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Color Characteristics of Monascus Pigments Derived by Fermentation with Various Amino Acids

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Various pigment colors were produced by *Monascus* fermentations with separate addition of 20 amino acids. The color characteristics and structures of the pigment derivatives were investigated. When each amino acid was added to the fermentation broth as a precursor, pigment extracts with different hue and chroma values were obtained depending on the content ratios of yellow, orange, and red colors in the fermentation broth. The yellow and orange pigments were identical regardless of amino acid addition. The red compounds varied on the basis of the type of amino acid added. LC-MS and ^{1}H and ^{13}C NMR structural analyses confirmed that the derivative pigments contained the moieties of the added amino acids. *L**, *a**, and *b** values of the CIELAB color system for the derivative pigments were measured. Values of hue and chroma were then calculated. The colors of the derivative pigments were in the range of orangish red to violet red. The hydrophilicities/hydrophobicities of the derivative pigments could be predicted from their log *P* values, which were estimated using computer programs.

KEYWORDS: Monascus; pigment; amino acid derivatives; color analysis

INTRODUCTION

Species of the genus *Monascus* have been used for many years in the manufacture of traditional foods (red wines, tofu, meats, etc.) in east Asian countries. Recently, *Monascus* pigments have been used in sausages and hams as a coloring agent. There are reports that the pigments produced by *Monascus* species consist of six major compounds. These are yellows of monascin (*1*−*3*) and ankaflavin (*4*), oranges of monascorubrin (*5*, *6*) and rubropunctatin (*7*), and reds of monascorubramine (*8*) and rubropunctamine (*9*) (**Figure 1**).

The structures of the orange compounds in ethanol can be transformed in the presence of nitrogenous compounds (*10*). The oxygen part of orange pigments was considered to be replaced by the nitrogen of the added compounds (*10*, *11*). Amino acids, peptides, amino sugars, amino alcohols, chitosan, and nucleic acids have been proposed as substituent agents (*11*). The structures of pigments derived with glutamic acid (*12*, *13*), aspartic acid, and alanine (*14*) have been partly investigated. However, studies on a broad spectrum of derivatives have not yet been reported. There are only a few publications, which deal primarily with the color characteristics of derivatives.

We added 20 individual amino acids as precursors in *Monascus* cultivations for synthesis of pigment derivatives. Various red colors were produced and the color characteristics investigated. The structures of the derivative pigments were also analyzed.

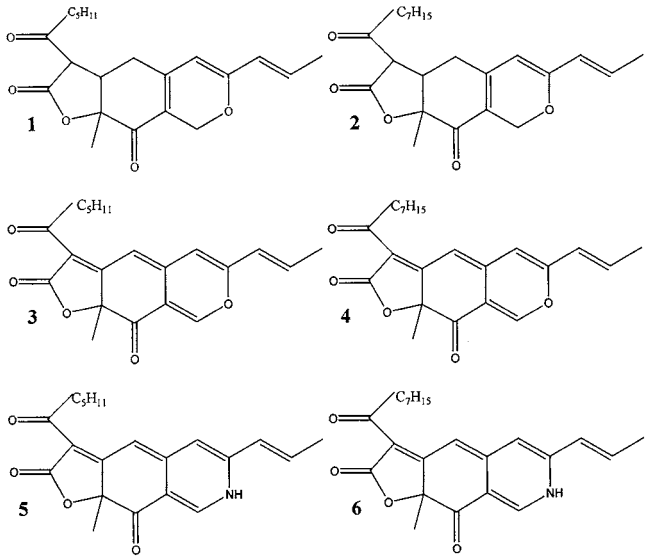

Figure 1. Structures of six major pigments produced by *Monascus* species: **1**, monascin; **2**, ankaflavin; **3**, monascorubrin; **4**, rubropunctatin; **5**, monascorubramine; **6**, rubropunctamine.

MATERIALS AND METHODS

Reagents. Amino acids were purchased from Sigma-Aldrich Co. Glucose−peptone medium and fermentation medium were obtained from Difco Co. Chloroform and methanol were purchased from Tedia Co. The other chemicals were products of Duksan Pure Chemical Co.

