and glutamate (Mayer and Harel 1979). In sweetpotato, certain amino acids such as cysteine, L-lysine, D-phenylalanine, L-methionine, glycine, L-isoleucine and L-glutamine were found to be natural inhibitors of PPO (Chung 1988, Lourenco et al 1992).

The significant factors in the multiple regression equation for a^* values of the PS test with water were L^* , b^* , reducing sugar, total sugar, and ash content of flour (Table IV). For a^* of PS test with alkali, only PPO, ash, and protein content were significant. For b^* value of the PS test with water and with alkali, the L^* value, b^* , and PPO activity of the flour had most effect. Yellow pigment content was significant in the equation for the b^* value of the PS test with water, not with alkali. The color of SPF is greatly affected by both enzymatic and nonenzymatic browning reactions,

which are dependent on availability of substrate, natural inhibitors, and enzyme levels that vary in each genotype. This is further complicated by the presence of anthocyanins, from traces in some varieties to high levels in purple ones. Under alkaline conditions such in the case of the PS test with alkali or in yellow-alkaline noodle dough sheets, varying shades of green are developed. In a mild alkaline medium, an anionic form of anthocyanin may exist resulting in a blue color. Yang and Yang (1987) found that blueberry puree became darker and more bluish as the pH is shifted from low to high. It was also observed that some fruits and vegetables become greenish as alkali is added. This color is probably caused by the presence of flavones or flavonols which turn yellow while anthocyanins turn blue, and the mixture of the two colors appears green (Penfield and Campbell 1990). Even in the multiple regressions of the flour characteristics with the PS colors, the a^* value of the PS with alkali had the lowest multiple correlation coefficient ($R = 0.82$).

Color of Wheat-SPF Composite Flour Noodles

SPF has potential to partially or wholly replace wheat in many products, and it is thus important to control the effect on the color of the final product. The PS test done on SPF could be used to predict the color of a wheat-sweetpotato composite flour product. We tested the applicability of the test to composite flour noodles. The color values of the PS with water were extremely highly correlated to the respective color values in the composite flour dough sheet for white-salted noodles (Table V). The highest correlation was that for the L^* value ($r = 0.97, P < 0.001$). This was similarly true for the relationship between L^* and b^* of the PS in alkali with those of yellow-alkaline noodles (for L^* , $r = 0.99, P < 0.001$; for b^* , $r = 0.89, P < 0.001$), but only a moderate, but still significant, correlation was found for a^* ($r = 0.45, P < 0.05$).

Color Attributes of Selected Genotypes

UPLSP2, G88, and 25-11A showed the highest L^* values in the PS test with water and with alkali. They had relatively stable colors and could be used for products with critical color attributes such as white-salted and yellow-alkaline noodles. A wide range of interesting colors were found in wheat-sweetpotato flour composites. P5, Inubi-Zambales, Taiwan, and No.-46-CIP gave different shades of green in alkaline noodles. Green pasta and noodles, often colored with spinach, are present in the marketplace in Asia and elsewhere. Anthocyanin colors can be stabilized with the addition of metal salts such as aluminum chloride (Asen et al 1969). CN1425170 and P16 gave bright orange salted noodles due to their high carotenoid pigment content, with the added advantage of conferring high pro-vitamin A. In describing highly colored product results such as these, the Hunter L^* , a^* , b^* values should be used in conjunction with permanent color standards.

TABLE V
Correlation Coefficients of the Color of the Modified Pekar Slick (PS) Test with Water (W) and with Alkali (A) with Color of White-Salted Noodles (WSN) and Yellow-Alkaline Noodles (YAN) from Wheat-Sweetpotato Composite Flour^{a,b}

	W- L^*	W- a^*	W- b^*	A- L^*	A- a^*	A- b^*	WSN- L^*	WSN- a^*	WSN- b^*	YAN- L^*	YAN- a^*
W- L^*	...										
W- a^*	-0.84***	...									
W- b^*	-0.34	0.61**	...								
A- L^*	0.99***	-0.79***	-0.28	...							
A- a^*	0.05	0.22	0.44	0.14	...						
A- b^*	0.43*	-0.13*	0.63***	0.50*	0.48*	...					
WSN- L^*	0.97***	-0.81***	-0.24	0.98***	0.11	0.53**	...				
WSN- a^*	-0.84*	0.91***	0.43*	-0.82*	0.34	-0.27*	-0.85***	...			
WSN- b^*	-0.31	0.68***	0.83***	-0.23	0.42*	0.43*	-0.21	0.52***	...		
YAN- L^*	0.99***	-0.81***	-0.32	0.99***	0.13	0.47*	0.97***	-0.83***	-0.27	...	
YAN- a^*	0.45*	-0.19	0.23	0.47	0.45*	0.66***	0.45*	-0.25	0.05	0.49*	...
YAN- b^*	0.44*	-0.02	0.56**	0.50*	0.58**	0.89***	0.53**	-0.17	0.56**	0.49*	0.74***

^a L^* = brightness (measures total light reflected), a^* = redness, b^* = yellowness.

^b $n = 25$. *, **, *** in the data refer to significance level at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

CONCLUSIONS

PPO correlated significantly to the L^* values of dry flour and both the PS tests. The yellow pigment content correlated significantly to the b^* of the dry flour and the PS test with water, but to a lesser extent with the PS test with alkali. The correlation of the yellow pigment content to a^* of both PS tests probably resulted from an interaction of the yellow pigments with other pigments, possibly anthocyanins, present in the SPF samples. Other biochemical factors like α -amylase activity, total sugar, soluble N, ash, and protein content had moderate although significant correlations with some color attributes of the dry flour and PS tests. Multiple factors contribute to the final color of any product made from SPF or from wheat-sweetpotato flour composites. Results from two types of noodles showed that appropriate PS tests could be used as a rapid and useful method to screen and predict final product color. Some genotypes of sweetpotato adversely affect color through darkening reactions, others can be selected that have no effect on color of wheat flour composites. Yet others represent potentially useful natural colorants that should be developed further.

ACKNOWLEDGMENTS

We thank Eufemio T. Rasco, Jr., for cooperation and assistance with the production and supply of the sweetpotato genotypes. Financial support was received from the Hong Kong Research Grants Council and from the University of Hong Kong Committee on Research and Conference Grants.

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[Received March 20, 1997. Accepted June 18, 1997.]