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Cultivation for Synthesis of Derivatives. The strain used for production of pigments was *Monascus* sp. KCCM 10093 (KCCM: Korea Culture Center for Microorganisms). After 5 mL of distilled water was put into a strain slant and vortexed, the spore solutions were collected. Seed cultures were grown in 500 mL baffled flasks containing 75 mL of glucose−peptone medium that had been inoculated with 5 mL of the spore solutions. Flasks were then cultivated for 36 h at 30 °C and 200 rpm on an HM-90R rotary shaker (Human Science Co., Seoul, Korea). The composition of the glucose−peptone medium was as follows: 5.0% glucose, 2.0% peptone, 0.8% KH_2PO_4, 0.05% CH_3-COOK, 0.2% NaCl, and 0.05% $MgSO_4 \cdot 7H_2O$. For fermentation cultures, after the 500 mL baffled flasks containing 75 mL of the fermentation medium had been inoculated with 7% of the seed cultures, they were cultivated for 5 days at 30 °C and 200 rpm on a rotary shaker. The fermentation medium consisted of 5% glucose, 1.0% NH_4NO_3, 0.1% KH_2PO_4, 0.05% $MgSO_4 \cdot 7H_2O$, 0.05% KCl, and 0.001% $FeSO_4$ at pH 6.6. For derivation of pigments with amino acids, the fermentation medium was the same except that 1.0% NH_4NO_3 was replaced with 0.3% NH_4NO_3 and 0.7% amino acid. Each amino acid (20 types of L-amino acid) was not initially added but at 24 h of cultivation, and the cultivations were continued for an additional 4 days under the same conditions.

Extraction of Pigments. After 100 mL of cell culture had been collected in the 500 mL flasks, 100 mL of 95% ethyl alcohol was added. The flasks were incubated on a reciprocal shaker (International Science Co., Seoul, Korea) at 30 °C and 180 rpm. The solutions were then filtered to produce crude pigment extracts.

Color Analysis of Pigments. The absorbance values of pigment solutions at 510 nm were adjusted to the range of 1.0−2.0 for color analysis. The values of L^*, a^*, and b^* were measured by a CR-300 colorimeter with the CIELAB color system (*15*) (Minolta Camera Co., Ltd., Osaka, Japan). These values were then used to calculate chroma (C^*) and hue angle (h_{ab}) values. L^* indicates lightness from 0 (black) to 100 (white). Positives and negatives in a^* represent red and green, respectively, whereas positives and negatives in b^* represent yellow and blue, respectively. Chroma values denote the saturation or purity of the color. Values close to the center at the same L^* value indicate dull or gray colors, whereas values near the circumference represent vivid or bright colors. Hue angle values represent 0 for redness, 90 for yellowness, 180 for greenness, and 270 for blueness. L^*, a^*, and b^* values of the pure pigments were obtained from preparative TLC after the spots had been collected, extracted with 95% ethanol, and filtered.

TLC and HPTLC of Pigment Extracts. Crude extracts of fermentation broths were analyzed by TLC. After ethanol extracts had been applied to plates, the silica gel 60 F_{254} plates (Merck, Darmstadt, Germany) were developed with a solution of chloroform/methanol/water (90:25:4). The R_f values and areas of pigment spots were measured on the basis of image analysis by an HPTLC of winCATS Planar Chromatograph (Camag Scientific, Inc., Wilmington, NC).

Purification and Structural Analysis of Pigment Derivatives. After the major pigment spots on preparative TLC (silica gel 60, 50 TLC plates, Merck) had been collected and dissolved in ethanol, they were filtered through a 0.45 μm PTFE syringe filter (Whatman) to remove silica gel. Pure pigment solutions were thus obtained. LC-MS spectrometry was used to measure molecular weights as a means of identifying the derivative pigments. A Micromass Quattro-LC triple-quadrupole mass spectrometer (Micromass, Manchester, U.K.) equipped with an APcI probe and Z-spray interface was used as the detector. APcI was performed in the positive mode with the desolvation gas set at 580 L/h and the temperature of the probe set at 450 °C. MS tunning parameters were obtained with a corona voltage setting of 3.72 kV, a cone voltage of 31 V, and a source block temperature of 100 °C. HPLC (HP-1100) was carried out on a 250 × 4.6 mm, i.d., 5 μm ODS C_{18} column (Hypersil, Kleinostheim, Germany). Operational conditions included a run time of 40 min, a flow rate of 0.8 mL/min, and an elution gradient of distilled water/methanol from 100:0 to 30:70. Absorbance values at 425 nm were measured on a UV-120-2 spectrometer (Shimadzu Co., Kyoto, Japan). For detailed analysis of the structure of the glycine derivative of the pigment, NMR spectra were recorded in CD_3OD using a Bruker Avance-600 (Bruker, Rheinstetten, Germany) operating at 600 MHz for ^1H NMR and at 150.9 MHz for ^{13}C NMR.

Table 1. Colorimetric Values of Fermentation Extracts Depending on Various Amino Acids

added amino acid	CIELAB color system				
	L^*	a^*	b^*	chroma[a]	hue angle[b]
NH_4NO_3 (control)	50.54 ± 0.04	59.12 ± 0.13	47.50 ± 0.09	75.84	38.78
serine	59.60 ± 0.02	52.62 ± 0.05	35.23 ± 0.02	63.32	33.80
threonine	68.83 ± 0.02	38.26 ± 0.03	70.07 ± 0.06	79.84	61.36
cysteine	71.11 ± 0.02	41.71 ± 0.07	56.09 ± 0.05	69.90	53.36
methionine	70.43 ± 0.03	37.22 ± 0.08	40.15 ± 0.05	54.75	47.17
asparagine	63.65 ± 0.04	46.12 ± 0.11	59.82 ± 0.13	75.53	52.37
glutamine	67.04 ± 0.02	45.96 ± 0.07	4.88 ± 0.05	46.22	6.06
aspartic acid	84.99 ± 0.03	41.28 ± 0.11	74.47 ± 0.04	85.15	61.00
glutamic acid	69.10 ± 0.06	37.43 ± 0.09	61.81 ± 0.10	72.26	55.80
lysine	71.89 ± 0.02	38.89 ± 0.08	55.76 ± 0.06	67.98	55.11
arginine	69.10 ± 0.24	44.47 ± 0.18	49.38 ± 0.14	66.45	47.99
histidine	71.62 ± 0.03	35.27 ± 0.11	36.51 ± 0.06	50.76	45.99
phenylalanine	63.72 ± 0.04	46.9 ± 0.13	83.85 ± 0.11	96.12	60.73
tyrosine	69.75 ± 0.05	35.11 ± 0.12	54.61 ± 0.08	64.92	57.26
tryptophan	63.81 ± 0.04	47.46 ± 0.12	62.46 ± 0.10	78.45	52.77
glycine	50.90 ± 0.05	63.67 ± 0.11	22.12 ± 0.08	67.40	19.16
alanine	50.35 ± 0.03	62.33 ± 0.10	38.66 ± 0.06	73.35	31.81
valine	70.68 ± 0.02	33.58± 0.09	83.26 ± 0.08	89.78	68.04
leucine	55.63 ± 0.05	56.25 ± 0.13	84.50± 0.11	101.51	56.35
isoleucine	59.21 ± 0.04	51.09 ± 0.12	96.02 ± 0.12	108.77	61.98
proline	60.41 ± 0.05	46.15 ± 0.15	70.11 ± 0.11	83.94	56.65

[a] Chroma (C) = $[(a^*)^2 + (b^*)^2]^{1/2}$. [b] Hue angle ($h_{ab}$) = $\tan^{-1}(b^*/a^*)$.

RESULTS AND DISCUSSION

Color Characteristics of Fermentation Extracts. Twenty different individual amino acids were added as nitrogen source to the fermentation medium during *Monascus* cultivation. Fermentation broths were extracted with ethanol and used for analysis of color characteristics. The values of L^*, a^*, and b^* were all positive when either ammonium nitrate or an amino acid was used as a nitrogen source, indicating yellowness and redness (**Table 1**). The lightness values were 50−70. The hue angle of the control (with ammonium nitrate) was 39, indicating orangish red on the basis of a scale of 0 for redness, 90 for yellowness, 180 for greenness, and 270 for blueness. The values for serine, glutamine, glycine, and alanine corresponded to red. Values for the other amino acids were 40−80, indicating more orangish red compared to the control. The chroma values varied in a range from 40 (gray) to 110 (bright) according to the amino acid. On the basis of the hue angle and chroma values the pigments derived with amino acids had various shades of red. HPTLC analysis was used to determine the reason for the various shades of red exhibited by the pigment extracts. Colors were classified into three categories of yellow, orange, and red (**Figure 2**). Ratios of major spots for the samples shown in **Table 2** were measured by using an HPTLC image analyzer. The colors varied according to the amino acid used as a precursor in the fermentation medium. When serine, glutamine, glycine, alanine, and histidine were added, the red content was responsible for >50% of the total. However, with phenylalanine, valine, leucine, and isoleucine, the total content of yellow and orange was >50%. The variety of colors dependent upon an amino acid precursor was determined by the amounts of yellow, orange, and red produced during fermentation. The R_f values were measured by HPTLC. Spots I, II, and III indicate the respective R_f values of yellow, orange, and red for the pigment extracts. The R_f values for spot I

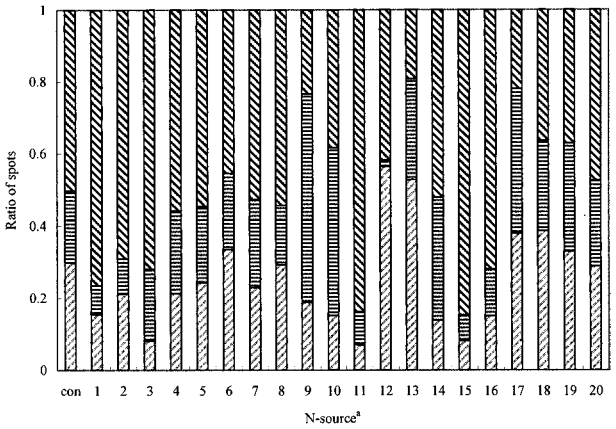

Figure 2. Ratios of major pigments in fermentation extracts: (bars with slashes) yellow spot; (bars with horizontal lines) orange spot; (bars with backslashes) red spot. N source: con, NH_4NO_3 (control); 1, serine; 2, threonine; 3, cysteine; 4, methionine; 5, asparagine; 6, glutamine; 7, aspartic acid; 8, glutamic acid; 9, lysine; 10, arginine; 11, histidine; 12, phenyalanine; 13, tyrosine; 14, tryptophan; 15, glycine; 16, alanine; 17, valine; 18, leucine; 19, isoleucine; 20, proline.

Table 2. HPTLC for Major Spots of Fermentation Extracts

added amino acid	spot I[a]	spot II[b]	spot III[c]
NH_4NO_3 (control)	0.98	0.95	0.88
serine	0.99	0.94	0.31
threonine	0.99	0.95	0.35
cysteine	0.98	0.93	0.06
methionine	0.99	0.93	0.53
asparagine	0.98	0.93	0.25
glutamine	0.98	0.93	0.88
aspartic acid	0.98	0.93	0.14
glutamic acid	0.99	0.94	0.14
lysine	0.98	0.92	0.15
arginine	0.98	0.93	0.18
histidine	0.98	0.93	0.18
phenylalanine	0.98	0.93	0.24
tyrosine	0.98	0.93	0.54
tryptophan	0.98	0.95	0.40
glycine	0.99	0.94	0.42
alanine	0.98	0.92	0.30
valine	0.99	0.94	0.42
leucine	0.99	0.94	0.55
isoleucine	0.99	0.94	0.56
proline	0.98	0.92	0.88

[a] Yellow spot. [b] Orange spot. [c] Red spot.

(yellow) were essentially the same for all extracts. The values for spot II (orange) were similar in all cases. These results indicate that the same yellow and orange compounds were produced during fermentation, regardless of the amino acid supplement. The yellow and orange pigments were hydrophobic with respect to the R_f values. However, the R_f values of spot III (reds) varied in a low range from 0.1 to 0.6 depending on the added amino acid, indicating the formation of different red compounds. When hydrophilic amino acids such as aspartic acid and glutamic acid were used as supplements, the R_f values of the pigments were lowered. The pigments were generally more hydrophilic than the control (NH_4NO_3). The amino acids used as supplements were apparently incorporated into the structure of the pigments.

Structural Analyses of Derivative Pigments. The red spots on preparative TLC plates were collected and analyzed by LC-MS. The retention times and molecular weights of the pigments were measured. Each red spot consisted of two compounds

Table 3. Evaluation of Retention Times and Molecular Weights for the Amino Acid Derivatives of *Monascus* Pigments by LC-MS

	C_5H_{11}[a]			C_7H_{15}[a]		
amino acid moiety	expected molecular formula	retention time (min)	molecular weight	expected molecular formula	retention time (min)	molecular weight
control yellow	$C_{21}H_{26}O_5$	29.8	359.8	$C_{23}H_{30}O_5$	31.1	385.8
control orange	$C_{21}H_{22}O_5$	30.0	355.8	$C_{23}H_{26}O_5$	31.5	384.1
control red	$C_{21}H_{22}NO_4$	26.2	354.7	$C_{23}H_{26}NO_4$	28.9	382.7
serine	$C_{24}H_{27}NO_7$	15.1	442.9	$C_{26}H_{31}NO_7$	17.7	470.9
threonine	$C_{25}H_{29}NO_7$	16.2	456.9	$C_{27}H_{33}NO_7$	19.5	484.9
cysteine	$C_{24}H_{27}NO_6S$	15.5	458.9	$C_{26}H_{31}NO_6S$	18.5	486.9
methionine	$C_{26}H_{31}NO_6S$	18.4	486.9	$C_{28}H_{35}NO_6S$	21.5	514.9
asparagine	$C_{25}H_{28}N_2O_7$	13.9	491.8	$C_{27}H_{32}N_2O_7$	15.2	519.8
aspartic acid	$C_{25}H_{27}NO_8$	12.9	492.8[b]	$C_{27}H_{31}NO_8$	14.6	520.8[b]
glutamic acid	$C_{26}H_{29}NO_8$	14.5	506.8	$C_{28}H_{33}NO_8$	16.8	534.8
lysine	$C_{27}H_{34}N_2O_6$	23.3	479.9	$C_{29}H_{38}N_2O_6$	26.5	507.1
arginine	$C_{27}H_{34}N_4O_6$	26.1	508.1[b]	$C_{29}H_{38}N_4O_6$	26.4	535.9[b]
histidine	$C_{27}H_{29}N_3O_6$	23.3	494.9[b]	$C_{29}H_{33}N_3O_6$	27.5	521.1[b]
phenylalanine	$C_{30}H_{31}NO_6$	17.3	502.8	$C_{32}H_{35}NO_6$	20.2	531.0
tyrosine	$C_{30}H_{31}NO_7$	14.6	518.9	$C_{32}H_{35}NO_7$	16.7	546.9
tryptophan	$C_{32}H_{32}N_2O_6$	17.6	541.9	$C_{34}H_{36}N_2O_6$	20.3	569.9
glycine	$C_{23}H_{25}NO_6$	14.3	412.8	$C_{25}H_{29}NO_6$	16.0	440.8
alanine	$C_{24}H_{27}NO_6$	14.5	426.8	$C_{26}H_{31}NO_6$	16.6	454.9
valine	$C_{26}H_{31}NO_6$	16.2	454.8	$C_{29}H_{37}NO_6$	19.3	483.0
leucine	$C_{27}H_{33}NO_6$	18.4	468.8	$C_{29}H_{37}NO_6$	21.0	497.0
isoleucine	$C_{27}H_{33}NO_6$	17.5	468.8	$C_{29}H_{37}NO_6$	20.3	496.2

[a] C_5H_{11} and C_7H_{15} are side chains of the *Monascus* pigments shown in **Figure 1**. [b] The molecular weights measured from the data of mass spectrometry were not completely in agreement with the predicted values.

(**Table 3**) with supposed R_1 groups of C_5H_{11} and C_7H_{15} (*16*). The retention times of the control red pigments were 26.2 min for C_5H_{11} and 28.9 min for C_7H_{15}. Their molecular weights were 354.7 and 382.7, respectively, which are the same as the weights of monascorubramine (*8*) and rubropunctamine (*9*). Thus, the control red pigments were confirmed as monascorubramine and rubropunctamine. Conversely, the retention times of the derivative pigments that were produced with amino acid supplementation were considerably lower in most cases compared to the control reds due to the increase of hydrophilicity. Under the assumption that amino acids were incorporated into pigments (*10*, *11*, *13*), the molecular formulas and weights of the derivative pigments were predicted. When these values were compared with values obtained from LC-MS analysis, most cases showed the same weights except aspartic acid, arginine, and histidine, with values differing by 3−4 mass units. However, glutamine and proline were probably not incorporated as supplements. The fragmentation patterns of the derivative pigments obtained by mass spectrometry were compared with the patterns of *Monascus* pigments (*16*, *17*). The base peaks for *Monascus* pigments (*m*/*z* 354.7, 312.7, 214.5, 188.7, 146.3, 114.4, and 106.3) were identical for the control red and the derivative pigments excluding the amino acid moiety. The glycine pigment derivative was selected for further purification by preparative TLC and preparative HPLC and analyzed by ^1H NMR and ^{13}C NMR. **Table 4** shows that the carbons and protons of chemical shifts in the glycine derivative are close to the shifts of *Monascus* pigments (*12*, *14*, *18*). The glycine moiety of the pigment was confirmed by the chemical shifts of two carbons (α and β, 73.19 and 173.78 ppm, respectively) and protons (3.60 m). The structure of the glycine derivative pigment is shown in **Figure 3**. The structures of the other derivative pigments are probably similar except for the amino acid moiety.

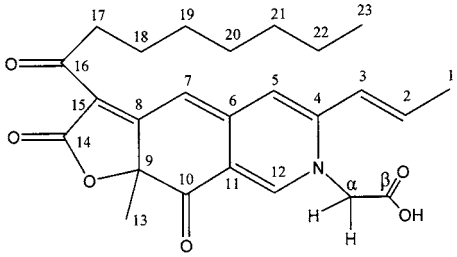

Figure 3. Structure of the glycine derivative of *Monascus* pigments.

Table 4. ^{1}H (600 MHz) and ^{13}C (150 MHz) NMR Assignments of the Glycine Derivative

carbon[a]	δ_C	δ_H	carbon[a]	δ_C	δ_H
1	23.58	1.97dd	14	173.36	
2	141.54	6.40m	15	93.93	
3	116.99	6.71m	16	198.64	
4	152.55		17	41.20	2.82t
5	118.52	7.11s	18	26.02	1.60m
6	153.71		19	26.35	1.33m
7	98.58	6.66s	20	30.57	1.33m
8	171.80		21	32.84	1.33m
9	86.88		22	19.16	1.34m
10	196.54		23	14.28	0.90t
11	123.10		α	73.19	3.60m
12	144.79	8.20s	β	173.78	
13	30.55	1.65s			

[a] Carbon numbers are shown in **Figure 3**.

Color Characteristics of Amino Acid Derivative Pigments. After the red compounds had been purified from the fermentation cultures in which amino acids were used as supplements, color characteristics and absorption spectra were analyzed using a colorimeter and a UV−vis spectrophotometer. On the basis of reports (*12*) that there is no difference in color characteristics between the R_1 groups (C_5H_{11} and C_7H_{15}) of a pigment, mixtures of two red compounds with different R_1 groups were used as samples for color analysis. As shown in **Table 5** and **Figure 4**, the hue angles of the control yellow and orange pigments were approximately 90, corresponding to light yellow and middle orange. The red control pigment exhibited a hue angle of 30, which represents middle or scarlet red. The red pigments of the amino acid derivatives generally had hue angles of 0−30 and are considered to be deep red or rose. However, the red derivatives of cysteine, lysine, and arginine exhibited higher hue values than the control red, corresponding to orangish red. Ultimately, various pigments in the range of orangish red to deep red were produced by derivation of the control pigment with amino acids. The absorption spectra of the derivative pigments were measured (**Table 5**). The control red pigment had maximum wavelengths of 422 and 508 nm, similar to reported values (*19*, *20*). Most of the derivative red pigments had two λ_{max} values of 417−427 and 498−525 nm. The λ_{max2} values of the derivative red pigments were generally in a range of 512−525 nm, which were higher than for the control red. The glycine derivative of deep red had the highest values, whereas the cysteine and lysine derivatives of orangish red had values below 500 nm.

Hydrophilicities/Hydrophobicities of Derivative Pigments. The logarithmic values of partition coefficients (log *P*) were calculated using QSAR computer programs based on the structures of the derivative pigments (*21*, *22*). Although some differences existed between the programs used, the trends were similar. The hydrophobic pigments (derivatives of phenylalanine, tyrosine, tryptophan, leucine, and isoleucine) exhibited high log *P* values (**Table 6**). The hydrophilic pigments with glycine, serine, threonine, aspartic acid, and glutamic acid exhibited low log *P* values, as predicted. These results are in agreement with trends based on R_f values from the TLC and t_R values of HPLC. The partition coefficients of the pigments apparently can be adjusted via derivation with amino acids.

Table 5. Colorimetric Values for Amino Acid Derivatives of *Monascus* Pigments

	CIELAB color values					absorption spectra (nm)	
	L^*	a^*	b^*	chroma[a]	hue angle[b]	λ_{max1}[c]	λ_{max2}[c]
control yellow	98.62	−7.11	23.96	24.99	106.52	354	418
control orange	92.79	12.69	25.36	28.36	63.41	356	470
control red	73.27	37.03	26.45	45.51	30.53	422	508
serine	59.88	59.78	21.84	63.64	20.07	422	514
threonine	60.98	60.51	18.33	63.23	16.85	417	516
cysteine	74.32	42.11	35.46	55.05	40.10	423	498
methionine	54.67	62.24	35.42	71.61	29.64	423	512
asparagine	60.97	57.13	23.66	61.84	22.50	425	514
aspartic acid	70.25	46.18	13.76	48.19	16.59	418	516
glutamic acid	62.05	55.53	20.26	59.11	27.71	424	514
lysine	84.18	23.05	23.21	32.84	36.84	423	502
arginine	81.12	28.60	25.54	39.06	35.90	426	501
histidine	67.20	49.94	23.77	55.31	25.45	424	506
phenylalanine	65.44	52.16	17.70	55.08	18.74	426	512
tyrosine	75.24	36.86	12.29	38.85	18.44	423	513
tryptophan	68.72	49.55	11.26	50.81	12.80	419	520
glycine	56.35	59.99	11.07	61.00	10.46	422	525
alanine	60.99	55.37	22.41	59.73	11.18	423	514
valine	61.76	55.70	21.19	59.59	20.83	427	513
leucine	71.20	42.89	13.16	44.86	17.06	427	513
isoleucine	61.34	55.11	20.53	58.81	20.43	423	514

[a] Chroma (C) = $[(a^*)^2 + (b^*)^2]^{1/2}$. [b] Hue angle = $\tan^{-1}(b^*/a^*)$. [c] Maximum wavelength of UV–vis absorption spectra.

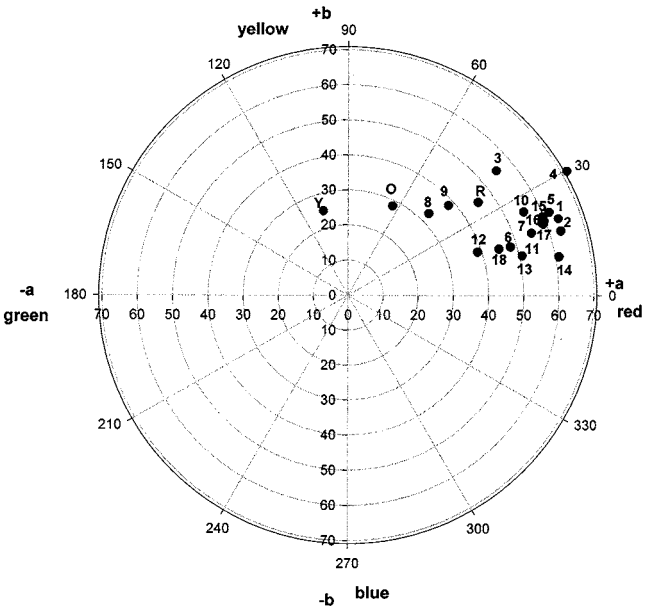

Figure 4. Description of the CIELAB colorimetric system and a general scatter plot for amino acid derivatives of *Monascus* pigments: ●, derivative pigments: Y, control yellow pigments; O, control orange pigments; R, control red pigments; 1, serine; 2, threonine; 3, cysteine; 4, methionine; 5, asparagine; 6, aspartic acid; 7, glutamic acid; 8, lysine; 9, arginine; 10, histidine; 11, phenyalanine; 12, tyrosine; 13, tryptophan; 14, glycine; 15, alanine; 16, valine; 17, leucine; 18, isoleucine.

Table 6. Calculated log *P* for Amino Acid Derivatives of *Monascus* Pigments

amino acid moiety[b]	IA_LOGP[c]		CLOGP[d]		LOGKOW[e]		CD_LOGP1[f]		CD_LOGP2[g]	
	C_5[a]	C_7[a]	C_5[a]	C_7[a]	C_5[a]	C_7[a]	C_5[a]	C_7[a]	C_5[a]	C_7[a]
control yellow	3.66	4.67	2.48	3.54	2.36	3.34	1.48	2.31	1.21	2.00
control orange	2.71	3.89	1.75	2.81			1.15	1.98	0.89	1.68
control red	4.13	2.58	2.87	3.93	2.09	3.07	1.07	1.90	0.78	1.58
serine	–1.87	–1.50	1.55	2.61	0.84	1.82	0.21	1.40	0.32	1.36
threonine	–1.24	–0.81	1.86	2.92	1.26	2.24	0.53	1.36	0.74	1.53
cysteine	0.32	1.16	2.61	3.67	2.25	3.23	1.04	1.87	0.91	1.70
methionine	0.51	1.13	2.92	3.98	2.88	3.87	1.40	2.23	1.10	1.89
asparagine	0.10	0.37	1.22	2.34	0.31	1.29	–0.37	0.47	–0.37	0.42
aspartic acid	–0.29	–0.15	1.98	3.04	0.97	1.96	0.28	1.12	0.49	1.28
glutamic acid	–0.75	–0.30	1.88	2.94	1.47	2.45	0.56	1.40	0.74	1.53
lysine	1.59	2.36	0.20	1.26	–0.89	0.09	0.80			1.67
arginine	0.20	0.74	–1.17	–0.11	1.29	2.27	0.53	1.36	1.64	0.88
histidine	1.71	2.30	1.79	2.85	2.08	3.06	–0.08	0.75	0.07	0.86
phenyalanine	2.04	2.60	4.19	5.25	4.01	5.00	2.74	3.57	2.80	3.59
tyrosine	0.42	0.95	3.52	4.58	3.53	4.52	2.35	3.18	2.51	3.30
tryptophan	4.57	5.53	4.18	5.24	4.08	5.06	2.93	3.76	2.74	3.53
glycine	0.71	1.55	2.24	3.30	1.14	2.12	0.47	1.40	0.57	1.36
alanine	0.94	1.74	2.77	3.83	2.31	3.29	1.71	2.55	1.74	2.54
valine	1.26	2.04	3.70	4.76	3.22	4.69	2.60	3.43	2.62	3.41
leucine	2.04	2.30	4.23	5.29	3.71	4.69	2.30	3.13	2.30	3.10
isoleucine	2.04	2.30	4.23	5.29	3.71	4.69	2.62	3.45	2.61	3.40

[a] C_5H_{11} and C_7H_{15} are side chains for the structure of *Monascus* pigments shown in **Figure 1**. [b] Amino acid moiety of *Monascus* pigments. [c–g] Calculated log *P* of QSAR online program: [c] http://www.logp.com; [d] http://www.daylight.com/meetings/mug98/Leo/clogp_history.html; [e] http://esc.syrres.com/interkow/kowdemo.Htm; [f,g] CS ChemDraw Ultra 5.0.

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